A COMPARATIVE STUDY OF HYDRAULIC CONDUCTIVITY DETERMINATIONS FOR A FINE-GRAINED ALLUVIUM AQUIFER

By

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CHAPTER I

INTRODUCTION

Research Objective

The purpose of this study is to compare hydraulic conductivity determinations for a shallow, fine-grained aquifer. Hydraulic conductivity, also referred to as the coefficient of permeability or the constant of proportionality in Darcy's Law, is a measure of the capacity of a porous medium to transmit water under a pressure gradient. It is an essential parameter in most hydrogeologic investigations.

In the past, many ground-water studies were concerned with determining the hydraulic conductivity of coarse-grained materials for the purpose of developing ground-water supplies. Recently, there has been increased emphasis on characterizing the hydraulic properties of fine-grained sediments and soils in order to understand the movement of contaminants in these systems. Selecting the most appropriate method for determining hydraulic conductivity of fine-grained materials has become a source of controversy. The debate is fueled by the fact that the U.S. Environmental Protection Agency (EPA) requires a determination of hydraulic conductivity at hazardous waste sites; however, the method(s) to be used have not been specified (CFR, 1988).

In general, hydraulic conductivity is estimated either by in-situ tests or by laboratory analysis of samples collected from the field. In-situ methods include aquifer pumping, slug, tracer, and flow meter tests. Laboratory methods include constant- and falling-head permeameter tests and grain-size analyses.

Factors that should be considered in selecting an appropriate methodology include the reliability of the method for a particular geologic setting, the correspondence between the site's boundary conditions and those assumed by available models, convenience, and expense. Aquifer pumping tests are generally considered to be the most reliable method; however, in many fine-grained deposits it is impossible to conduct a constant-rate aquifer pumping test because the hydraulic conductivity of the saturated materials is too low to allow a sustained flow rate. Also, at hazardous waste sites where it is possible to maintain a constant discharge rate, the requirement for pumping large volumes of contaminated ground water, all of which may need to be stored, may prohibit this option. Consequently, other methods, such as slug tests or laboratory tests on samples must be considered.

In this study three commonly used methods for determining hydraulic conductivity were employed. The resulting values provide a basis for discussion of the appropriateness of each method and of the factors that influence the results for this particular hydrogeologic setting.

General Approach

The field site is located in a residential neighborhood in northeastern Stillwater, Payne County, Oklahoma. The aquifer is composed of approximately 43 feet of fine-grained alluvium overlying a weathered shale. The alluvium exhibits some soil characteristics and the surface material has been mapped as the Ashport silty clay loam (Soil Conservation Service, 1987).

This research involved in-situ aquifer testing methods and laboratory tests on "undisturbed" samples collected from the field site. A 3-day, constant-rate aquifer pumping test and slug tests were performed in order to evaluate the in-situ hydraulic conductivity of the aquifer. Samples of the aquifer were obtained with a tube sampler and the hydraulic conductivity of selected intervals was determined with a constant-head permeameter in the laboratory. Particle-size, water content, bulk density, and clay mineralogy analyses also were conducted on selected samples.

Units of Hydraulic Conductivity

Hydraulic conductivity is commonly expressed in metric units of centimeters per second (cm/sec). In the past, many U.S. hydrogeologists used the units of U.S. gallons per day per square foot (gpd/ft^2). For the convenience of the reader of this thesis, hydraulic conductivity will be expressed in both of these units. The conversion between the two sets of units is explained in Chapter V.

CHAPTER II

LITERATURE REVIEW

Previous Work at Field Site

Hagen (1986) reported hydraulic conductivity values ranging between 25 and 81 gpd/ft^2 ($1.2x10^{-3}$ - $3.8x10^{-3}$ cm/sec), which were determined by aquifer pumping tests, using partially penetrating wells. He noted that these values appeared unusually high considering the fine-grained texture of the aquifer material. Hagen also suggested that fractures or macropores may be responsible for the higher than expected hydraulic conductivity values and may influence water-quality fluctuations.

Similarly, the results of aquifer pumping tests conducted by Hoyle (1987) indicated that hydraulic conductivity values ranged between 27 and 125 gpd/ft^2 ($1.3x10^{-3}$ - $5.9x\ 10^{-3}$ cm/sec). Hoyle used a fully penetrating pumping well and partially penetrating observation wells. She also suggested that soil structure and macropores, such as root casts, provide significant conduits for fluid flow. Ross (1988) concluded that rapid changes in soil- and ground-water quality may be caused by flow of solutes through macropores. In his detailed description of the soil profile, Ross identified various types of weak to moderate soil structure and fine root casts throughout most of the profile that may influence ground-water flow.

Field Versus Laboratory Determinations of Hydraulic Conductivity

Many studies have been conducted in which field and laboratory determinations of hydraulic conductivity have been compared. Most of the literature that specifically addresses this topic is in periodicals in soil science, hydrology, geology, and engineering. Other papers include results of laboratory and field methods as part of a larger topic of discussion. There are numerous on-going studies of contaminated sites by environmental consulting firms and the EPA that employ various methodologies for calculating hydraulic conductivity. However, much of this information is not readily available, as many of these sites are subjects of litigation.

In their study of the hydraulic conductivity of unconsolidated sediments in the Netherlands, Ridder and Wit (1965) found that the results of laboratory tests on undisturbed samples of gravelly coarse-grained sands were in good agreement with those of aquifer pumping tests. The authors also showed similar results by calculations using the grain-size distribution of undisturbed samples.

MacFarlane and others (1983) reported similar estimates of the hydraulic conductivity of an unconfined sand aquifer using pumping and slug tests. Permeameter tests and grain-size analyses yielded values that were similar, but were in a slightly higher range than results of in-situ tests.

Taylor and others (1987) stated that the majority of the literature reports grain-size-derived hydraulic conductivities that differ by several orders of magnitude from field determinations. However, in their study of a moderately- to well-sorted sand aquifer, the hydraulic conductivity values estimated by grain-size methods were in the same order of magnitude as the in-situ values. Fetter (1985) also reported similar results for a well-sorted medium sand.

Olson and Daniel (1981) discussed measurement of the hydraulic conductivity of fine-grained soils. The authors tabulated data from various sites reported in the literature where both field and laboratory conductivities had been measured. The range in the ratio of field conductivity/laboratory conductivity was from 0.3 to 46,000. However, approximately 90 percent of the reported ratios ranged from 0.38 to 64. The authors concluded that field tests are preferred over laboratory tests because a larger volume of soil is permeated, which incorporates the effects of macrostructure, such as roots and fissures.

Watts and others (1982) compared hydraulic conductivities determined by a piezometer method and by laboratory tests on core samples for slowly permeable sandy loam and sandy clay loam soil horizons. In every test the laboratory-derived values were greater than the field-derived values. The average difference between the two methods was 260 times and ranged to over 700-fold.

In their hydrogeologic study of a clayey mine spoil, Pollock and others (1983) found that the average hydraulic conductivities, based on aquifer pumping tests, were between 2 and 20 gpd/ft^2 (10^{-4} to 10^{-3} cm/sec) horizontally and 2 x 10^{-2} gpd/ft^2 (10^{-6} cm/sec) vertically. Slug tests yielded an average horizontal permeability of 2 gpd/ft^2 (10^{-4} cm/sec), whereas laboratory permeameter test results ranged from 2 x 10^{-4} to 2 x 10^{-2} gpd/ft^2 (10^{-8} to 10^{-6} cm/sec). The authors concluded that the differences between laboratory and field results probably were due to the measurement of different flow directions and the absence of fracture flow in the laboratory samples.

Herzog and Morse (1984) conducted a comparative study of laboratory- and field-determined values of hydraulic conductivity at a waste disposal site. The authors noted that relatively few data have been published comparing these values from actual disposal sites. The results of permeameter, slug, and recovery tests indicated that the laboratory-determined values were at least one order of magnitude lower than the values determined in the field. They suggested that field tests are preferable to laboratory tests when determining hydraulic conductivity at waste disposal sites.

Keller and others (1985) performed both field and laboratory tests on an unweathered clayey till near Saskatoon, Saskatchewan, Canada. Their data showed that the bulk permeability of the till exceeds its matrix permeability by two orders of magnitude. Although there was no visual evidence of fractures in Shelby tube samples of the till, the authors concluded that the unweathered till has considerable vertical and horizontal fracture permeability based on the discrepancy between field- and laboratory-determined hydraulic conductivity values.

Many researchers have studied the hydraulic conductivity of clay liners for hazardous waste sites. Daniel (1987, p.15) stated that he "knows of only one instance in the open literature in which laboratory hydraulic conductivity tests are known to have yielded correct values for a compacted clay liner". Laboratory tests have consistently yielded hydraulic conductivities that are "much too low". The author concluded that in-situ tests should always be employed to determine hydraulic conductivities of compacted clay liners.

Laboratory Permeameter Testing

Olsen and Daniel (1981) presented a state-of-the-art review of measurement of hydraulic conductivity of fine-grained soils. They found that the most common laboratory permeameter test for fine-grained soils was the falling-head test. Although less commonly used for the testing of fine-grained soils, constant-head tests offer the advantage of simplicity of data interpretation. Numerous other techniques are described in the literature but a discussion of these other methods is beyond the scope of this research.

In their discussion of hydraulic gradients for permeameter testing, Olson and Daniel (1981) provided examples from the literature where increasing the hydraulic gradient resulted in increases, as well as decreases, in hydraulic conductivity (Schwartzendruber, 1968; Mitchell and Younger, 1967; Gairon and Schwartzendruber, 1975). Olson and Daniel (1981) contended that gradients should be kept as low as possible while still allowing tests to be performed within a reasonable amount of time. They also suggested that undisturbed samples should be used and that the permeant should be a fluid similar to that found in the field. Olson and Daniel (1981) warned that without proper experimental technique, the laboratory-derived values for hydraulic conductivity may differ from field-determined values by several orders of magnitude.

Aquifer Pumping Test Analyses

Theim (1906) developed a solution for determining the transmissivity (hydraulic conductivity multiplied by aquifer thickness) of confined (artesian) aquifers under equilibrium conditions. A method for calculating the transmissivity of confined aquifers under nonequilibrium conditions was later presented by Theis (1935). Cooper and Jacob (1946) and Jacob (1950) modified the Theis nonequilibrium well equation and this method is commonly referred to as the "Jacob" straight-line method. Boulton (1963), Prickett (1965), and Neuman (1975) presented methods for estimating the transmissivity of unconfined (water-table) aquifers, which take into account delayed yield from storage. Many other methods are available, including leaky artesian, semi-confined, and anisotropic aquifer models.

Slug Test Analyses

Slug tests involve causing a sudden water-level change in a well, piezometer, or boring and monitoring the water level rise or fall as it returns to quasi-equilibrium conditions. Numerous researchers have developed methods for determining hydraulic conductivity using these data. Four methods commonly cited in the literature are briefly described below. A more detailed description of these analyses is presented in Chapter VI and in Appendix D.

Hvorslev (1951) presented many formulas for various piezometer geometries and aquifer conditions. Both fully and partially penetrating wells were considered. His method of analysis is based on a mathematical model that assumes negligible compressive storage; that is, the aquifer water and matrix are incompressible and flow is quasi-steady (Chirlin, 1989).

The Cooper and others (1967) model is similar to that developed by Hvorslev. In the case of a fully penetrating well the models are identical except the effect of compressive storage is included in the method of Cooper and others (Chirlin, 1989). A set of type curves, computed from their solution, is matched with experimental data to determine aquifer transmissivity. Additional type curves were published by Papadopulos and others (1973).

Bouwer and Rice (1976) developed a procedure for calculating hydraulic conductivity that is based on the Theim (1906) equation of steady-state flow to a well. The authors used a resistance network analog to evaluate the effective radius (R_e) over which the head difference between the equilibrium water table in the aquifer and the water level in the well is dissipated after a volume of water is suddenly removed from a well. This enabled the derivation of an empirical equation that relates R_e to the geometry and boundary conditions of the system.

The method of analysis developed by Nguyen and Pinder (1984) assumes that the slug test is conducted in a partially penetrating well where the effects of a water table or leakage from a confining layer can be ignored, at least in the short term. The authors state that their method is most appropriate for the analysis of materials of moderate to low hydraulic conductivity.

CHAPTER III

SITE DESCRIPTION

Location

The study area is located in a residential neighborhood in northeastern Stillwater, Payne County, Oklahoma, NE 1/4 Sec. 11, T 19 N, R 2 E, as shown on Figures 1 and 2. The site is on the flood plain of a small stream, Boomer Creek, and is approximately 500 feet northeast of the confluence of Boomer Creek and an unnamed tributary.

Monitoring Wells

Forty-three monitoring wells have been installed at the field site. The wells are located in clusters labeled A through J, as shown on Figure 3. Details of the construction of the wells are in Appendix A.

Hydrogeology

General Geology

The study area is underlain by approximately 43 feet of Quaternary fine-grained alluvium that overlies the Doyle Shale, Oscar Group, of Late Pennsylvanian age. A

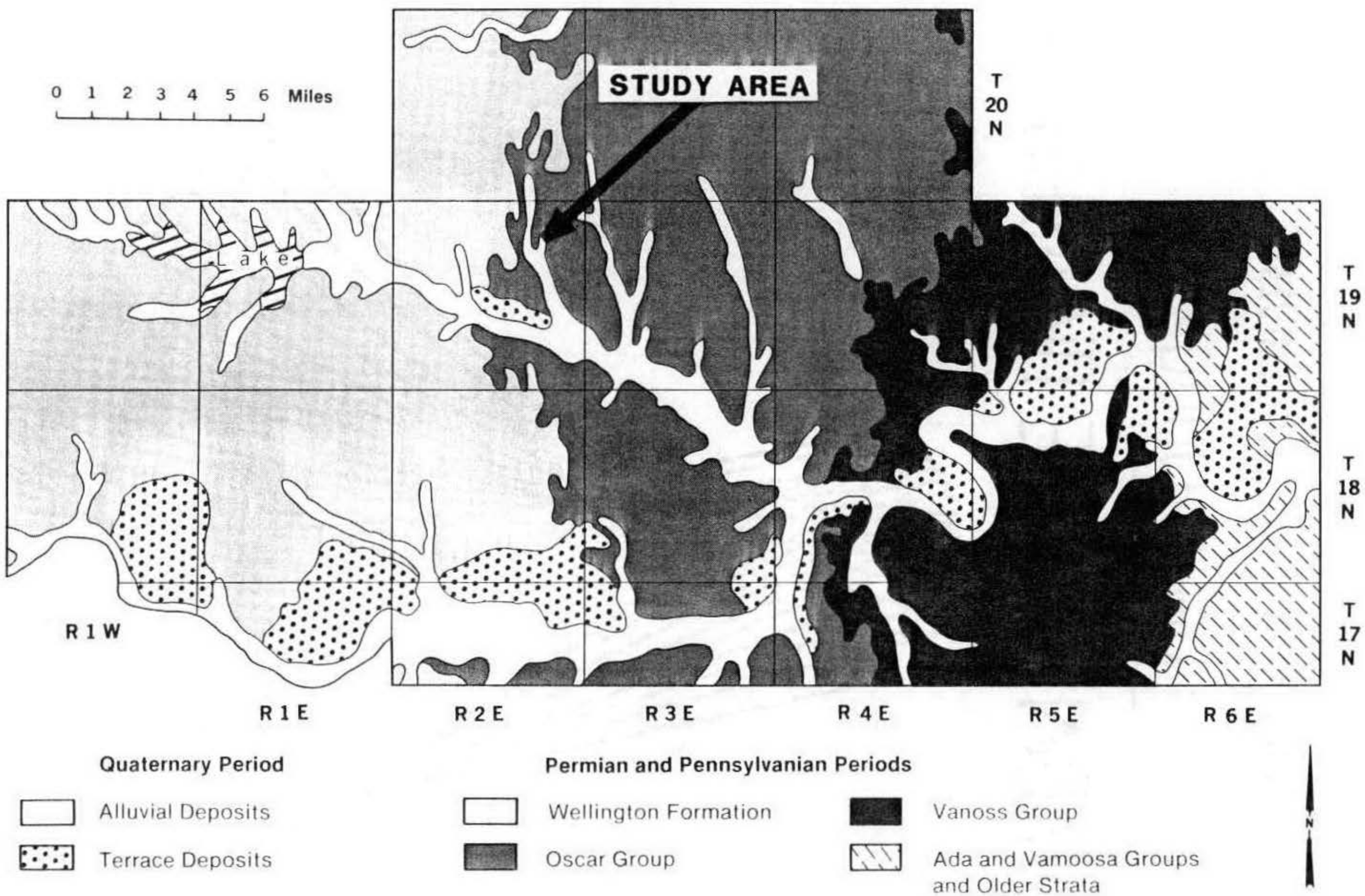


Figure 1. Site Location and General Geology of Payne County, Oklahoma. Source: Soil Conservation Service, 1987.

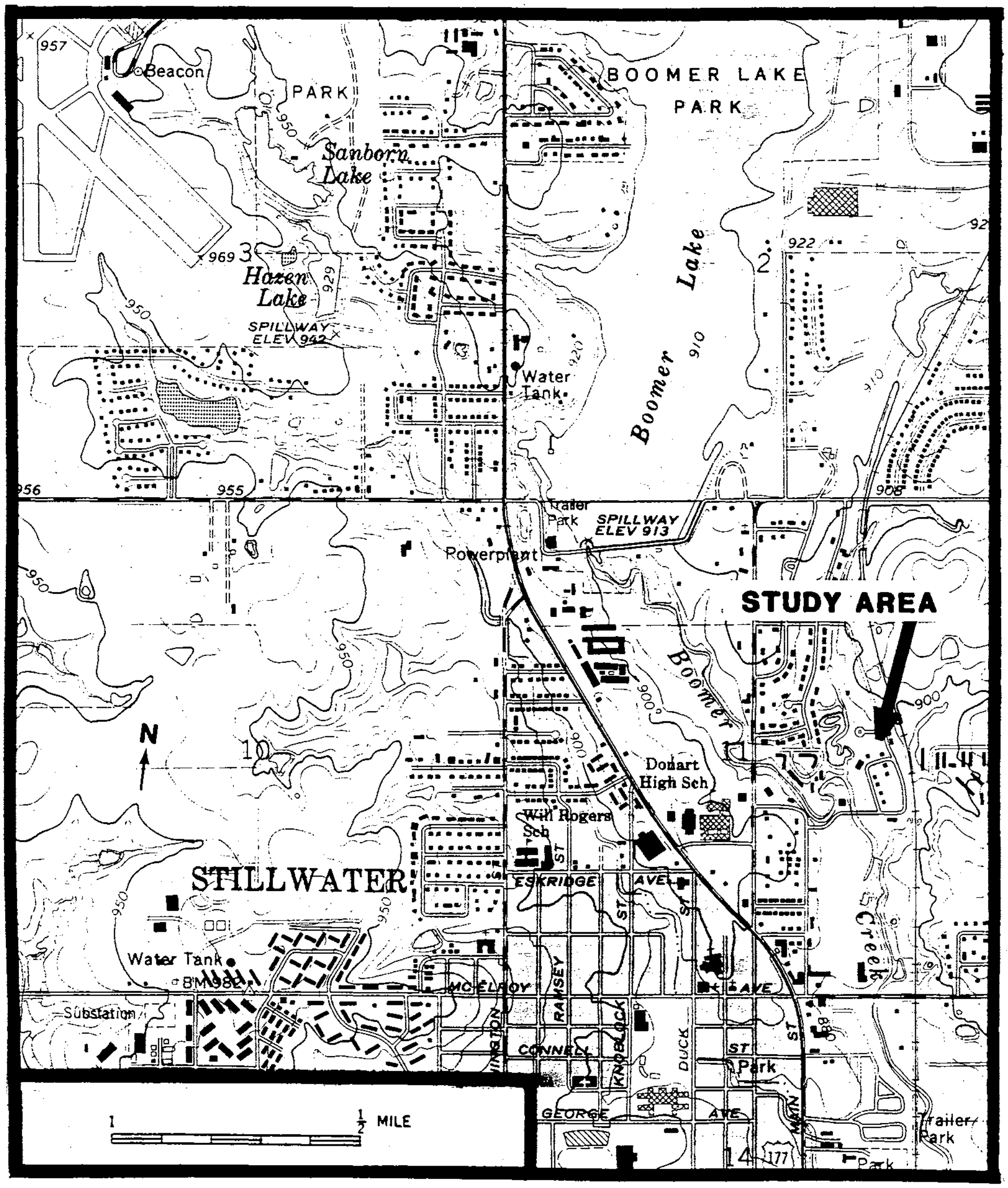


Figure 2. Site Location Map. Source: U.S.G.S., 1979.

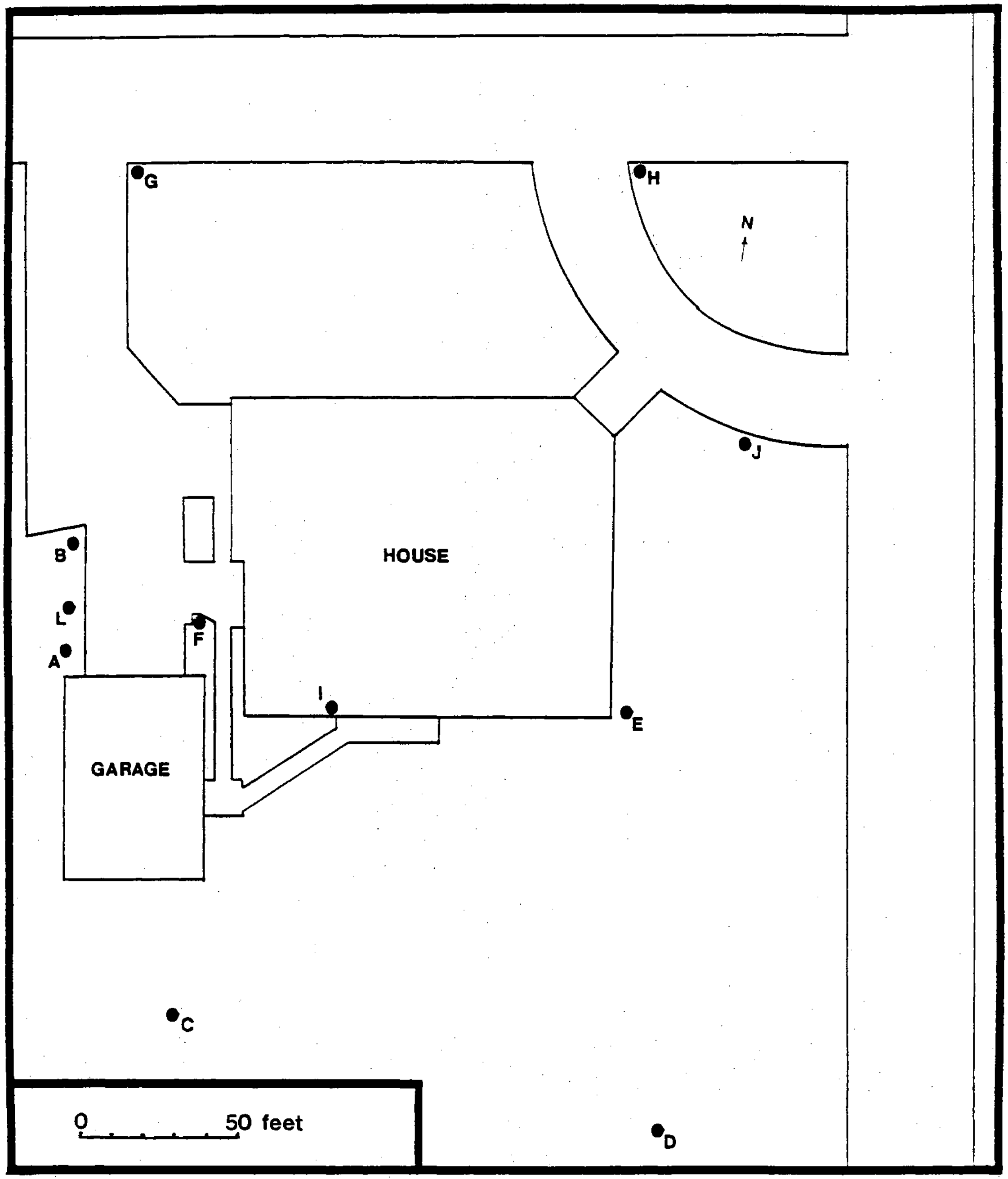


Figure 3. Location of Monitoring Wells. Source: Froneberger, 1989.

generalized geologic cross-section of the area is shown on Figure 4.

Aquifer Material

In general geologic terms, the aquifer is composed entirely of alluvium. However, soil scientists distinguish between alluvium, which does not show evidence of alteration by soil-forming processes, and soils, which have formed in alluvium or other parent material. Ross (1988) described the aquifer extensively in soil science terms. He identified three soil profiles in a 45-foot "core" that was obtained by combining cored material from the B and F sites, shown on Figure 3. A soil profile is shown on Figure 5 and a description of the composite core is in Appendix B.

Ross (1988) identified three soil profiles, including 28 separate horizons. The soil textures of these horizons included silty clay, silty clay loam, silt loam, and loam. Throughout most of the soil profiles the dominant soil structure is weak to moderate, medium, subangular blocky. Root casts are common throughout most of the soils. The deepest buried A horizon, at a depth of approximately 28 feet below land surface (b.l.s.), formed 10,600 $\pm$ 170 years ago, based on radiocarbon dating (Beta-20144) (Ross, 1988).

Ross (1988) identified layers of poorly-sorted gravel and well-sorted, fine-grained, thinly laminated sand from approximately 35 feet to 43 feet b.l.s., which suggests

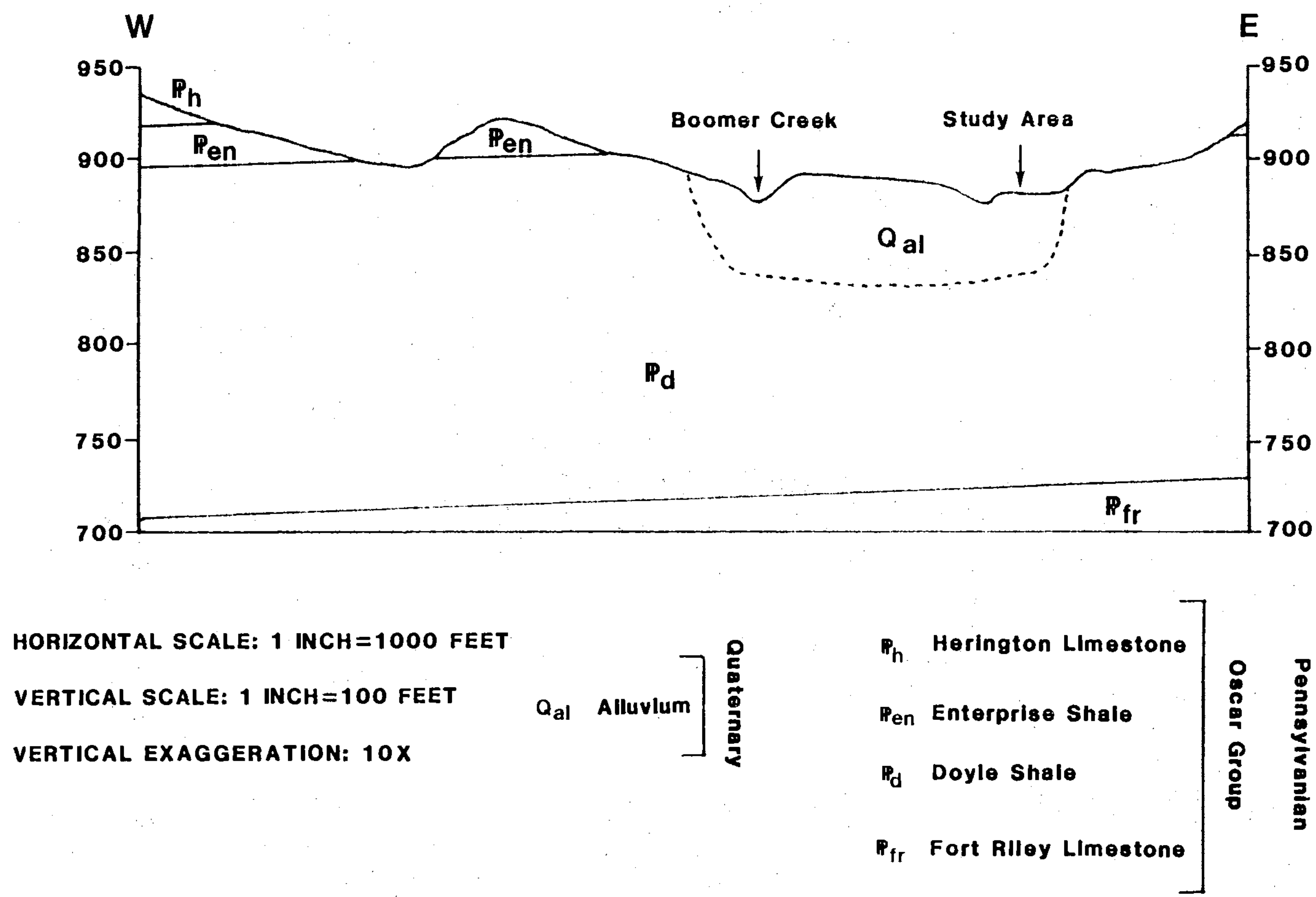


Figure 4. Geologic Cross-Section. Source: Froneberger, 1989.

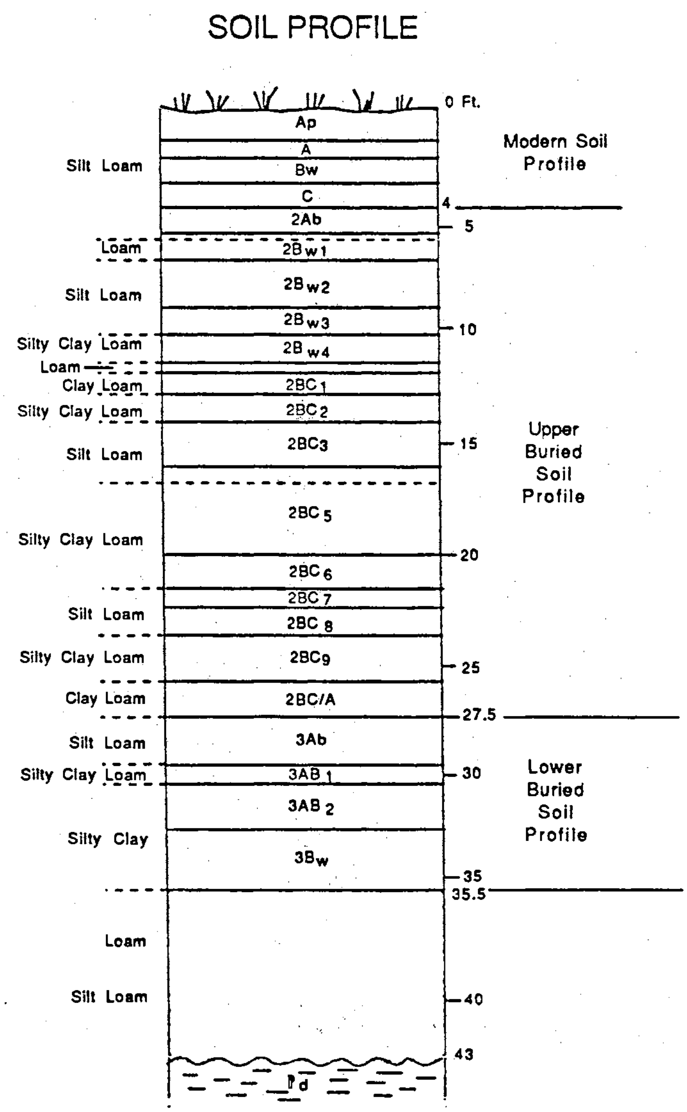


Figure 5. Soil Profile and Textures. Source: Modified from Ross, 1988.

that this zone is highly permeable. However, intermixed with the sand and gravel are significant amounts of clay and silt, which should make the hydraulic conductivity of this layer much lower than Ross' observations imply. Particle-size analyses of this unit indicate a silt loam or loam texture in terms of the soil classification system developed by the U.S. Department of Agriculture.

Soil textural classification diagrams for Ross' (1988) composite core and for the well B12 core are presented on Figures 6 and 7, respectively. The clay fractions were determined using the pipet method, as described by Gee and Bauder (1986). Bulk density, porosity, texture, and clay mineralogy of selected samples from the well B12 borehole are presented in Table I. Porosities were calculated with the following equation:

$$n = 1 - Pb/Ps \qquad (3.1)$$

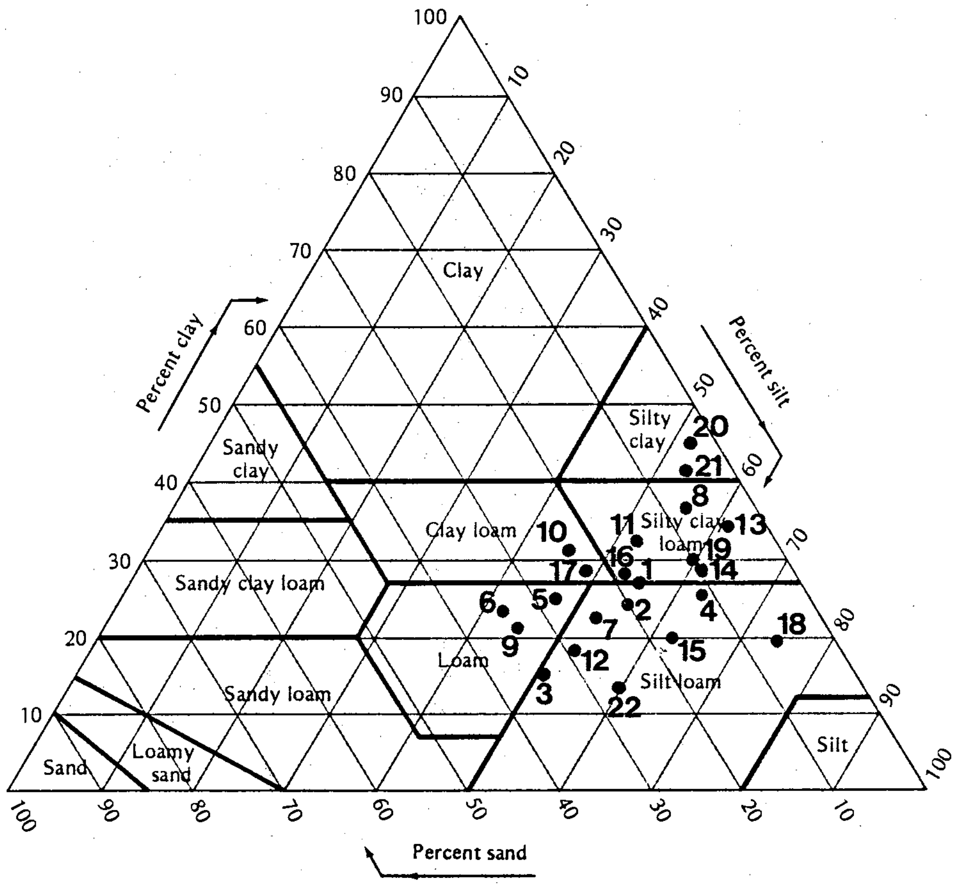
where

n = porosity

Pb = bulk density, in g/cm^3

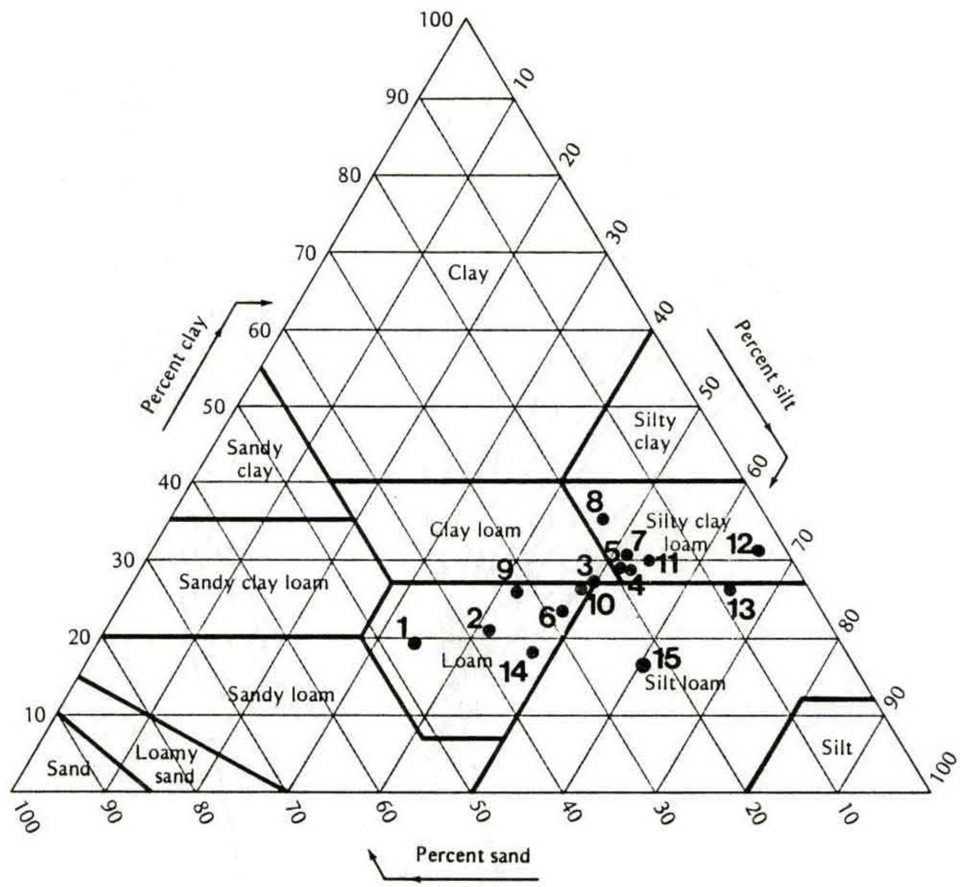
Ps = mean particle density, assumed to be that of quartz, 2.65 g/cm^3

Clay composition was determined at the Oklahoma State University Agronomy Department with a X-ray diffractometer, using the methodology described by Whittig and Allardice (1986). The relative percentages of clay types were estimated based on relative intensities of x-ray diffractions (peak heights) and do not represent quantitative results.



Number	Depth (ft.)	Number	Depth (ft.)
1	1.6-2.2	12	16
2	2.2-3.2	13	19
3	3.2-4.2	14	21
4	4.2-5.3	15	23
5	5.3-5.7	16	25
6	5.7-6.5	17	26.5
7	6.5-9.0	18	28
8	11	19	30
9	12-12.5	20	31.5
10	13	21	34
11	14	22	37

Figure 6. Soil Texture Diagram from Ross (1989). Source: Modified from Ross, 1989.



Number	Depth (ft.)	Number	Depth (ft.)
1	12.3-13.1	9	21.8-22.1
2	12.3-13.1	10	22.1-22.4
3	13.6-15.4	11	28.1-28.5
4	13.6-15.4	12	35.5-35.8
5	15.4-15.7	13	35.8-36.2
6	15.7-16.2	14	38.9-39.1
7	19.3-19.7	15	39.1-39.5
8	19.7-19.9		

Figure 7. Soil Texture for Location of Well B12.

TABLE I

BULK DENSITY, POROSITY, TEXTURE, AND CLAY MINERALOGY OF SELECTED SAMPLES FROM LOCATION OF WELL B12

Depth (ft.)	Pb (g/cm^3)	n	Texture	Clay Mineralogy *(Approximate)
12.3-13.1	1.83	0.31	Loam	41% Kaolinite 41% Quartz 13% Interstratified Smec.-Vermic. <5% Hydroxy-Interlayer Vermiculite
13.6-15.4	1.75	0.34	CL-SiCL	
15.4-15.7	1.83	0.31	SiCL	
15.7-16.2	1.74	0.34	Loam	
19.3-19.7	1.58	0.40	SiCL	
19.7-19.9	1.55	0.41	SiCL	
21.8-22.1	1.67	0.37	CL-L	
22.1-22.4	1.52	0.43	Clay Loam	33% Kaolinite 22% Smectite 22% Illite 22% Quartz
28.1-28.5	1.63	0.38	Silty Clay Loam	33% Kaolinite 33% Quartz 22% Illite 12% Interstratified Smec.-Vermic.
35.5-35.8	1.58	0.40	Silty Clay Loam	32% Kaolinite 32% Quartz 21% Smectite 10% Illite <5% Hydroxy-Interlayer Vermiculite
35.8-36.2	1.56	0.41	SiL-SiCL	
39.1-39.5	1.66	0.37	Silt Loam	33% Kaolinite 33% Quartz 22% Smectite 12% Illite

TABLE I (Continued)

Note:

* The relative percentages of clay types were estimated based on relative intensities of x-ray diffractions and do not represent quantitative results.

Pb = bulk density
Ps = mean particle density
n = porosity = 1 - Pb/Ps (Ps assumed to be 2.65 g/cm^3)
C = Clay
L = Loam
Si = Silt
Smec. = Smectite
Vermic. = Vermiculite

Hydraulic Coefficients

The results of constant-rate aquifer pumping tests conducted by the author and by Hoyle (1987) indicate that the hydraulic conductivity of the aquifer ranges from 27 to 164 gpd/ft^2 (1.3×10^{-3} to 7.7×10^{-3} cm/sec) and the storativity (storage coefficient) is about 0.01.

CHAPTER IV

DRILLING, SAMPLING, AND WELL INSTALLATION

Drilling and Soil Sampling

On July 6, 1988, employees of the EPA's Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma drilled an 8-inch diameter borehole to a depth of 44 feet at the location of well B12 (B site), shown on Figure 3. The borehole was drilled using a truck-mounted drilling rig with hollow-stem flight augers. During the drilling operation, continuous "undisturbed" samples of the soil/alluvium were collected with a 4-inch diameter, 5-foot long, thin-walled tube sampler. The core barrel sampler was pressed, without turning, into the sediments through the hollow-stem of the flight augers. Upon retrieval, the core samples were immediately sealed to prevent water loss and stored indoors for subsequent laboratory permeability testing.

Installation of Well B12

On July 6, 1988, the 4-inch diameter well B12 was installed to a depth of approximately 34 feet b.l.s. A 2-

inch diameter well (B13) was also installed in the same borehole for the purpose of determining well loss. The constuction details of the wells are included in Appendix A. Originally, the intention was to install well B12 to a depth of approximately 43 feet in order to provide a well that fully penetrates the aquifer. However, it was not possible to install the well to the intended depth. The drillers decided to remove the augers from the borehole before installing the well screen/casing and began to add sand, to serve as a filter pack around the screen, once the augers were removed from the borehole. The formation partially collapsed and/or the borehole filled too much with sand before the well screen could be set to the proper depth. Due to these circumstances, the degree of hydraulic connection between the bottom the well and the lower section of the original borehole is uncertain.

After well B12 was installed, it was developed by removing water and fine-grained materials that entered the well with an air-lift system consisting of an air hose lowered into the well and connected to an air compressor. The air-lift was alternately turned on and off in order to move water in and out of the formation. During the development process, short-duration specific capacity tests were performed in order to assess the progress of the well development. After there was no significant increase in specific capacity, the well was considered to be sufficiently developed.

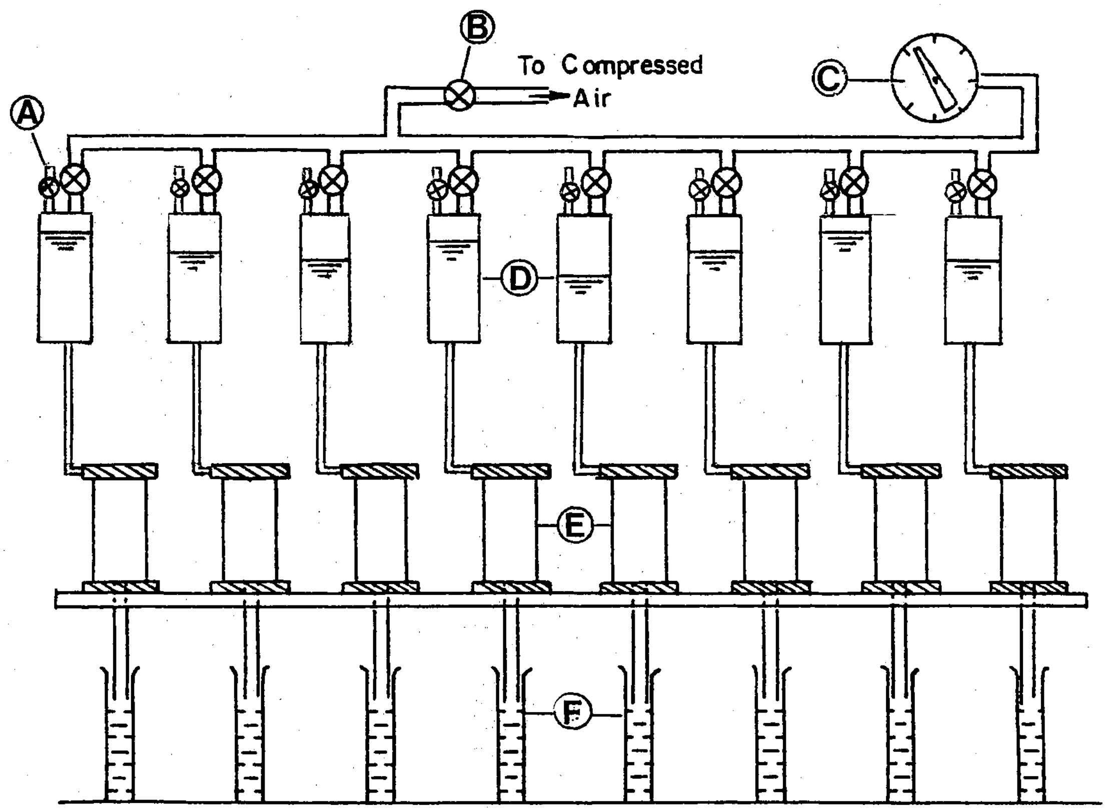
CHAPTER V

LABORATORY PERMEAMETER TESTING

Methodology

Laboratory determinations of hydraulic conductivity were obtained with a constant-head permeameter in the Soil Mechanics Laboratory of the School of Engineering at Oklahoma State University. In order to produce accurately measurable flows of water through the samples, in a reasonable amount of time, the hydraulic gradient was increased by applying air pressure to the resevoirs which supplied water to the samples. Using a compressed air system, the hydraulic gradients employed during the tests ranged between 98 and 295. A diagram of the permeameter setup is shown on Figure 8. No standard method for this permeameter was found in the literature. Therefore, the following provides a detailed description of the permeameter and the methodology that was followed. The use of this permeameter is also described by Rahimi (1977).

"Undisturbed" core samples, obtained during the drilling of well B12, were trimmed to a diameter slightly larger than the permeameter mold. The molds are Harvard-type, miniature size (Model K620) stainless steel tubes,



Ⓐ Water Refill Pipe
Ⓑ Valve
Ⓒ Pressure Guage
Ⓓ Water Resevoir
Ⓔ Mold (Sample Holder)
Ⓕ Graduated Cylinder

Figure 8. Schematic Diagram of Laboratory Constant-Head Permeater. Source: Modified from Rahimi, 1977.

2.82 inches (7.16 cm) long and 1.31 inches (3.33 cm) in diameter, manufactured by Soiltest, Inc. The inside surface of the mold was coated with silicon grease. The sample was then placed in the mold by carefully pressing the mold, with a cutting edge mounted on the end of the mold, over the the sample. Both vertical and horizontal orientations were obtained. Every precaution was taken to minimize disturbance to the permeameter samples; however, some disturbance, particularly smearing of clays, was inevitable. A porous stone was placed on each end of the sample and the sample molds were then fastened into the permeameter apparatus with clamps.

During sample preparation, the soils were described and the cuttings and the mold samples were weighed for determinations of gravimetric water content and bulk density. Water contents and calculated porosities were compared in order to verify that the soil samples were completely saturated during testing. Volumetric water contents were derived from gravimetric water contents with the following equation:

$$\theta = W * Pb/Pw \qquad (5.1)$$

where

θ = volumetric water content

W = gravimetric water content

Pb = bulk density of the soil, in g/cm^3

Pw = density of water, assumed to be 1 g/cm^3

As shown on Figure 8, the permeameter apparatus can be used to analyze up to eight samples simultaneously. Compressed air was supplied to the water resevoirs above each sample mold and was monitored by a pressure guage. The water used for the testing was degassed ground water obtained from well B12.

Figure 9 shows a detailed drawing of one of the permeameter sample cells. Water flowed from the resevoir above the sample through pipe A to the top of the sample, shown on Figure 9. Any air in the system was expelled by opening a valve in pipe B at the beginning of the test. Water that flowed through the sample was collected in a covered vial, to prevent evaporation, and was measured in a graduated cylinder. In most cases, several days were required before flow was established through the sample. The outflow was measured over several time intervals.

Hydraulic conductivity was calculated from the following equation:

$$K = \frac{V}{T} * \frac{L}{H * A} \tag{5.2}$$

where

K = hydraulic conductivity in cm/sec

V = volume of water collected in cm^3

T = time in seconds for V cm^3 of water to be collected

L = length of permeameter in cm

A = cross-sectional area of sample mold in cm^2

H = constant pressure applied to the water resevoir expressed in cm of head

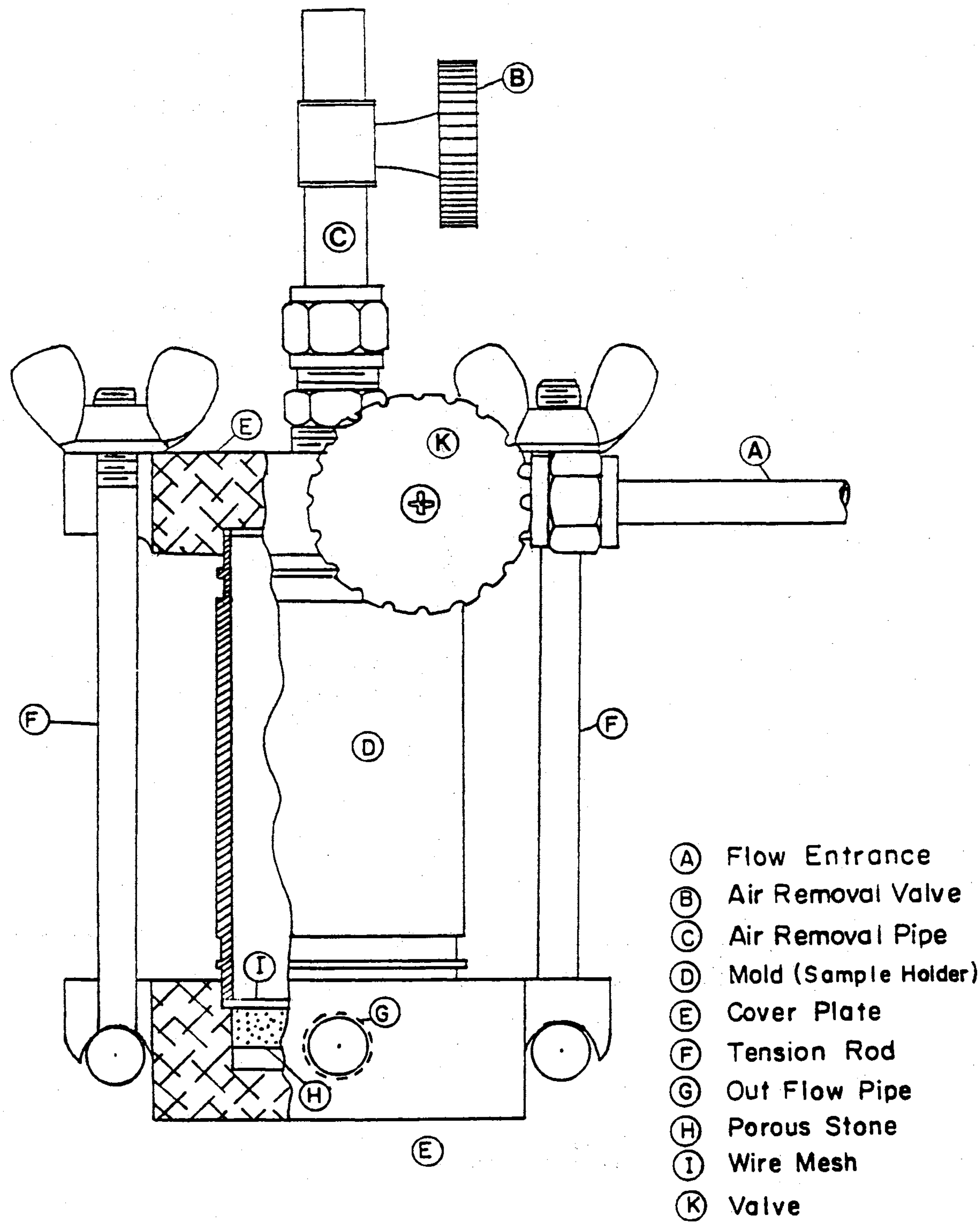


Figure 9. Detail of One Permeameter Unit. Source: Rahimi, 1977.

Equation Derivation and Conversion of Units

The hydraulic conductivity values calculated with equation 5.2, in units of cm/sec, were converted to the units of gpd/ft^2 by multiplying these values by $2.12x10^4$ (1 cm/sec = 21,200 gpd/ft^2). The following discussion explains the derivation of equation 5.2 and of the conversion factor.

Equation 5.2 was derived from Darcy's Law, which in its simplest form can be expressed as:

$$Q = KIA \qquad (5.3)$$

where

Q = discharge

$= \frac{V}{T} = \frac{Volume}{Time}$

K = hydraulic conductivity

I = hydraulic gradient

$= \frac{H_1 - H_2}{L}$ = change in head over length

A = cross-sectional area through which flow occurs

Equation 5.2 can therefore be expressed as:

$$\frac{V}{T} = K * \frac{H_1 - H_2}{L} * A \qquad (5.4)$$

Then, solving for K:

$$K = \frac{V}{T} * \frac{L}{H_1 - H_2} * \frac{1}{A} \qquad (5.5)$$

In the case of the permeameter used in this study, the change in head is the difference between the head at the top (inlet, H_1) of the permeameter sample minus the head at the bottom (outlet, H_2) of the sample. The head at the top of the sample is equal to the pressure applied to the water at the sample inlet, in pounds per inch squared (psi), multiplied by 70.3 (1 psi = 70.3 cm of water). The head at the outlet is atmospheric pressure, considered to be 0. Therefore, the hydraulic gradient equals H_1 minus H_2 divided by the length of the sample, or $\frac{H}{L}$.

Hence, in the case of this experiment, K can be expressed as:

$$K = \frac{V}{T} * \frac{L}{H} * \frac{1}{A} \tag{5.6}$$

Substituting the dimensions of length (L) and time (T) in this expression, we obtain:

$$K = \frac{L^3}{T} * \frac{L}{L} * \frac{1}{L^2} = \frac{L}{T}$$

Thus, we can obtain hydraulic conductivity in units of cm/sec:

$$K = \frac{cm^3}{sec} * \frac{cm}{cm} * \frac{1}{cm^2} = cm/sec$$

Or K can be expressed in units of gpd/ft^2:

$$K = \frac{gal}{day} * \frac{ft}{ft} * \frac{1}{ft^2} = \frac{gal}{day \times ft^2} = gpd/ft^2$$

The conversion factor can be obtained as follows:

$$1\ cm/sec = \frac{1\ cm^3}{1\ sec} * \frac{1\ cm}{1\ cm} * \frac{1}{1\ cm^2} * \frac{1\ liter}{1000\ cm^3} * \frac{1\ gal}{3.785\ l}$$

$$* \frac{1\ cm^2}{1.076x10^{-3}\ ft^2} * \frac{86,400\ sec}{1\ day}$$

$$= 2.12x10^4\ gpd/ft^2$$

CHAPTER VI

AQUIFER TESTING

Aquifer Pumping Test

A 72-hour aquifer pumping test was conducted in order to determine aquifer hydraulic coefficients. From August 14 to August 17, 1988, well B12 was pumped with a submersible pump at a constant rate of 2.7 gallons per minute (gpm). The pumped water was routed via a hose to the street, approximately 70 feet northwest of the pumped well. The water discharged at the street flowed along the street and then into a storm sewer. The flow rate was monitored using a graduated bucket and a stopwatch. Water-level drawdown and recovery measurements were made in the pumping and observation wells with electric and steel tapes.

The data were analyzed with the Theis (1935) and the Cooper and Jacob (1946) analytical models. The data were not analyzed using the methods developed by Prickett (1965) and Neuman (1975) for analyzing water-table aquifers because delayed drainage was not apparent during the duration of the test. Water-level drawdown and residual drawdown data were calculated by extrapolating the water-level trend before pumping started through the pumping and recovery periods, and determining the difference between the water levels measured during the test and the extrapolated water levels. The extrapolated water-level trend is shown on Figure 10.

Drawdown measurements were corrected for reduction of the saturated thickness of the aquifer during pumping using the method presented by Jacob (1944). The following equation was used to correct for dewatering of the aquifer:

$$s_a = s_o - s_o^2/(2 * m) \qquad (6.1)$$

where

s_a = adjusted drawdown, in feet

s_o = observed drawdown, in feet

m = initial saturated aquifer thickness, in feet

Partial penetration effects were considered; however, the data were not corrected for these impacts for reasons that are discussed in Chapter VIII. Plots of water-level drawdown versus time, water-level drawdown versus distance from the pumping well, and residual drawdown versus t/t' are included in Appendix C.

Theis (1935) Time-Drawdown Method

The Theis method of analysis involves matching a logarithmic plot of drawdown versus time to a type curve of W(u) versus 1/u. The Theis type curve is shown on Figure 11. A match point is chosen and values of s, t, W(u), and 1/u are determined and substituted into the following

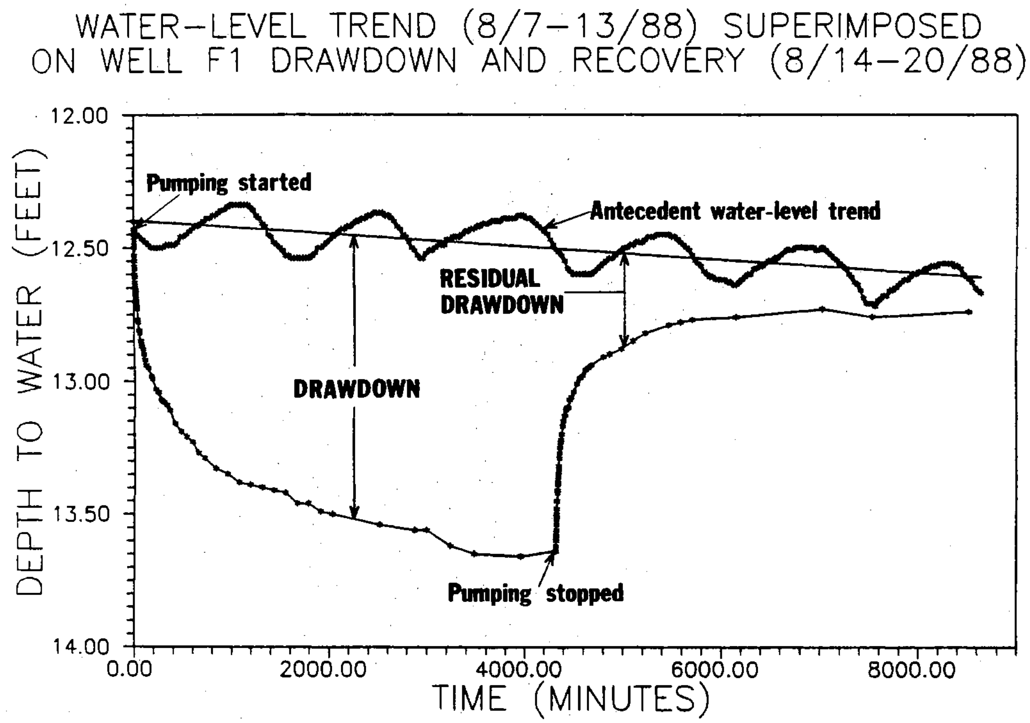


Figure 10. Plot of Water-Level Trend, Drawdown, and Recovery.

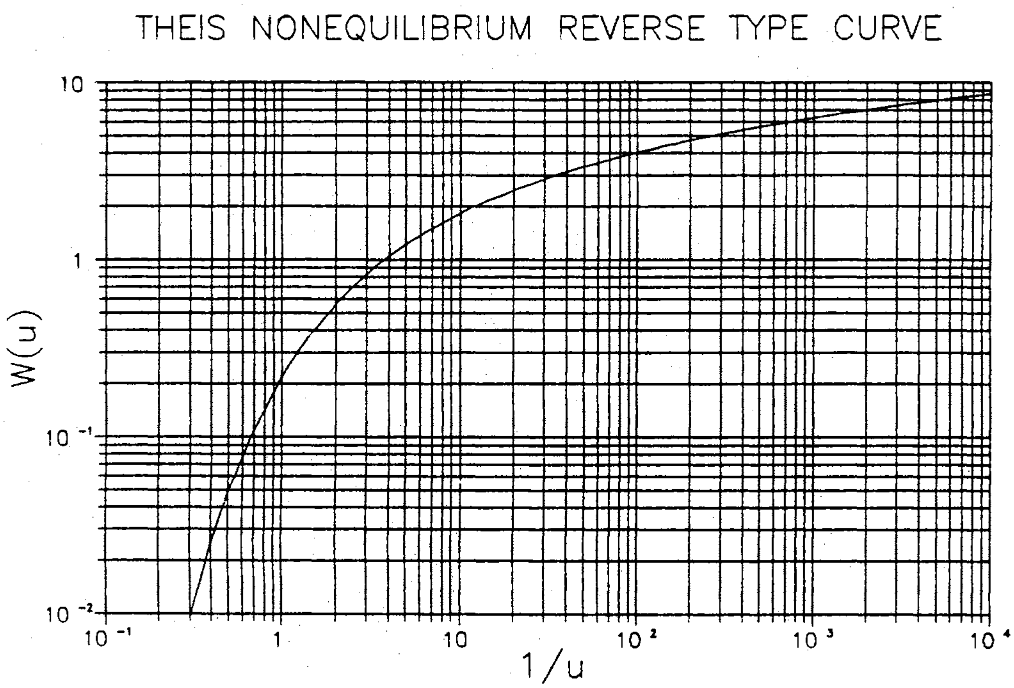


Figure 11. Theis (1935) Nonequilibrium Type Curve.

equations for transmissivity and storativity:

$$T = \frac{114.6\ Q\ W(u)}{s} \qquad (6.2)$$

where

T = transmissivity, in gpd/ft

Q = pumping rate, in gpm

W(u) = Well function of u (It represents a dimensionless exponential integral.)

s = drawdown, in feet

$$S = \frac{T\ u\ t}{2693\ r^2} \qquad (6.3)$$

where

S = storativity (dimensionless)

T = transmissivity, in gpd/ft

t = time since pumping started, in minutes

r = distance from pumped well to the observation well, in feet

Cooper and Jacob (1946)

Time-Drawdown Method

In the Jacob method of analysis a semilogarithmic plot of drawdown versus time is prepared and a straight-line segment of the plotted data is chosen. The straight line should be selected where u is less than 0.05 (Driscoll, 1986; Heath, 1984). The time at which u is less than 0.05 is obtained using the following formula:

$$t = \frac{53,856\ r^2\ S}{T} \qquad (6.4)$$

where

r = distance from the pumped well to the observation well, in feet

S = estimated storativity (dimensionless)

T = estimated transmissivity, in gpd/ft

The transmissivity and storativity are then calculated using the following equations:

$$T = \frac{264\ Q}{\Delta s} \qquad (6.5)$$

where

T = transmissivity, in gpd/ft

Q = pumping rate, in gpm

Δs = slope of the time-drawdown graph expressed as the change in drawdown between any two times on the logarithmic scale for which the ratio is 10 (one log cycle)

$$S = \frac{T * t_0}{4790\ r^2} \qquad (6.6)$$

where

S = storativity

T = transmissivity, in gpd/ft

t_0 = intercept of the straight line at zero drawdown, in minutes

r = distance from pumped well to observation well, in feet

Cooper and Jacob (1946) Distance-Drawdown Method

The Jacob distance-drawdown method involves plotting "simultaneous" drawdowns in at least three observation wells versus distance from the pumping well on semilogarithmic graph paper. The time selected for the drawdown data should be long enough after pumping started such that u is less than 0.05. The following equations are used to calculate transmissivity and the storativity:

$$T = \frac{528\,Q}{\Delta s} \qquad (6.7)$$

where

Q = pumping rate, in gpm

Δs = slope of the selected straight line expressed as the change in drawdown, in feet, between any two values of distance on the logarithmic scale for which the ratio is 10

$$S = \frac{T\,t}{4790\,r_0^2} \qquad (6.8)$$

where

S = storativity

T = transmissivity, in gpd/ft

t = time after pumping started, in minutes

r_0 = intercept of extended straight line at zero drawdown, in feet

Theis (1935) Recovery Method

In the Theis (1935) method of analysis, residual drawdown, s', versus the ratio of the time since pumping started, t, to the time since pumping stopped, t', is plotted on a semilogarithmic graph. Theis' original recovery method has been modified and a commonly used adaptatation is decribed by Driscoll (1986). A straight line is drawn through the data points and transmissivity is calculated with the following equation:

$$T = \frac{264\ Q}{\Delta s'} \qquad (6.9)$$

where

T = transmissivity, in gpd/ft

Q = pumping rate, in gpm

$\Delta s'$ = change in residual drawdown over 1 log cycle

As explained by Driscoll (1986) the residual-drawdown plot cannot be used for determining the storativity.

Aquifer Slug Tests

Several slug tests were performed on wells B12 and F1. The tests were conducted by removing a "slug" of water from the well with a bailer and obtaining rapid water-level recovery (rising head) measurements in the same well with a pressure transducer. Three different sizes of bailers were used in order to determine the effect of the size of the "slug" on the results. The capacities of the bailers were 0.29, 0.79, and 1.75 gallons.

The slug test data were analyzed by four different methods: Hvorslev (1951), Cooper and others (1967), Bouwer and Rice (1976), and Nguyen and Pinder (1984). These methods can be used to analyze either rising head or falling head tests. The data used in the analyses and plots for each method are included in Appendix D. The methodology of each analysis is briefly explained below and examples using data from the study area are provided in Appendix D.

Hvorslev (1951) Method

Hvorslev's method, as described by Fetter (1988), involves determining the ratio H/H(0), where H(0) or H_0 is the distance the water level declines upon removal of a "slug" of water and H is the height of the water level below the static water level at some time, t, after the slug is removed. This ratio is plotted versus time on semilogarithmic graph paper and is expected to plot on a straight line. A diagram of well geometry for the Hvorslev method is shown on Figure 12. For the case where the length of the piezometer is greater than 8 times the radius of the well screen, the following formula is employed:

$$K = \frac{r^2 \ln(L/R)}{2LT_0} \qquad (6.10)$$

where

K = hydraulic conductivity

r = radius of the well casing

R = radius of the well screen

L = length of the well screen

T_0= time required for the water level to rise to 37 percent of the initial change, obtained from the graph of H/H(0) vs. time

Cooper and others (1967) Method

The Cooper and others (1967) method assumes that the well completely penetrates a confined aquifer. An idealized representation of such a well and parameters to

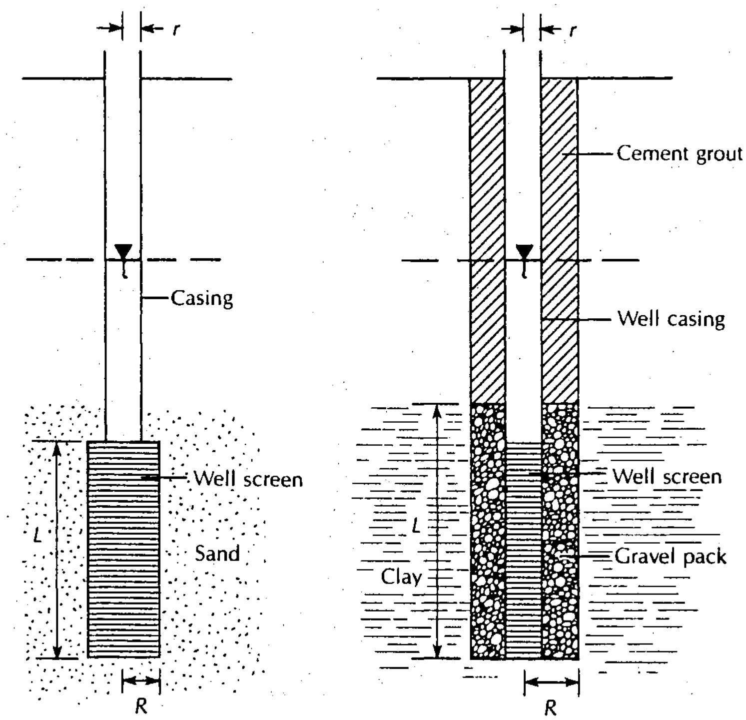


Figure 12. Geometry and Symbols for Hvorslev (1951) Model. Source: Fetter, 1988.

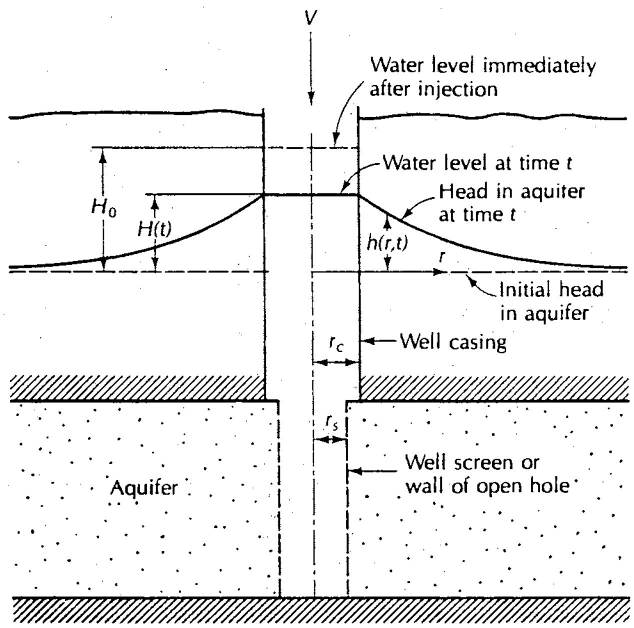


Figure 13. Geometry and Symbols for Cooper and others (1967) Model. Source: Cooper and others, 1967.

be measured are shown on Figure 13. A plot of the ratio of measured head after injection or withdrawl to the initial head (H/H(0)) versus time is matched to one of the type curves presented in Papadopulos and others (1973). These type curves are shown on Figure 14. From this curve match, the time (t) is selected for which $Tt/r_c^2 = 1.0$, where T is the transmissivity, and r_c is the radius of the casing. Transmissivity is solved by the equation:

$$T = 1.0\ r_c^2/t \qquad (6.11)$$

Bouwer and Rice (1976) Method

The method of Bouwer and Rice (1976) is based on the Thiem (1906) equation and is applicable to fully or partially penetrating wells in unconfined aquifers. A schematic diagram of such a well is shown on Figure 15. Hydraulic conductivity is computed using the formula:

$$K = \frac{r_c^2 \ln (R_e/r_w)}{2L_e} \frac{1}{t} \ln \frac{y_0}{y_t} \qquad (6.12)$$

where

R_e = effective radial distance over which the head difference, y, is dissipated

r_w = radial distance between well center and undisturbed aquifer (r_c plus thickness of gravel envelope or developed zone outside casing)

y_0 = y at time zero

y_t = y at time t

t = time since y_0

Values of the effective radius, R_e, for various system

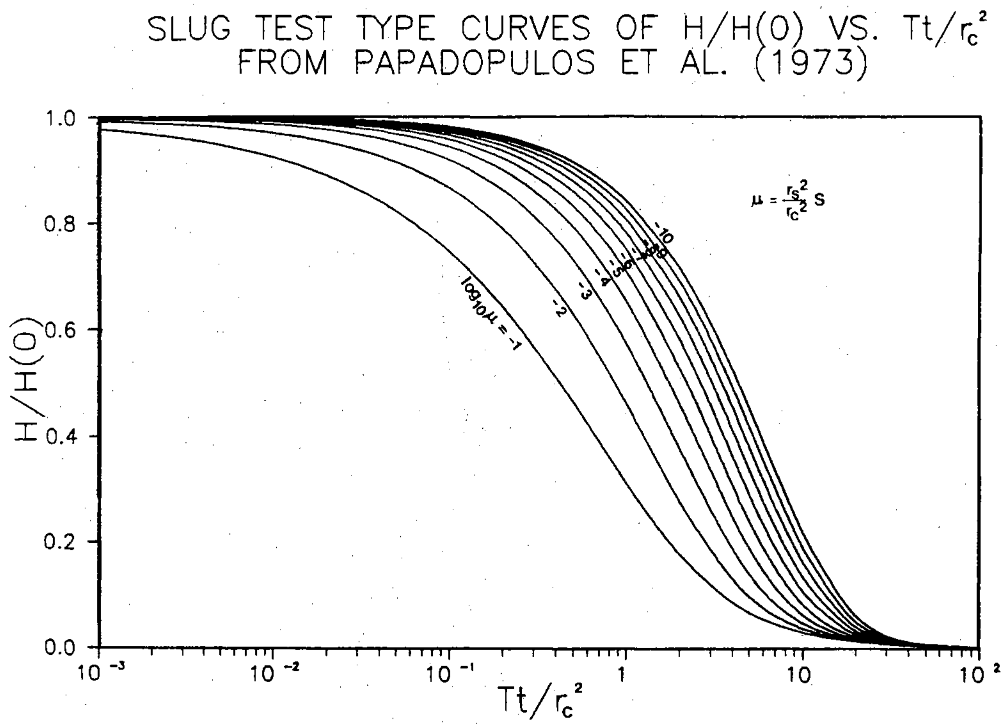


Figure 14. Papadopulos and others (1973) Type Curves. Source: Modified from Papadopulos and others, 1973.

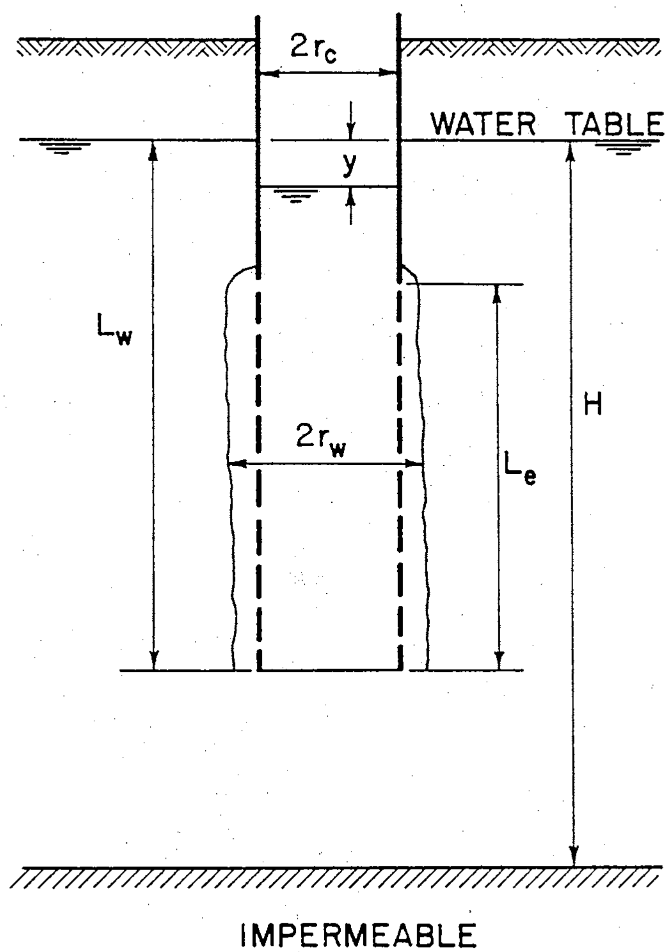


Figure 15. Geometry and Symbols for Bouwer and Rice (1973) Model. Source: Bouwer, 1989.

geometries, were determined experimentally using a resistance-network analog. This allowed the derivation of the following empirical equation, which relates R_e to the geometry and boundary conditions of the system:

$$\ln \frac{R_e}{r_w} = \frac{1}{\frac{1.1}{\ln (L_w/r_w)} + \frac{A + B \ln[(H- L_w)/r_w]}{(L_e/r_w)}} \qquad (6.13)$$

where

A, B = dimensionless parameters in relation to L_e/r_w, as shown on Figure 16.

A semilogarithmic plot of observed values of y versus t should form a straight line. The straight-line portion of the plot is then used to evaluate $1/t \ln (y_0/y_t)$ for calculation of K in equation 6.12.

<u>Nguyen and Pinder (1984) Method</u>

The method of Nguyen and Pinder (1984) is applicable to partially penetrating wells with well and aquifer geometries similar to those shown on Figure 17. Plots of log H(t) versus log t and log - H/ t versus 1/t are prepared and the slopes of these graphs, C_1 and c_2, are determined. The following equation is then used to calculate hydraulic conductivity:

$$K = \frac{r_e^2 C_3}{4C_4(z_2-z_1)} \qquad (6.14)$$

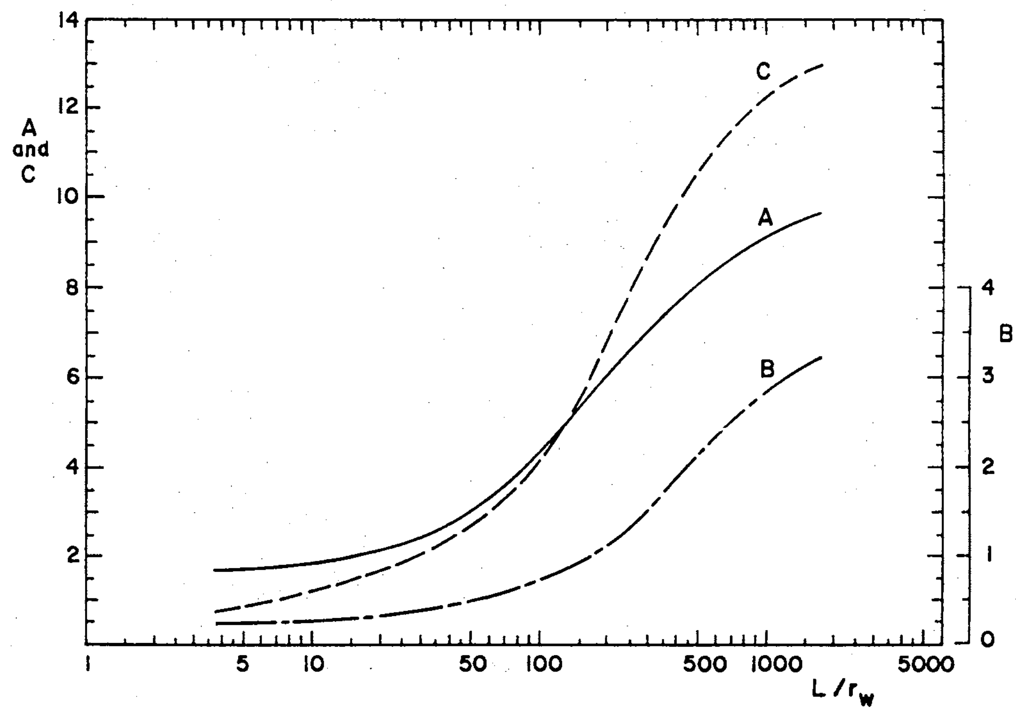


Figure 16. Curves relating coefficients A, B, and C to L/r_w for Bouwer and Rice (1973) Model. Source: Bouwer and Rice, 1973.

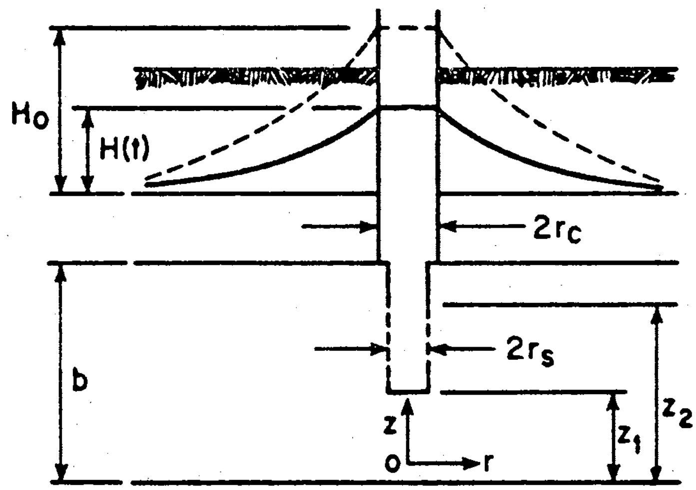


Figure 17. Geometry and Symbols for Nguyen and Pinder (1984) Model. Source: Nguyen and Pinder, 1984.

CHAPTER VII

RESULTS

Laboratory Constant-Head Tests

At the beginning of the laboratory constant-head permeability testing, the intention was to run tests on samples obtained from approximately every 1-foot interval, starting at the approximate depth of the water table during sample collection. During the first run of permeability tests (8 samples), it became apparent that the inordinate amount of time required for sample preparation and for monitoring flows through the samples, even with the increased hydraulic gradients, made this research objective unfeasible. Consequently, the remainder of the testing intervals (depths below 16.2 feet) were selected by choosing those intervals that appeared to have the highest permeability, based on visual inspection.

As discussed previously, after flow was established through the samples it was monitored over many time intervals in order to observe any changes in hydraulic conductivity with time. The hydraulic gradient also was changed during the testing of some of the samples in order to determine the effect of different gradients on the results. The hydraulic conductivity of some samples varied by as much as one order of magnitude. In six of seven samples in which the hydraulic gradient was changed, hydraulic conductivity decreased with a decrease in hydraulic gradient. In one sample, decreasing the gradient resulted in a small increase in calculated hydraulic conductivity.

The results of the laboratory permeability tests are presented in Table II.

TABLE II

SUMMARY OF LABORATORY PERMEAMETER RESULTS

Depth (ft)	Orientation	Hydraulic Conductivity (gpd/ft^2)
12.3 - 13.1	Vertical	$1.2x10^{-2}$ - $3.2x10^{-2}$ ($5.8x10^{-7}$ - $1.5x10^{-6}$ cm/sec)
12.3 - 13.1	Vertical	$1.0x10^{-3}$ - $2.8x10^{-3}$ ($4.9x10^{-8}$ - $1.3x10^{-7}$ cm/sec)
12.3 - 13.1	Horizontal	$3.8x10^{-4}$ - $1.1x10^{-3}$ ($1.8x10^{-8}$ - $5.3x10^{-8}$ cm/sec)
13.6 - 15.4	Vertical	$1.6x10^{-4}$ - $2.3x10^{-4}$ ($7.4x10^{-9}$ - $1.1x10^{-8}$ cm/sec)
13.6 - 15.4	Vertical	$8.9x10^{-5}$ - $2.0x10^{-4}$ ($4.2x10^{-9}$ - $9.6x10^{-9}$ cm/sec)
13.6 - 15.4	Horizontal	$7.2x10^{-5}$ - $9.5x10^{-5}$ ($3.4x10^{-9}$ - $4.5x10^{-9}$ cm/sec)
15.4 - 15.8	Vertical	$2.0x10^{-4}$ - $2.0x10^{-3}$ ($9.2x10^{-9}$ - $9.2x10^{-8}$ cm/sec)

TABLE II (Continued)

Depth (ft)	Orientation	Hydraulic Conductivity (gpd/ft^2)
15.8 - 16.2	Horizontal	$5.9x10^{-5}$ - $7.4x10^{-5}$ ($2.8x10^{-9}$ - $3.5x10^{-9}$ cm/sec)
19.3 - 19.7	Vertical	$1.6x10^{-3}$ - $2.3x10^{-3}$ ($7.6x10^{-8}$ - $1.1x10^{-7}$ cm/sec)
19.7 - 19.9	Horizontal	$2.7x10^{-4}$ - $6.2x10^{-4}$ ($1.3x10^{-8}$ - $2.9x10^{-8}$ cm/sec)
21.8 - 22.1	Horizontal	$1.6x10^{-3}$ - $5.7x10^{-3}$ ($7.6x10^{-8}$ - $2.7x10^{-7}$ cm/sec)
22.1 - 22.4	Vertical	$2.3x10^{-3}$ - $3.2x10^{-3}$ ($1.1x10^{-7}$ - $1.5x10^{-7}$ cm/sec)
28.1 - 28.5	Vertical	$2.5x10^{-4}$ - $3.4x10^{-4}$ ($1.2x10^{-8}$ - $1.6x10^{-8}$ cm/sec)
35.5 - 35.8	Vertical	$3.2x10^{-4}$ - $2.5x10^{-3}$ ($1.5x10^{-8}$ - $1.2x10^{-7}$ cm/sec)
35.8 - 36.2	Horizontal	$9.8x10^{-4}$ - $2.1x10^{-3}$ ($4.6x10^{-8}$ - $1.0x10^{-7}$ cm/sec)
39.1 - 39.5	Vertical	$6.6x10^{-3}$ - $2.3x10^{-2}$ ($3.1x10^{-7}$ - $1.1x10^{-6}$ cm/sec)

Aquifer Pumping Test

The results of the time-drawdown, distance-drawdown, and recovery (residual drawdown) analyses are summarized in Tables III, IV, and V, respectively. The Theis model was not used for wells from which little or no early data were collected. In general, the results are in agreement with the interpretation of Hoyle (1987).

TABLE III

SUMMARY OF AUGUST 1988 AQUIFER TEST TIME-DRAWDOWN RESULTS

Well	r (ft)	Model	T (gpd/ft)	K (gpd/ft^2)	S
A5	18.3	Jacob	1,584	51 (2.4×10^{-3} cm/sec)	0.005
B7	2.3	Jacob	1,516	49 (2.3×10^{-3} cm/sec)	0.0002
B8	2.3	Jacob	1,345	43 (2.0×10^{-3} cm/sec)	0.0004
B9	1.8	Jacob	1,426	46 (2.2×10^{-3} cm/sec)	0.0001
B10	1.7	Jacob	1,620	52 (2.4×10^{-3} cm/sec)	0.0001
C5	85	Jacob	2,970	96 (4.5×10^{-3} cm/sec)	0.0004
D5	150	Jacob	2,458	79 (3.7×10^{-3} cm/sec)	0.003
E5	105	Jacob	2,160	70 (3.3×10^{-3} cm/sec)	0.005
F1	25	Theis	1,719	55 (2.6×10^{-3} cm/sec)	0.002
		Jacob	1,584	51 (2.4×10^{-3} cm/sec)	0.005
G2	70	Jacob	1,550	50 (2.4×10^{-3} cm/sec)	0.01
H2	130	Jacob	1,584	51 (2.4×10^{-3} cm/sec)	0.01
J1	125	Jacob	1,658	53 (2.5×10^{-3} cm/sec)	0.008

Note:

r = distance from pumping well (B12) to observation well.

TABLE IV

SUMMARY OF AUGUST 1988 AQUIFER TEST DISTANCE-DRAWDOWN RESULTS

Time After Pumping Started (min)	T (gpd/ft)	K (gpd/ft^2)	S
1316	1,229	40 (1.9x10^{-3} cm/sec)	0.008
1701	1,208	39 (1.8x10^{-3} cm/sec)	0.009
3021	1,218	39 (1.8x10^{-3} cm/sec)	0.01
4085	1,198	39 (1.8x10^{-3} cm/sec)	0.01

TABLE V

SUMMARY OF AUGUST 1988 AQUIFER TEST RECOVERY RESULTS

Well	r (ft)	T (gpd/ft)	K (gpd/ft^2)
A5	18.3	1,828	59 (2.8x10^{-3} cm/sec)
B7	2.3	1,658	53 (2.5x10^{-3} cm/sec)
B8	2.3	1,426	46 (2.2x10^{-3} cm/sec)
B9	1.8	1,697	55 (2.6x10^{-3} cm/sec)

TABLE V (Continued)

Well	r (ft)	T (gpd/ft)	K (gpd/ft^2)
B10	1.7	1,658	53 (2.5×10^{-3} cm/sec)
B12	---	1,426	46 (2.2×10^{-3} cm/sec)
C5	85	2,299	74 (3.5×10^{-3} cm/sec)
D5	150	3,564	115 (5.4×10^{-3} cm/sec)
E5	105	2,970	96 (4.5×10^{-3} cm/sec)
F1	25	1,828	59 (2.8×10^{-3} cm/sec)
G2	70	2,741	88 (4.2×10^{-3} cm/sec)
H2	130	5,091	164 (7.7×10^{-3} cm/sec)

Slug Tests

The results from the four slug test methods of analysis are shown in Table VI. For each slug test, two hydraulic conductivity values were determined for the Hvorslev (1951) and Cooper and others (1967) methods because two different values for the initial head change, H(0), were subjectively chosen during the analyses.

TABLE VI

SUMMARY OF SLUG TEST RESULTS

Well	Date	Static DTW (feet)	Volume Removed (gal)	Method	K (gpd/ft^2)
F1	8/13/88	12.53	0.29	H	133 (6.3×10^{-3} cm/sec)
					79 (Alt.) (3.7×10^{-3} cm/sec)
				CBP	49 (2.3×10^{-3} cm/sec)
					62 (Alt.) (2.9×10^{-3} cm/sec)
				B+R	62 (2.9×10^{-3} cm/sec)
				N+P	2 (9.6×10^{-5} cm/sec)
F1	9/15/88	12.73	0.79	H	108 (5.1×10^{-3} cm/sec)
					87 (Alt.) (4.1×10^{-3} cm/sec)
				CBP	59 (2.8×10^{-3} cm/sec)
					114 (Alt.) (5.4×10^{-3} cm/sec)
				B+R	38 (1.8×10^{-3} cm/sec)
				N+P	10 (4.6×10^{-4} cm/sec)
B12	9/14/88 (7:00 PM)	12.87	0.29	H	88 (4.2×10^{-3} cm/sec)
					51 (Alt.) (2.4×10^{-3} cm/sec)
				CBP	34 (1.6×10^{-3} cm/sec)
					84 (Alt.) (4.0×10^{-3} cm/sec)

TABLE VI (Continued)

Well	Date	Static DTW (feet)	Volume Removed (gal)	Method	K (gpd/ft^2)
				B+R	30 (1.4×10^{-3} cm/sec)
				N+P	2 (7.3×10^{-5} cm/sec)
B12	9/14/88 (8:00 PM)	12.87	0.79	H	131 (6.2×10^{-3} cm/sec) 56 (Alt.) (2.6×10^{-3} cm/sec)
				CBP	63 (3.0×10^{-3} cm/sec) 93 (Alt.) (4.4×10^{-3} cm/sec)
				B+R	31 (1.4×10^{-3} cm/sec)
				N+P	8 (3.7×10^{-4} cm/sec)
B12	1/27/89	8.90	1.75	H	54 (2.5×10^{-3} cm/sec) 39 (Alt.) (1.8×10^{-3} cm/sec)
				CBP	36 (1.7×10^{-3} cm/sec) 106 (Alt.) (5.0×10^{-3} cm/sec)
				B+R	28 (1.3×10^{-3} cm/sec)
				N+P	2 (8.2×10^{-5} cm/sec)

Note:

DTW = Depth to water below top of casing.
Alt.= Alternative H(0) chosen in analysis.

TABLE VI (Continued)

H = Hvorslev, M.J. 1951. Time Lag and Soil Permeability in Ground Water Observations. U.S. Army Corps of Engineers Waterways Experiment Station, Bulletin 36, 50 pp.

CBP = Cooper, H.H., J.D. Bredehoeft, and I.S. Papadopulos. 1967. Response of finite-diameter well to an instantaneous charge of water. Water Resources Research. v. 3, no. 1, pp. 263 - 269.

B+R = Bouwer, H. and R.C. Rice. 1976. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. Water Resources Research. v. 12, no. 3, pp. 423 - 428.

N+P = Nguyen, V. and G.F. Pinder. 1984. Direct calculation of aquifer parameters in slug test aquifers. Groundwater Hydraulics, Water Resources Monograph Series 9, pp. 222-239.

CHAPTER VIII

DISCUSSION

Before comparing the results of various methodologies for obtaining hydraulic conductivity values, it is important to recognize the limitations and assumptions of each method. Samples obtained from the field represent a very small percentage of the aquifer material at the field site. Also, the samples were obtained from discrete depth intervals. On the other hand, aquifer pumping tests derive hydraulic information from a much larger area and from the total screened interval of a pumping well. Slug tests generally affect a much smaller radius of aquifer material than an aquifer pumping test because a much smaller volume of water is displaced. In general, the hydraulic conductivity values obtained from aquifer pumping and slug tests represent averaged horizontal conductivities. Also, as discussed previously, the aquifer testing analytical methods are based on various assumptions that may not be satisfied by the existing well and aquifer geometries and boundary conditions.

With these considerations in mind, comparison of methods employed in this investigation can yield useful information. Aquifer pumping tests are considered generally to be the most reliable techniques for determining the average hydraulic coefficients of an aquifer. Therefore, in this analysis the aquifer pumping test results are considered to represent the "real", average values or the determinations that warrant a higher degree of confidence than those of other methods.

As indicated in Tables II, III, and IV, calculated hydraulic conductivity values ranged from 39 to 164 gpd/ft^2 (1.8×10^{-3} to 7.7×10^{-3} cm/sec) at the field site, based on time-drawdown, distance-drawdown, and recovery analyses. The mean hydraulic conductivity calculated using these aquifer pumping test methods was 62 gpd/ft^2 (2.9×10^{-3} cm/sec). These analytical methods assume fully penetrating pumping and observation wells; therefore, it is expected that the most reliable data were obtained from the fully penetrating observation well, F1, which is approximately 25 feet from the pumped well, B12. Also, for the purpose of comparison in this study, attention should be focused on wells F1 and B12 because these are the wells in which the slug tests were conducted and well B12 was the location where the permeameter samples were collected. The mean hydraulic conductivity value calculated from well F1 time-drawdown and recovery analyses was 55 gpd/ft^2 (2.6×10^{-3} cm/sec).

As explained in Chapter IV, the depth of the pumped well, B12, is 34 feet b.l.s.; however, the hydraulic connection between the bottom of the well and the original

43-feet-deep borehole is uncertain. Consequently, well B12 may or may not effectively behave as a partially penetrating well when pumped. A partially penetrating pumping well will have more drawdown than a fully penetrating well because of longer flow paths and a smaller cross-sectional area through which flow converges. Partial penetration impacts in observation wells decrease with distance from the pumping well. Hantush (1964) provided the following equation for determining the distance from a pumping well for which partial penetration impacts are negligible:

$$rp = 1.5 * m * (Kh/Kv)^{1/2} \tag{8.1}$$

where

rp = distance, in feet, from production well beyond which partial penetration impacts are neglible

m = aquifer thickness, in feet

Kh = aquifer horizontal hydraulic conductivity, in gpd/ft^2

Kv = aquifer vertical hydraulic conductivity, in gpd/ft^2

With an aquifer thickness of 31 feet (43 feet minus 12 feet), and assuming Kh/Kv ratios of 1, 2, and 10, rp equals 46 feet, 66 feet, and 147 feet, respectively.

In general, the hydraulic conductivity values determined from observation wells farthest from the pumped well were higher than those obtained from closer wells. This suggests that the values determined from the closer observation wells were lower due to partial penetration impacts. Hoyle (1987) also obtained higher conductivities in the wells farthest from the F site and she attributed these higher values to increase in mean grain size of the aquifer material in the vicinity of the D and E sites.

In order to determine if the water-level data collected in wells closest to the pumping well were significantly affected by partial penetration impacts, a computer program written by Walton (1987), which is based in part on equations developed by Hantush (1964), was used. Assuming that the effective depth of the pumped well, B12, is 34 feet b.l.s., it was found that partial penetration impacts for data collected in well F1 were negligible. The conductivity values determined from the wells close to well B12 are in the same range as that obtained for well F1; therefore, it was decided to not correct for partial penetration impacts in these wells. Consequently, the hydraulic conductivity of the aquifer in the area of interest, in the vicinity of the B and F sites, is considered to be approximately 55 gpd/ft^2 (2.6×10^{-3} cm/sec).

The hydraulic conductivity values determined with the laboratory permeameter ranged between 5.9×10^{-5} gpd/ft^2 (2.8×10^{-9} cm/sec) and 3.2×10^{-2} gpd/ft^2 (1.5×10^{-6} cm/sec). The approximately three to six orders of magnitude discrepancy between the permeameter results and those obtained from the aquifer pumping test is striking. Disturbance of the permeameter specimens during field sampling and preparation for laboratory testing is a distinct possibility for the differences. However, every effort was taken to minimize disturbance.

Subjective estimates of the hydraulic conductivity of the soil/alluvium by the author and others (Pettyjohn, 1989) based on visual inspection of the samples are in agreement with the laboratory permeameter results. The aquifer material looks like it would be suitable for a landfill liner to impede fluid migration. As discussed in Chapter III, the aquifer material does exhibit some characteristics of soil; however, the relatively young age of the profile has limited the degree of soil structure development (weak to moderate structure grades). It is hypothesized by the author and other researchers at the site that macropores, or pore spaces formed between aggregates of the fine-grained sediments, significantly influence ground-water flow in the aquifer and in the unsaturated zone. These macropores may have formed along soil ped surfaces or as a result of biological activity, such as the formation of root casts and animal burrows. In the zone of water-table fluctuation, wetting and drying of the aquifer material may have promoted fracturing. As discussed in Chapter II, other researchers have attributed higher-than-expected conductivties to fractures that are not readily apparent upon visual inspection of core samples at other sites. Macropores or fractures may be destroyed during sample collection, although precautions to minimize disturbance are taken.

Hydraulic conductivity values determined from slug tests ranged between 2 gpd/ft^2 (8.2x10^{-5} cm/sec) and 133 gpd/ft^2 (6.3x10^{-3} cm/sec). The results of the Nguyen and Pinder (1984) method were consistently too low. The plots required in this method generally did not yield good straight-line relationships. Nguyen and Pinder (1984) pointed out that significant deviation from a straight-line plot indicates either inaccurate data or an inappropriate mathematical model. Assuming the latter situation, the results of the Nguyen and Pinder (1984) method should be ignored. Considering only the results of the Hvorslev (1951), Cooper and others (1967), and Bouwer and Rice (1976) methods, the calculated hydraulic conductivities ranged from 28 gpd/ft^2 (1.3x10^{-3} cm/sec) to 133 gpd/ft^2 (6.3x10^{-3}). These results are approximately within a factor of 2 of the aquifer pumping test results. Therefore, the results of the pumping and slug tests are considered to be in good agreement.

During the analyses of the slug test data there were many steps in which subjective choices were required, particularly in determining best fits on graphs and in the determination of the initial change in head, H(0). Theoretically, H(0) can be easily calculated based on the geometry of the slug test system. In practice, however, the water-level response is affected by turbulence when the bailer is removed from the well, water dripping from the outside of the bailer, water quickly entering the well from the sand pack, and the fact that the bailer cannot be removed from the well instantaneously.

Aquifer testing has been described as an art and the author concedes that this statement is especially true for slug test interpretation. Some researchers have attempted to make slug test analyses less subjective by adapting existing methodologies and developing standard numerical methods for analyzing the data (Pandit and Miner, 1986). Analyses of the data collected in this study using various computer software packages may yield results that are significantly different than those determined in this investigation. Given the inherent subjectivity of the slug test methods, it is notable that the slug test results were in such close agreement with those obtained from the constant-rate aquifer test.

Varying the volume of the "slug" removed apparently did not result in a consistent change in hydraulic conductivity values.

CHAPTER IX

SUMMARY AND CONCLUSIONS

The hydraulic conductivity of a fine-grained alluvium aquifer was determined using three commonly employed methods: aquifer pumping, slug, and laboratory permeameter tests. In the area under investigation at the study site the average hydraulic conductivity of the aquifer was determined to be approximately 55 gpd/ft^2 (2.6x10^{-3} cm/sec) based on aquifer pumping test analyses. Results of slug tests were approximately within a factor of two of this value, whereas results of permeameter tests were about three to six orders of magnitude lower than the aquifer pumping test results.

The discrepancy between permeameter test results and determinations obtained by in-situ methods has been attributed to macropores in the aquifer that were not present in sufficient quantity and/or orientation in the laboratory samples to significantly affect the permeameter test results. These macropores may not have been incorporated in laboratory permeameter tests due to sample disturbance and/or the high probability that they were not encountered during collection of small, discrete samples of the aquifer material. On a larger scale, macropores significantly affect ground-water flow. Consequently, the influence of macropores was evident in the aquifer pumping test because a much larger volume of the aquifer was affected. Slug tests also derive hydraulic information from a larger portion of the aquifer than permeameter tests do, however the area of influence of a slug test generally is much smaller than that of an aquifer pumping test. The relatively small discrepancy between the results of slug tests and the aquifer pumping test may be due to (a) measurement of hydraulic conductivity of a much smaller area than that affected by the aquifer pumping test, (b) the use of analytical models that do not conform sufficiently with the existing well and aquifer geometries and boundary conditions, and/or (c) the high degree of subjectivity inherent in the slug test analyses.

Based on the results of this study, in-situ aquifer tests are recommended for determination of hydraulic conductivity of unconsolidated, fine-grained sediments, whenever physically and economically feasible. In general, aquifer pumping tests are preferred. In cases in which it is not feasible to conduct a constant-rate pumping test in this hydrogeologic setting, slug test analyses apparently provide reliable estimates of hydraulic conductivity.

CHAPTER X

RECOMMENDATIONS FOR ADDITIONAL RESEARCH

During the course of this investigation it became apparent that there are numerous possibilities for expanding the scope of this thesis which would provide valuable information for ground-water scientists, engineers, and managers. The following is a list of suggestions for additional research.

- Compare other methods for determining hydraulic conductivity, such as tracer tests, flow meter tests, geophysical logging, and different laboratory permeameter methods. Other hydrogeologic settings should be considered, also.

- Assess the variability of hydraulic conductivity with depth, using inflatable packers in wells without sand packs surrounding the screens, in order to isolate zones for in-situ testing.

- Assess the spatial variability of hydraulic conductivity at the site using other well locations.

- Conduct a comparative study of unsaturated hydraulic conductivity determinations at the field site.

- Evaluate temporal variation of saturated and unsaturated hydraulic conductivities.

o Further evaluate the effects of partially penetrating wells, "skin" effects due to disturbance to the formation during well installation, and the ratio of horizontal to vertical hydraulic conductivity.

o Add a dye to the water which flows through a sample of the aquifer material and cut open the sample to detect any preferential paths of flow.

o Pump the aquifer for a longer period of time in order to evaluate delayed drainage from storage and to calculate storativity using the Prickett (1965) and Neuman (1975) methods.

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APPENDIXES

APPENDIX A

MONITORING WELL CONSTRUCTION DETAILS

MONITORING WELL CONSTRUCTION DETAILS

Well	Screen and Casing Diameter (in)	Screen Interval (ft b.c.p.)	Artificial Sand Pack (ft b.c.p.)
A1	2	8.0 - 8.2	7.3 - 8.5
A2	2	8.7 - 8.9	8.6 - 9.2
A3	2	9.9 - 10.1	9.3 - 10.3
A4	2	13.3 - 13.6	10.6 - 13.8
A5	2	7.0 - 14.0	7.0 - 14.0
B1	0.75	6.1 - 6.4	6.0?- 6.6
B2	2	8.8 - 9.1	8.7?- 9.3
B3	2	10.5 - 10.8	10.4?- 11.0
B4	2	12.7 - 13.0	12.6?- 13.2
B5	6	4.4 - 13.2	4.3?- 13.4
B6	0.5	11.0 - 11.2	10.3 - 11.3
B7	0.5	13.6 - 13.8	13.2 - 13.9
B8	0.5	18.4 - 18.6	17.8 - 18.7
B9	0.5	20.9 - 21.1	20.7 - 21.2
B10	0.5	25.4 - 25.6	24.3 - 25.7
B11	1.25	38.4 - 40.0	36.0 - 40.3
B12	4	4.0 - 34.0	2.0 - 43.8?
B13	2	4.0 - 34.0	2.0 - 43.8?
C1	2	7.9 - 8.1	8.0 - 8.3
C2	2	8.9 - 9.1	9.0 - 9.2
C3	2	9.9 - 10.4	9.8?- 10.6
C4	2	14.2 - 14.4	11.1 - 14.6
C5	2	7.0 - 14.0	7.0 - 14.0
D1	2	8.0 - 8.2	7.5 - 8.2
D2	2	9.0 - 9.2	8.8 - 9.3
D3	2	9.9 - 10.4	9.4 - 10.8
D4	2	13.6 - 13.9	11.2 - 14.2
D5	2	7.0 - 14.0	7.0 - 14.0
E1	2	8.3 - 8.5	8.2 - 8.7
E2	2	9.3 - 9.5	9.1 - 9.7
E3	2	10.1 - 10.3	9.9 - 10.5
E4	2	13.6 - 13.9	10.9 - 14.1
E5	2	7.0 - 14.0	7.0 - 14.0
F1	4	10.0 - 40.0	9.0?- 40.0
F2	2	10.0 - 40.0	9.0?- 40.0
G1	1	9.7 - 10.1	8.4 - 10.3
G2	1	13.5 - 13.8	9.9 - 14.0
H1	1	9.6 - 10.0	8.3 - 10.2
H2	1	13.4 - 13.7	10.4 - 13.9
I1	1	10.4 - 10.8	7.6 - 11.0
I2	1	14.0 - 14.3	9.2 - 14.5
I3	2	10.0 - 14.4	6.7 - 14.9
J1	1.25	11.6 - 13.2	6.2 - 13.5

MONITORING WELL CONSTRUCTION DETAILS (Continued)

Note:

b.c.p. = below concrete pad

? = uncertain

All wells are sealed with bentonite above sand pack.

All wells consist of PVC pipe, slotted by hand, and wrapped with nylon screen, with the following exceptions:

Wells B11, I3, and J1 are manufactured metal well point screens.

Well B12 is a Johnson PVC, 0.006 in.-slot well screen.

Wells F1 and F2 are installed in the same borehole.

Wells B12 and B13 are installed in the same borehole.

Wells B6, B7, B8, B9, and B10 are installed in the same borehole with bentonite seals installed between each well screen interval.

APPENDIX B

SOIL PROFILE DESCRIPTION

FROM ROSS (1989)

SOIL PROFILE DESCRIPTION

FROM ROSS (1989)

Horizon	Depth (in.)	Description
Ap	0-19	Reddish brown (2.5YR 4/4, dry) to dusky red (2.5 YR 3/2 moist) silt loam; moderate medium subangular blocky, parting to weak medium platy structure; friable; common roots and fine, continuous root casts; gradual boundary.
A	19-26	Dark reddish brown (2.5 YR 3/4, dry) to dark red (2.5YR 3/6) silt loam; weak, coarse, prismatic structure; friable; common, fine, continuous root casts in peds; gradual boundary.
Bw	26-38	Red (2.5YR 4/6, dry) to dark reddish brown (2.5YR 3/4, moist) silt loam; weak coarse, subangular structure; friable; common, fine, continuous root casts; gradual boundary.
C	38-50	Reddish brown (5YR 4/4, dry) to dark reddish brown (2.5YR 3/4, moist) silt loam; finely laminated, stratified sands; friable; few, fine root casts; clear boundary.
2Ab	50-64	Dark reddish gray (5YR 4/2, dry) to dark reddish brown (5YR 3/3, moist) silt loam; moderate, fine, subangular blocky structure; firm; roots; clear boundary.
2AB	64-68	Reddish brown (5YR 4/4, dry) to dark reddish brown (2.5YR 3/4, moist) silt loam; few, fine, faint, yellowish red (5YR 5/6) mottles; medium, fine, subangular blocky, parting to moderate, medium, prismatic structure; firm; common, fine, round, black (n 2/0) manganese nodules; few, fine, root

SOIL PROFILE DESCRIPTION (Continued)

Horizon	Depth (in.)	Description
		casts; gradual boundary.
2Bw1	68-78	Reddish brown (5YR 4/4, dry) loam; few, fine, faint, yellowish red (5YR 5/6) mottles; moderate, medium to fine, subangular blocky, parting to moderate, medium, prismatic, with moderate, coarse platy structure; firm; common, fine to medium, black (n 2/0) manganese nodules; few, fine root casts; gradual boundary.
2Bw2	78-108	Reddish brown (5YR 4/4, dry) to dark red (2.5YR 3/6) silt loam; few, medium, faint, yellowish red (5YR 5/6) and reddish brown (5YR 5/3) mottles; moderate, medium to fine, subangular blocky, parting to moderate, medium, prismatic structure; firm; common, medium, black (n 2/0) manganese nodules; few, fine carbonate threads and fine concretions; few, fine root casts; gradual boundary.
2Bw3	108-124	Yellowish red (5YR 5/6, dry) silt loam; pinkish gray (5YR 7/2) mottles; moderate, coarse to medium, prismatic, parting to moderate, medium, prismatic structure; firm; few, fine to medium, black (n 2/0) manganese nodules; few, fine to medium carbonate concretions; few, fine root casts, surrounded by intense, yellowish red (5YR 5/6) mottling; clear boundary.
2Bw4	124-138	Yellowish red (5YR 4/6, dry) silty clay loam; few, medium, faint, reddish gray (5YR 5/2) mottles; moderate, medium, prismatic, parting to moderate, medium, subangular blocky structure; firm; few, fine, irregular, black (n 2/0) manganese nodules; few, fine root casts; gradual boundary.
2Bw5	138-144	Yellowish red (5YR 4/6, dry) loam; few, fine, faint, reddish gray (5YR 5/2) mottles; moderate to weak, medium, subangular blocky, parting to moderate

SOIL PROFILE DESCRIPTION (Continued)

Horizon	Depth (in.)	Description
		to weak, medium,prismatic structure; firm; few, fine, black (n 2/0) manganese nodules; few to common root casts; diffuse boundary.
2BC1	144-156	Reddish brown (5YR 4/4, dry) clay loam; weak, medium, prismatic, parting to moderate, medium, subangular blocky structure; few, medium, black (n 2/0) manganese nodules; few, fine root casts; diffuse boundary.
2BC2	156-168	Reddish brown (5YR 4/4, dry) silty clay loam; weak, medium, prismatic, parting to weak, medium, subangular blocky structure; few, fine to medium, black (n 2/0) manganese nodules; few, fine root casts; diffuse boundary.
2BC3	168-192	Reddish brown (5YR 4/4, dry) silt loam; weak, medium, prismatic, parting to weak, medium, subangular blocky structure; firm; few, fine, irregular, with patches of many fine, round, black (n 2/0) manganese nodules; few, fine root casts; clear boundary.
2BC4	192-198	Yellowish red (5YR 4/6, dry) silt loam; massive, breaking to weak, medium, subangular blocky structure; firm; few medium, irregular, black (n 2/0) manganese nodules; very few, fine root casts; diffuse boundary.
2BC5	198-240	Reddish brown (5YR 4/4, dry) silty clay loam; weak, medium, prismatic, parting to weak, medium, moderate, platy structure; firm; few, medium, irregular, black (n 2/0) manganese nodules; few, fine root casts; diffuse boundary.
2BC6	240-255	Reddish brown (5YR 4/4, dry) silty clay loam; few, very faint, yellowish red (5YR 4/6) mottles; weak, medium, prismatic, parting to weak, medium, subangular blocky structure; friable; many continuous root casts and pores in

SOIL PROFILE DESCRIPTION (Continued)

Horizon	Depth (in.)	Description
		peds; few, medium, irregular, black (n 2/0) manganese nodules; diffuse boundary.
2BC7	255-264	Reddish brown (5YR 4/4, dry) silt loam; few, medium, faint, yellowish red (5YR 4/6) mottles; weak, medium, prismatic, parting to weak, medium, subangular blocky structure; firm; few, medium, irregular, black (n 2/0) manganese nodules; diffuse boundary.
2BC8	264-282	Yellowish red (5YR 4/6, dry) silt loam; few, medium, distinct, grayish brown (5YR 5/6) and yellowish brown (5YR 5/2) mottles; weak, medium, prismatic, parting to weak, medium, subangular blocky structure; firm; few, irregular, medium, black (n 2/0) manganese nodules; diffuse boundary.
2BC9	282-306	Yellowish red (5YR 4/6, dry) silty clay loam; few, medium, faint, pinkish gray (5YR 6/2) mottles; weak, medium, subangular blocky structure; firm; few to common, continuous root casts; few, medium, round, black (n 2/0) manganese nodules; diffuse boundary.
2BC/A	306-330	Dark reddish brown (5YR 3/4, dry) and yellowish red (5YR 4/6, dry) clay loam; few, fine, faint pinkish gray (5YR 6/2) mottles; weak, medium, subangular blocky structure; few, fine, black (n 2/0) organic matter fragments (charcoal); firm; few, fine root casts; diffuse boundary.
3Ab	330-354	Dark reddish brown (5YR 3/3, dry) silt loam; few, fine, faint, reddish gray (5YR 5/2) mottles; moderate, medium, subangular blocky structure, parting to weak, medium, platy structure; common, fine, continuous root casts; few, fine, black (n 2/0) organic matter fragments; clear boundary.

SOIL PROFILE DESCRIPTION (Continued)

Horizon	Depth (in.)	Description
3AB1	354-366	Reddish brown (5YR 4/4, dry) silty clay loam; few, fine, faint, yellowish red (5YR 5/6) and reddish gray (5YR 5/2) mottles; moderate to weak, medium, subangular blocky, parting to moderate to weak, medium, prismatic structure; gradual boundary.
3AB2	366-390	Reddish brown (5YR 4/3, dry) silty clay; common, fine, distinct, yellowish red (5YR 5/6), reddish gray (5YR 5/2) mottles; weak to moderate, medium, subangular blocky, parting to moderate to weak, medium, prismatic structure; firm; common, medium, distinct, gray (5Y 5/1) mottles surrounding common, medium root casts; gradual boundary.
3Bw	390-426	Reddish brown (5YR 4/6, dry) silty clay; common, fine, distinct, gray (5Y 5/1) mottles; weak to moderate, medium, subangular blocky, parting to weak to moderate, medium, prismatic structure; firm; common, medium, root casts; gradual boundary.
3C1	426-456	Reddish brown (5YR 4/6, dry) silt loam; few, fine, distinct, strong, brown (7.5YR 5/8) and pinkish gray (5YR 6/2) mottles; stratified, massive structure; friable; gradual boundary.
3D1	456-468	Reddish brown (5YR 4/6, dry) sandy loam (However, particle-size analyses indicate loam to silt loam); stratified, massive structure; friable; gradual boundary.
3D2	468-516	Reddish brown (5YR 4/3, dry) gravelly sandy loam (However, particle-size analyses indicate loam to silt loam); massive; friable; abrupt boundary.
3R	516-540	Upper Pennsylvanian Doyle shale.

APPENDIX C

AQUIFER PUMPING TEST DATA AND ANALYSES

Well A5 Drawdown
Distance to pumped well = 18.3 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	12.10	12.10	0.00	0.00
38.3	12.55	12.55	0.45	0.45
47	12.59	12.59	0.49	0.48
72	12.66	12.66	0.56	0.55
93.3	12.71	12.71	0.61	0.60
104	12.72	12.72	0.62	0.61
142.3	12.78	12.78	0.68	0.67
167	12.81	12.81	0.71	0.70
224	12.85	12.84	0.74	0.73
318	12.90	12.89	0.79	0.78
408	12.99	12.98	0.88	0.87
523	13.00	12.99	0.89	0.87
650	13.10	13.08	0.98	0.97
1106	13.21	13.18	1.08	1.06
1288	13.24	13.21	1.11	1.09
1582	13.27	13.23	1.13	1.11
1702	13.30	13.26	1.16	1.14
1825	13.30	13.26	1.16	1.13
1936	13.33	13.28	1.18	1.16
2088	13.36	13.31	1.21	1.18
2557	13.37	13.31	1.21	1.18
2890	13.39	13.32	1.22	1.19
3021	13.40	13.33	1.23	1.20
3271	13.46	13.38	1.28	1.25
3500	13.49	13.41	1.31	1.28
4075	13.55	13.45	1.35	1.32
4286	13.48	13.38	1.28	1.25

Well B7 Drawdown
Distance to pumped well = 2.3 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	11.90	11.90	0.00	0.00
23	13.18	13.18	1.28	1.25
31	13.31	13.31	1.41	1.37
41.5	13.40	13.40	1.50	1.46
66	13.51	13.51	1.61	1.56
86	13.59	13.59	1.69	1.64
97	13.62	13.62	1.72	1.67
106.5	13.64	13.64	1.74	1.68
143.5	13.67	13.67	1.77	1.71
201	13.74	13.74	1.84	1.78
264	13.78	13.77	1.87	1.81
297	13.83	13.82	1.92	1.86
399	13.88	13.87	1.97	1.90
455	13.93	13.92	2.02	1.95
510	13.97	13.96	2.06	1.98
571	13.98	13.97	2.07	1.99
636	Well Dry			

Well B8 Drawdown
Distance to pumped well = 2.3 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	11.87	11.87	0.00	0.00
21	12.91	12.91	1.04	1.02
31.7	13.24	13.24	1.37	1.34
42.5	13.40	13.40	1.53	1.49
67	13.56	13.56	1.69	1.64
87	13.65	13.65	1.78	1.72
98	13.66	13.66	1.79	1.73
107.5	13.69	13.69	1.82	1.76
144.5	13.73	13.73	1.86	1.80
203	13.79	13.79	1.92	1.85
265	13.85	13.84	1.97	1.90
308	13.87	13.86	1.99	1.92
400	13.94	13.93	2.06	1.98
459	14.00	13.99	2.12	2.04
512	14.04	14.03	2.16	2.07
575	14.08	14.07	2.20	2.11
637	14.09	14.07	2.20	2.12
741	14.14	14.12	2.25	2.16
854	14.18	14.16	2.29	2.20
977	14.22	14.20	2.33	2.23
1098	14.25	14.22	2.35	2.25
1224	14.26	14.23	2.36	2.26
1338	14.28	14.25	2.38	2.28
1458	14.30	14.27	2.40	2.29
1574	14.31	14.27	2.40	2.30
1695	14.33	14.29	2.42	2.32
1817	14.34	14.30	2.43	2.32
1930	14.36	14.31	2.44	2.34
2058	14.38	14.33	2.46	2.35
2547	14.38	14.32	2.45	2.34
2885	14.43	14.36	2.49	2.38
3015	14.45	14.38	2.51	2.40
3260	14.55	14.47	2.60	2.48
3495	14.59	14.51	2.64	2.51
4079	14.56	14.46	2.59	2.47
4288	14.56	14.46	2.59	2.47

Well B9 Drawdown
Distance to pumped well = 1.8 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	11.92	11.92	0.00	0.00
17	13.66	13.66	1.74	1.69
32.5	13.76	13.76	1.84	1.78
43.5	13.82	13.82	1.90	1.83
68	13.90	13.90	1.98	1.91
88	13.97	13.97	2.05	1.97
99	13.98	13.98	2.06	1.98
108	13.99	13.99	2.07	1.99
145.5	14.02	14.02	2.10	2.02
205	14.08	14.08	2.16	2.07
266	14.14	14.13	2.21	2.13
310	14.16	14.15	2.23	2.14
402	14.26	14.25	2.33	2.23
461	14.30	14.29	2.37	2.27
514	14.33	14.32	2.40	2.30
577	14.36	14.35	2.43	2.32
639	14.38	14.36	2.44	2.34
742	14.45	14.43	2.51	2.40
855	14.48	14.46	2.54	2.42
979	14.51	14.49	2.57	2.45
1099	14.53	14.50	2.58	2.46
1225	14.55	14.52	2.60	2.48
1340	14.57	14.54	2.62	2.50
1465	14.63	14.60	2.68	2.55
1576	14.60	14.56	2.64	2.52
1697	14.63	14.59	2.67	2.54
1819	14.64	14.60	2.68	2.55
1931	14.66	14.61	2.69	2.56
2059	14.68	14.63	2.71	2.58
2550	14.66	14.60	2.68	2.55
2880	14.76	14.69	2.77	2.63
3016	14.76	14.69	2.77	2.63
3265	14.88	14.80	2.88	2.73
3496	14.91	14.83	2.91	2.76
4080	14.87	14.77	2.85	2.71
4289	14.87	14.77	2.85	2.70

Well C5 Drawdown
Distance to pumped well = 85 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	12.18	12.18	0.00	0.00
74	12.36	12.36	0.18	0.18
128	12.47	12.47	0.29	0.29
235	12.56	12.55	0.37	0.37
326	12.58	12.57	0.39	0.39
470	12.68	12.67	0.49	0.48
598	12.70	12.69	0.51	0.50
1292	12.79	12.76	0.58	0.57
1706	12.83	12.79	0.61	0.60
1898	12.85	12.80	0.62	0.62
2563	12.89	12.83	0.65	0.64
3024	12.90	12.83	0.65	0.64
4085	12.96	12.86	0.68	0.67
4299	12.95	12.85	0.67	0.66

Well D5 Drawdown
Distance to pumped well = 150 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	12.40	12.40	0.00	0.00
76.5	12.42	12.42	0.02	0.02
125	12.48	12.48	0.08	0.08
238.5	12.54	12.53	0.13	0.13
349	12.58	12.57	0.17	0.17
354	12.62	12.61	0.21	0.21
618	12.65	12.64	0.24	0.23
1299	12.73	12.70	0.30	0.30
1710	12.78	12.74	0.34	0.34
1902	12.80	12.75	0.35	0.35
2566	12.84	12.78	0.38	0.38
3027	12.87	12.80	0.40	0.40
4090	12.95	12.85	0.45	0.45
4302	12.91	12.81	0.41	0.40

Well E5 Drawdown
Distance to pumped well = 105 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	12.30	12.30	0.00	0.00
79.5	12.34	12.34	0.04	0.04
123	12.38	12.38	0.08	0.08
252	12.44	12.43	0.13	0.13
353	12.48	12.47	0.17	0.17
478	12.53	12.52	0.22	0.22
622	12.56	12.55	0.25	0.24
1302	12.69	12.66	0.36	0.36
1713	12.74	12.70	0.40	0.40
1906	12.77	12.72	0.42	0.42
2630	12.83	12.77	0.47	0.46
3030	12.85	12.78	0.48	0.47
4093	12.93	12.83	0.53	0.53
4307	12.92	12.82	0.52	0.51

Well F1
Distance to pumped well = 25 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0.00	12.40	12.40	0.00	0.00
0.50	12.40	12.40	0.00	0.00
1.00	12.40	12.40	0.00	0.00
2.50	12.44	12.44	0.04	0.04
3.00	12.46	12.46	0.06	0.06
3.50	12.46	12.46	0.06	0.06
4.00	12.48	12.48	0.08	0.08
4.50	12.49	12.49	0.09	0.09
5.00	12.50	12.50	0.10	0.10
7.00	12.53	12.53	0.13	0.13
8.00	12.55	12.55	0.15	0.15
9.00	12.57	12.57	0.17	0.17
10.00	12.58	12.58	0.18	0.18
12.00	12.60	12.60	0.20	0.20
14.00	12.61	12.61	0.21	0.21
16.00	12.63	12.63	0.23	0.23
18.00	12.65	12.65	0.25	0.25
20.00	12.66	12.66	0.26	0.26
22.00	12.68	12.68	0.28	0.28
24.00	12.69	12.69	0.29	0.29
26.00	12.70	12.70	0.30	0.30
28.00	12.71	12.71	0.31	0.31
30.00	12.72	12.72	0.32	0.32
35.00	12.73	12.73	0.33	0.33
40.00	12.77	12.77	0.37	0.37
45.00	12.78	12.78	0.38	0.38
50.00	12.81	12.81	0.41	0.41
55.00	12.81	12.81	0.41	0.41
60.00	12.82	12.82	0.42	0.42
70.00	12.85	12.85	0.45	0.44
80.00	12.87	12.87	0.47	0.46
90.00	12.88	12.88	0.48	0.47
100.00	12.90	12.90	0.50	0.49
111.00	12.92	12.92	0.52	0.51
120.00	12.94	12.94	0.54	0.53
140.00	12.95	12.95	0.55	0.54
180.00	12.99	12.99	0.59	0.58
216.00	13.03	13.02	0.62	0.62
241.00	13.04	13.03	0.63	0.63
271.00	13.07	13.06	0.66	0.66

Well F1 Drawdown (Continued)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Adjusted D.T.W. (Feet)	Drawdown (Feet)	Adjusted Drawdown s' (Feet)
301.00	13.08	13.07	0.67	0.66
331.00	13.09	13.08	0.68	0.67
361.00	13.11	13.10	0.70	0.69
420.00	13.16	13.15	0.75	0.74
482.00	13.19	13.18	0.78	0.77
542.00	13.21	13.20	0.80	0.79
602.00	13.23	13.22	0.82	0.80
661.00	13.27	13.25	0.85	0.84
725.00	13.29	13.27	0.87	0.86
842.00	13.33	13.31	0.91	0.90
963.00	13.35	13.33	0.93	0.91
1083.00	13.38	13.35	0.95	0.94
1200.00	13.39	13.36	0.96	0.94
1320.00	13.40	13.37	0.97	0.95
1440.00	13.41	13.38	0.98	0.96
1560.00	13.42	13.38	0.98	0.97
1680.00	13.46	13.42	1.02	1.00
1800.00	13.46	13.42	1.02	1.00
1920.00	13.49	13.44	1.04	1.02
2040.00	13.50	13.45	1.05	1.03
2520.00	13.54	13.48	1.08	1.06
2880.00	13.56	13.49	1.09	1.07
3000.00	13.56	13.49	1.09	1.07
3240.00	13.62	13.54	1.14	1.12
3480.00	13.65	13.57	1.17	1.14
4052.00	13.66	13.56	1.16	1.14
4319.00	13.64	13.54	1.14	1.11

Well G2 Drawdown
Distance to pumped well = 70 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	10.30	10.30	0.00	0.00
113	10.34	10.34	0.04	0.04
260	10.42	10.41	0.11	0.11
357	10.46	10.45	0.15	0.15
500	10.50	10.49	0.19	0.19
634	10.53	10.51	0.21	0.21
1317	10.70	10.67	0.37	0.37
1722	10.77	10.73	0.43	0.43
1735	10.78	10.74	0.44	0.44
2577	10.86	10.80	0.50	0.49
3038	10.92	10.85	0.55	0.54
4100	11.01	10.91	0.61	0.61
4312	11.01	10.91	0.61	0.60

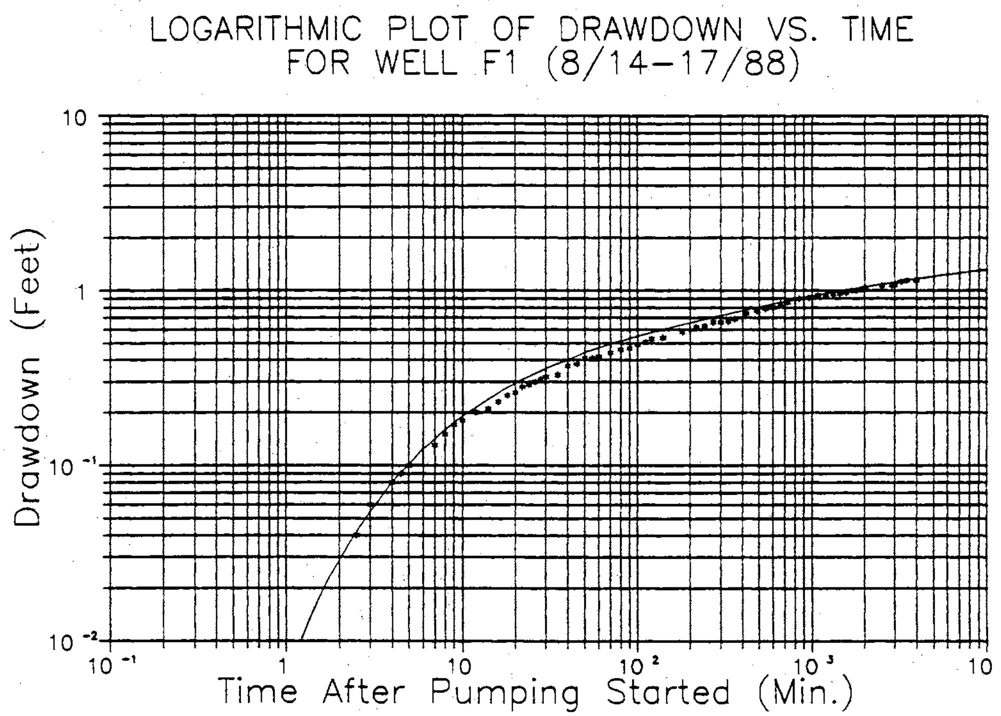
Well H2 Drawdown
Distance to pumped well = 130 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	10.92	10.92	0.00	0.00
114	10.94	10.94	0.02	0.02
257	10.98	10.97	0.05	0.05
355	10.99	10.98	0.06	0.06
503	10.98	10.97	0.05	0.05
631	11.00	10.98	0.06	0.06
1312	11.13	11.10	0.18	0.18
1718	11.19	11.15	0.23	0.23
1912	11.20	11.15	0.23	0.23
2635	11.28	11.22	0.30	0.30
3035	11.33	11.26	0.34	0.34
4098	11.42	11.32	0.40	0.40
4310	11.42	11.32	0.40	0.39

Well J1 Drawdown
Distance to pumped well = 125 feet
Pumped well B12 at 2.7 gpm
8/14/88 (1:00 PM) - 8/17/88 (1:00 PM)

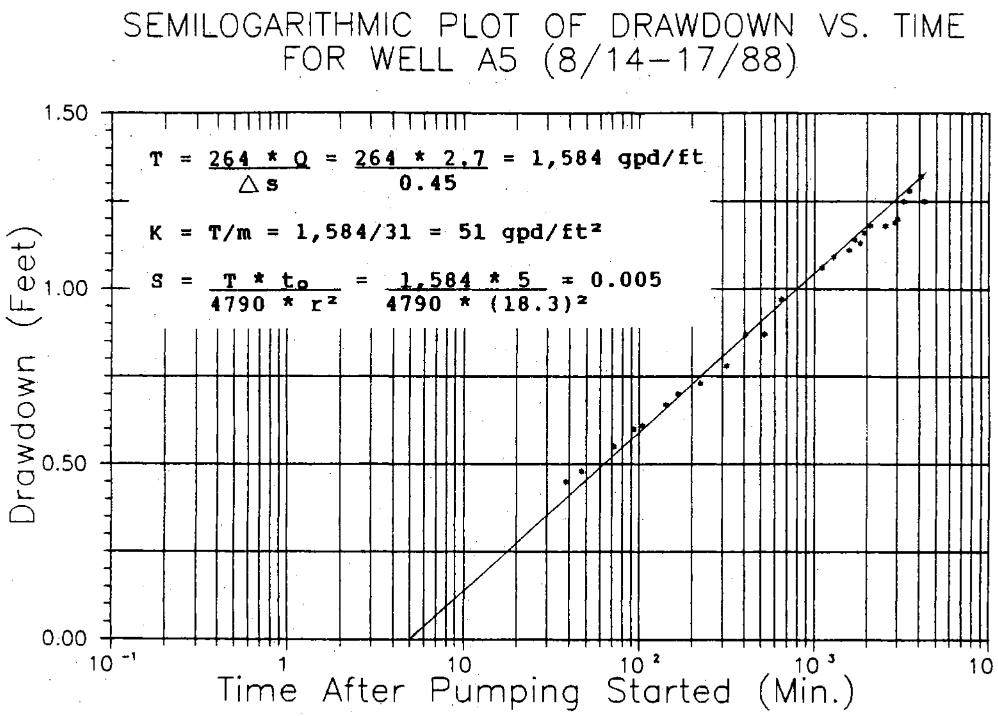
Time (Min.)	Depth to Water (D.T.W.) (Feet)	Decline-Adjusted D.T.W. (Feet)	Drawdown s (Feet)	Adjusted Drawdown s' (Feet)
0	11.68	11.68	0.00	0.00
505	11.81	11.80	0.12	0.12
629	11.90	11.89	0.21	0.20
1307	11.94	11.91	0.23	0.23
1716	12.00	11.96	0.28	0.28
1908	12.03	11.98	0.30	0.30
2633	12.11	12.05	0.37	0.36
3032	12.18	12.11	0.43	0.42
4095	12.22	12.12	0.44	0.44
4308	12.21	12.11	0.43	0.42

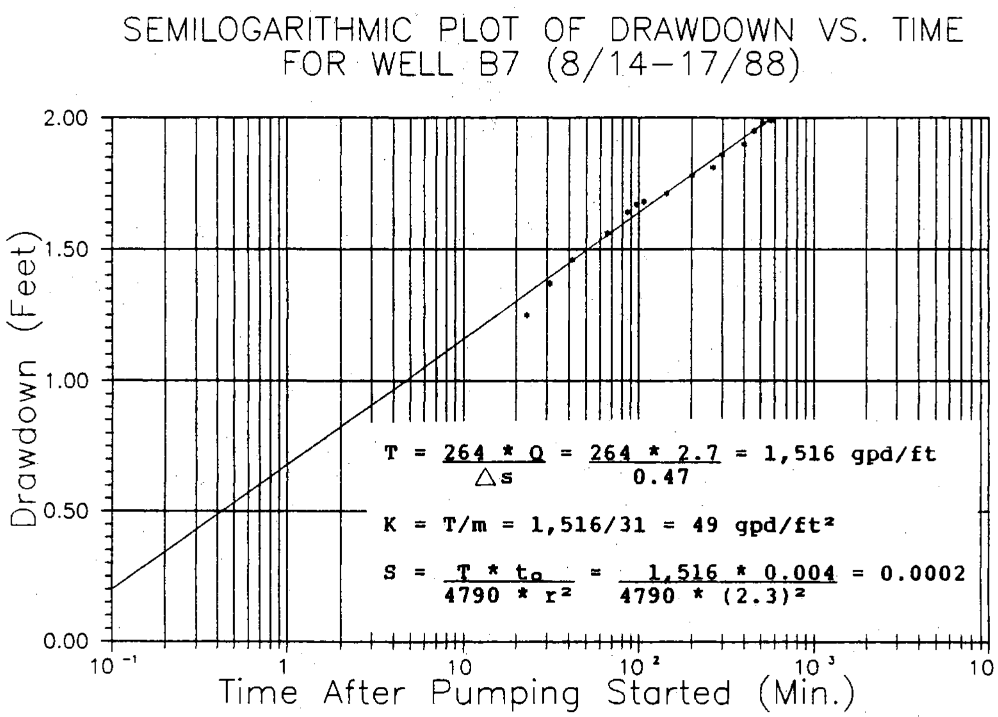
Theis (1935) Time-Drawdown Method



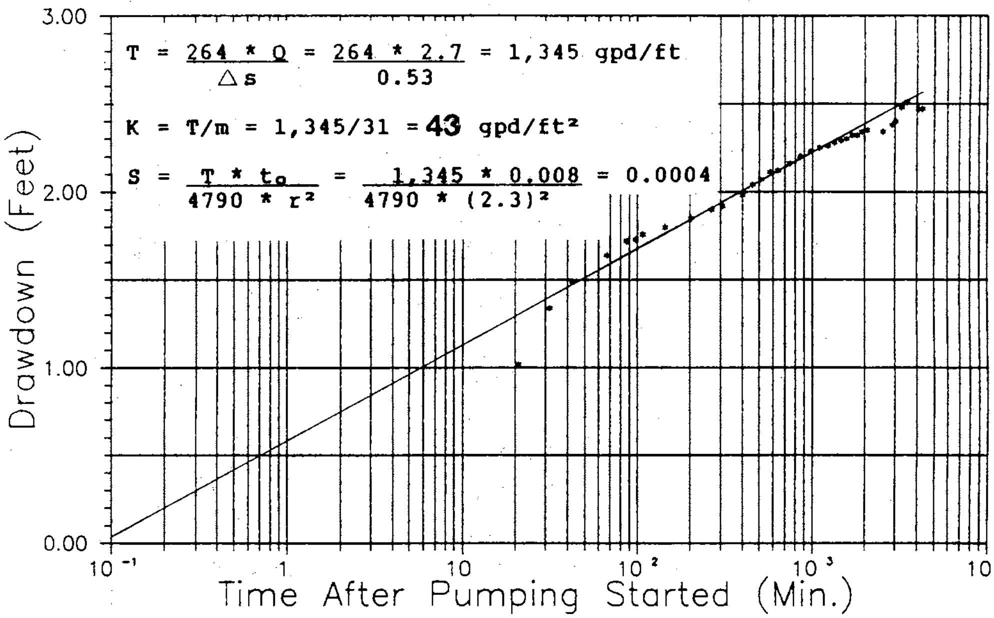
Cooper and Jacob (1946)

Time-Drawdown Method

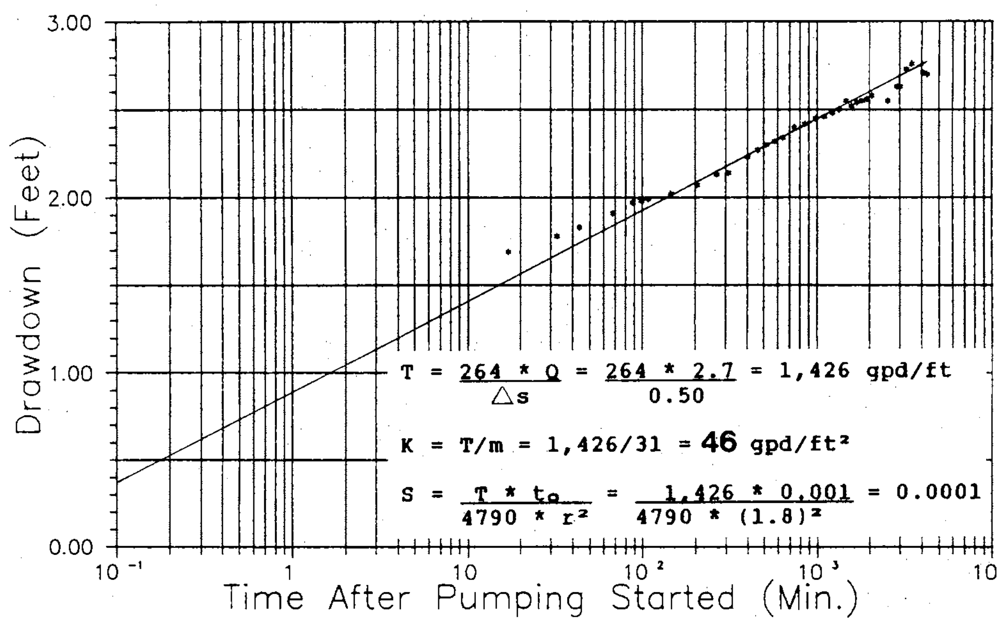




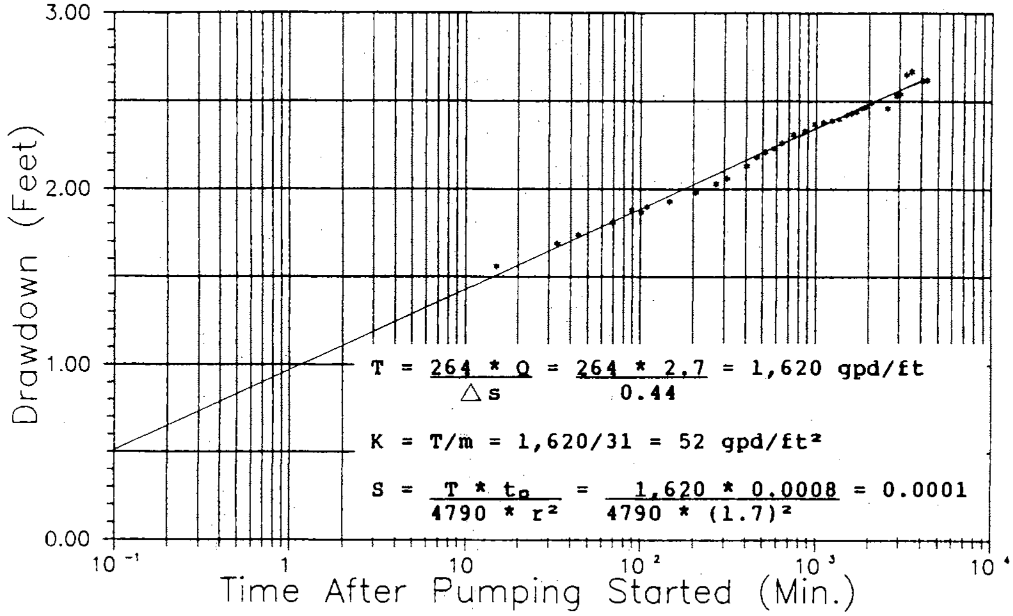
SEMILOGARITHMIC PLOT OF DRAWDOWN VS. TIME
FOR WELL B8 (8/14–17/88)



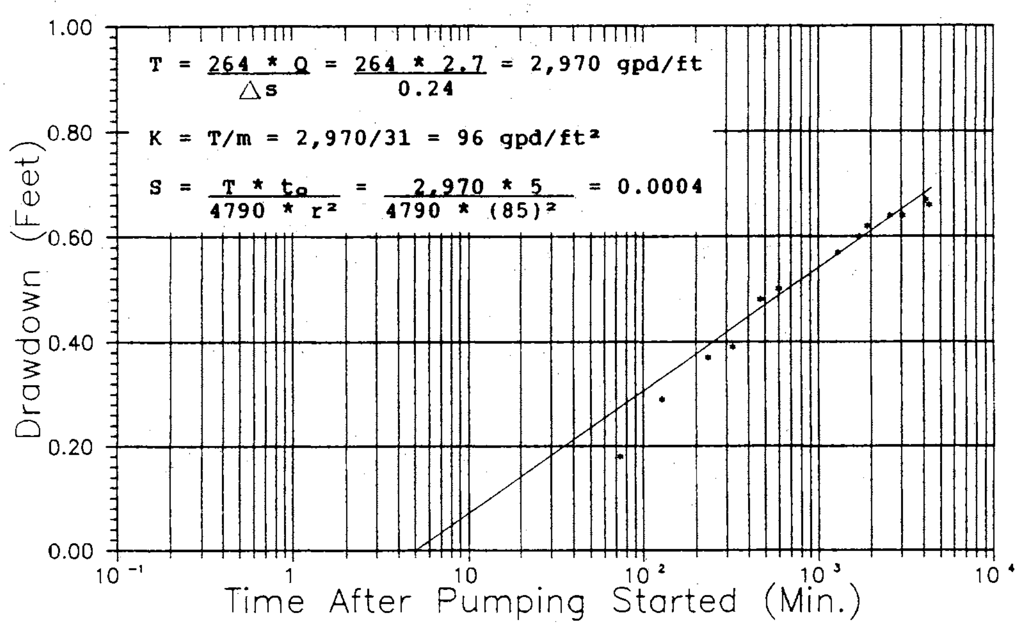
SEMILOGARITHMIC PLOT OF DRAWDOWN VS. TIME
FOR WELL B9 (8/14–17/88)



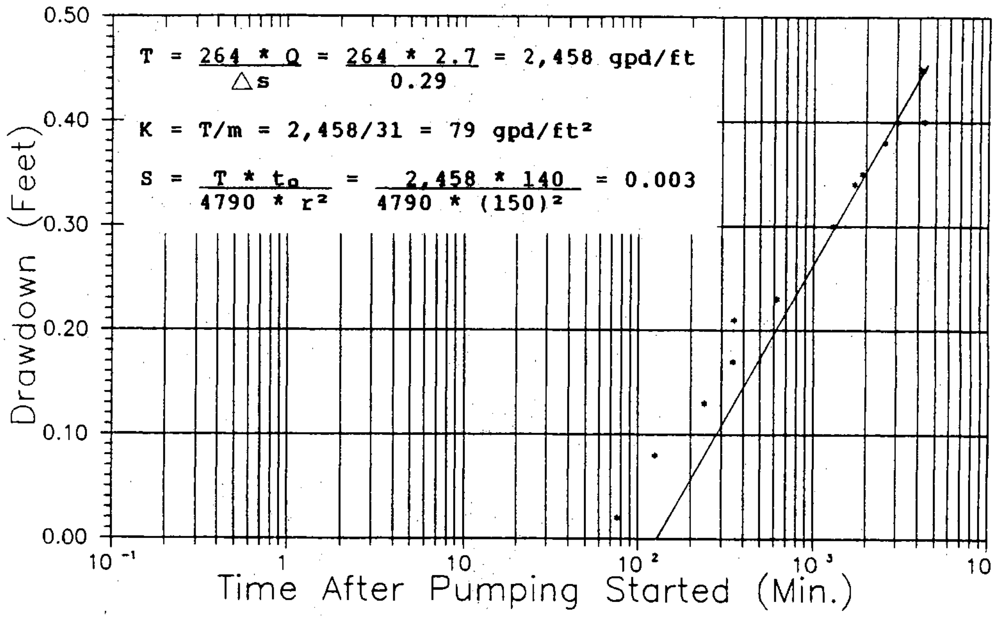
SEMILOGARITHMIC PLOT OF DRAWDOWN VS. TIME
FOR WELL B10 (8/14–17/88)



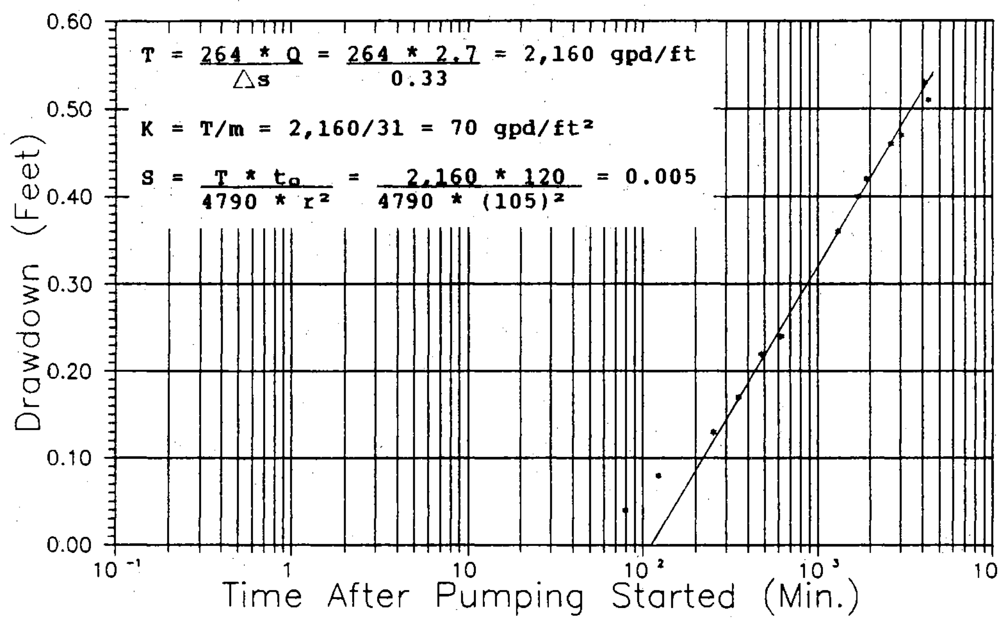
SEMILOGARITHMIC PLOT OF DRAWDOWN VS. TIME
FOR WELL C5 (8/14–17/88)



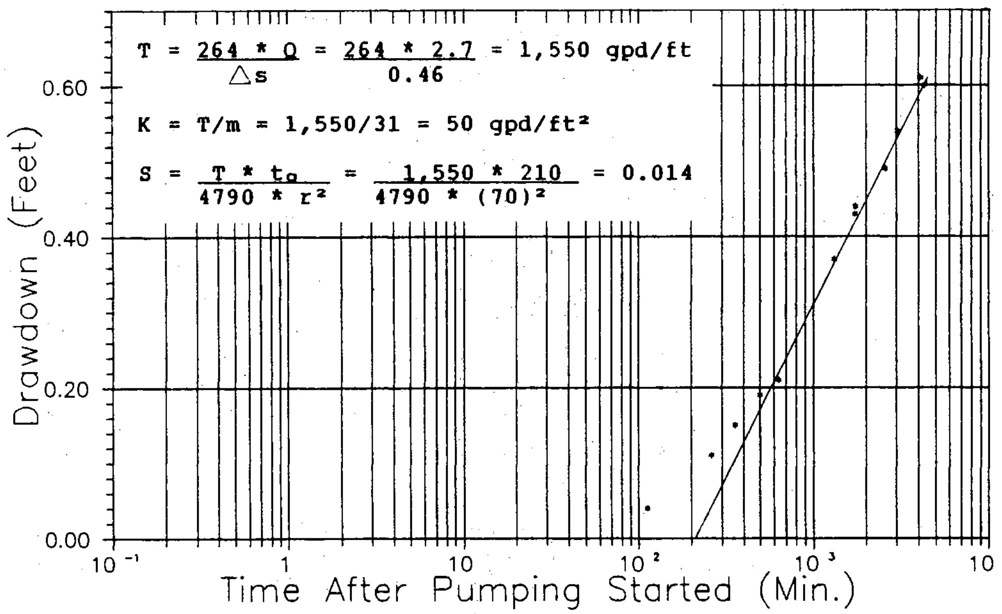
SEMILOGARITHMIC PLOT OF DRAWDOWN VS. TIME
FOR WELL D5 (8/14-17/88)



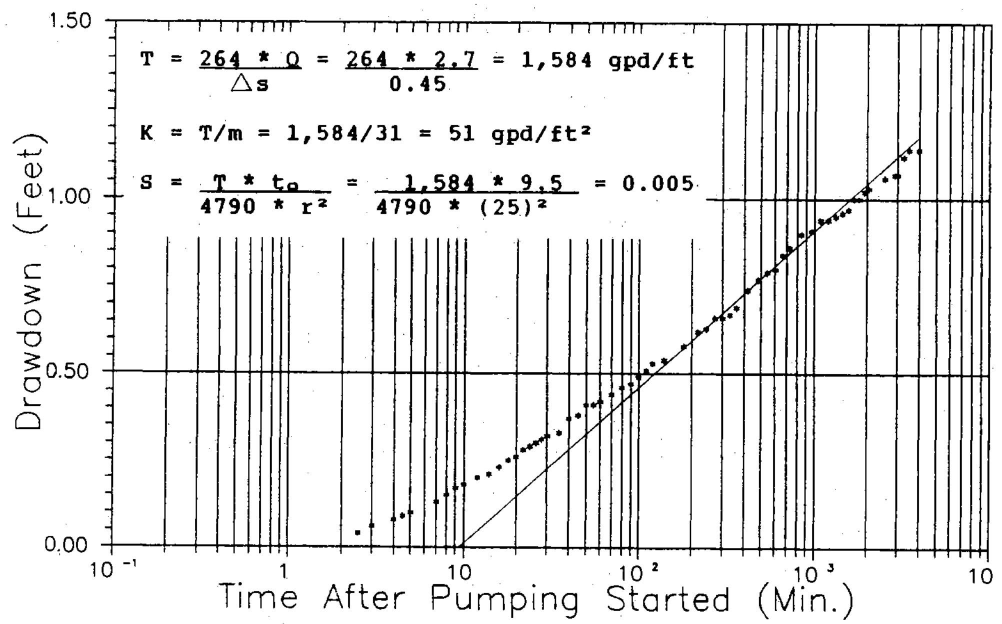
SEMILOGARITHMIC PLOT OF DRAWDOWN VS. TIME
FOR WELL E5 (8/14-17/88)



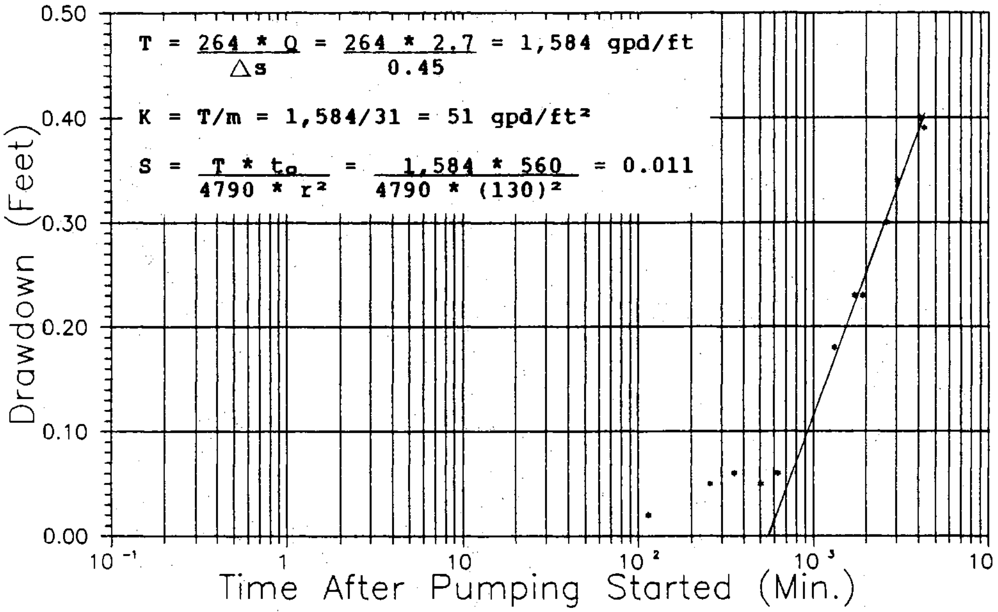
SEMILOGARITHMIC PLOT OF DRAWDOWN VS. TIME
FOR WELL G2 (8/14-17/88)



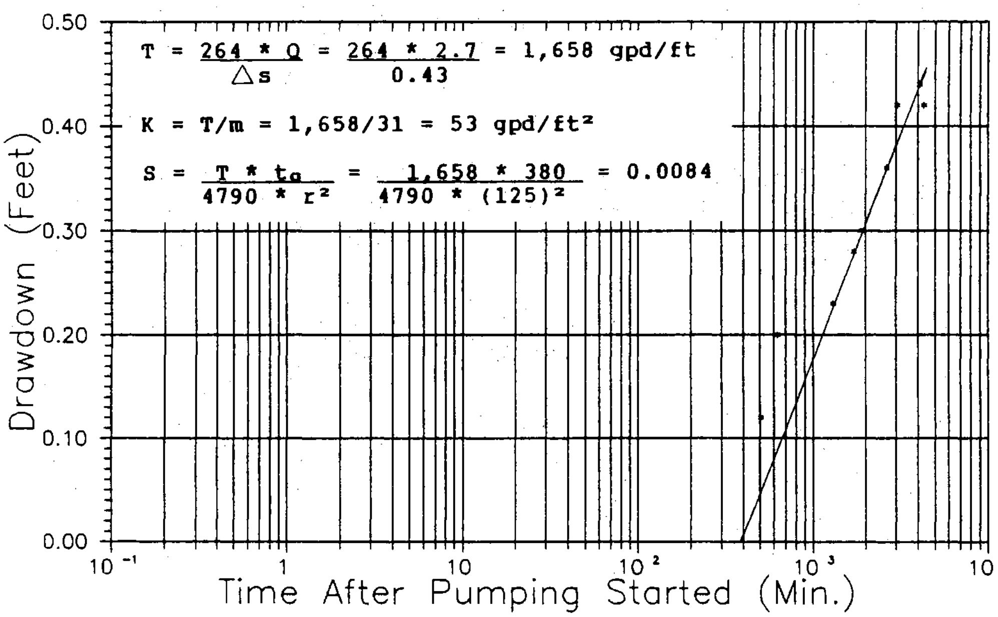
SEMILOGARITHMIC PLOT OF DRAWDOWN VS. TIME
FOR WELL F1 (8/14-17/88)



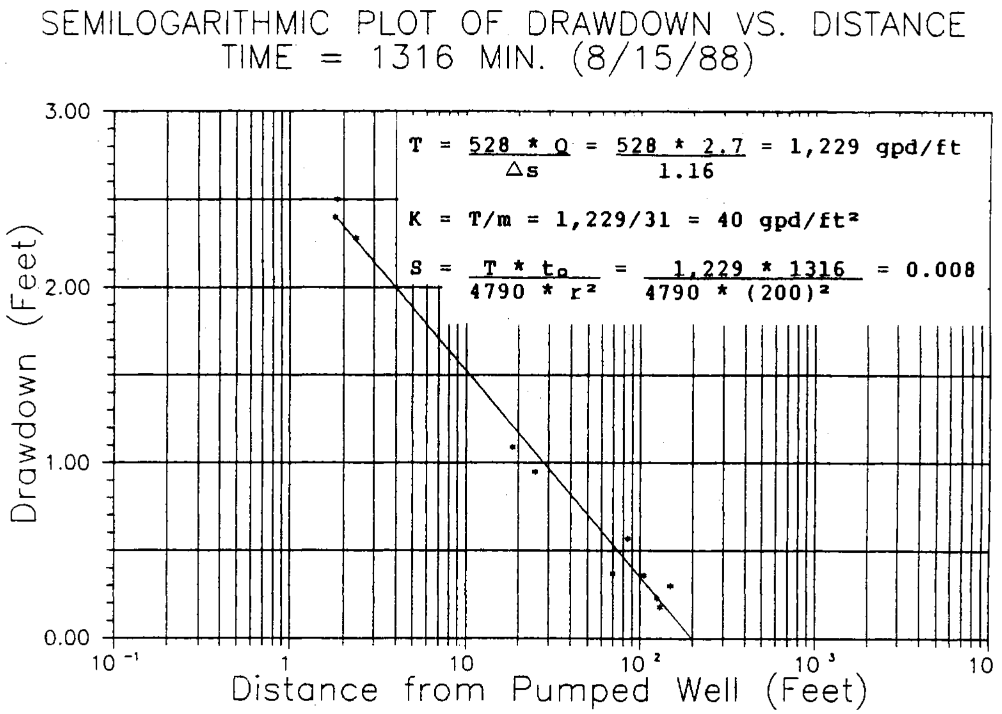
SEMILOGARITHMIC PLOT OF DRAWDOWN VS. TIME FOR WELL H2 (8/14-17/88)

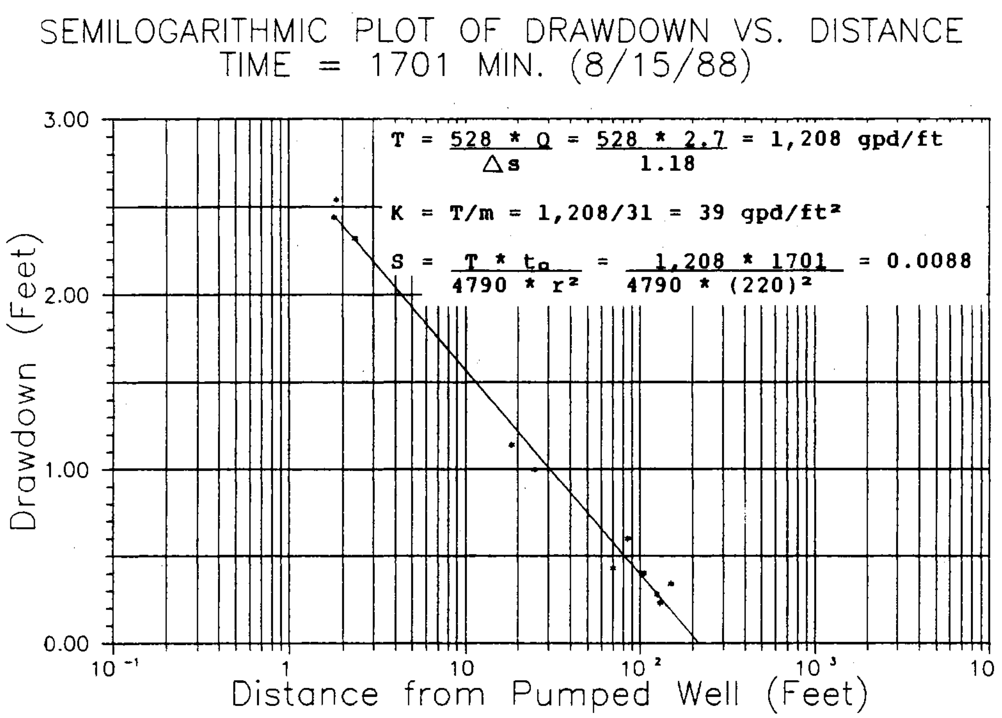


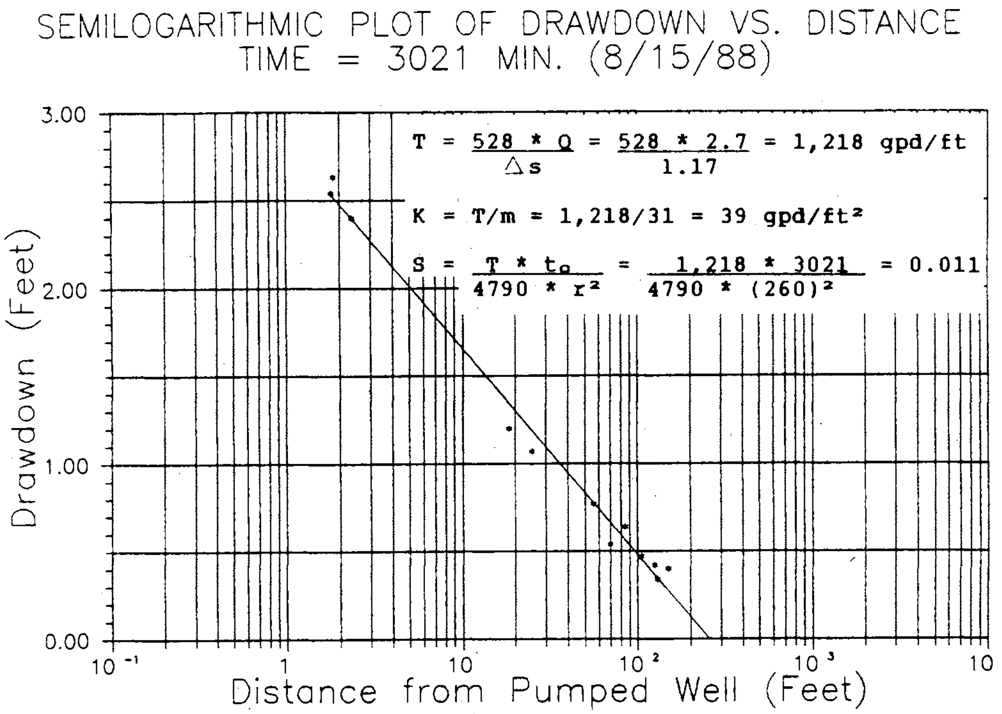
SEMILOGARITHMIC PLOT OF DRAWDOWN VS. TIME FOR WELL J1 (8/14-17/88)

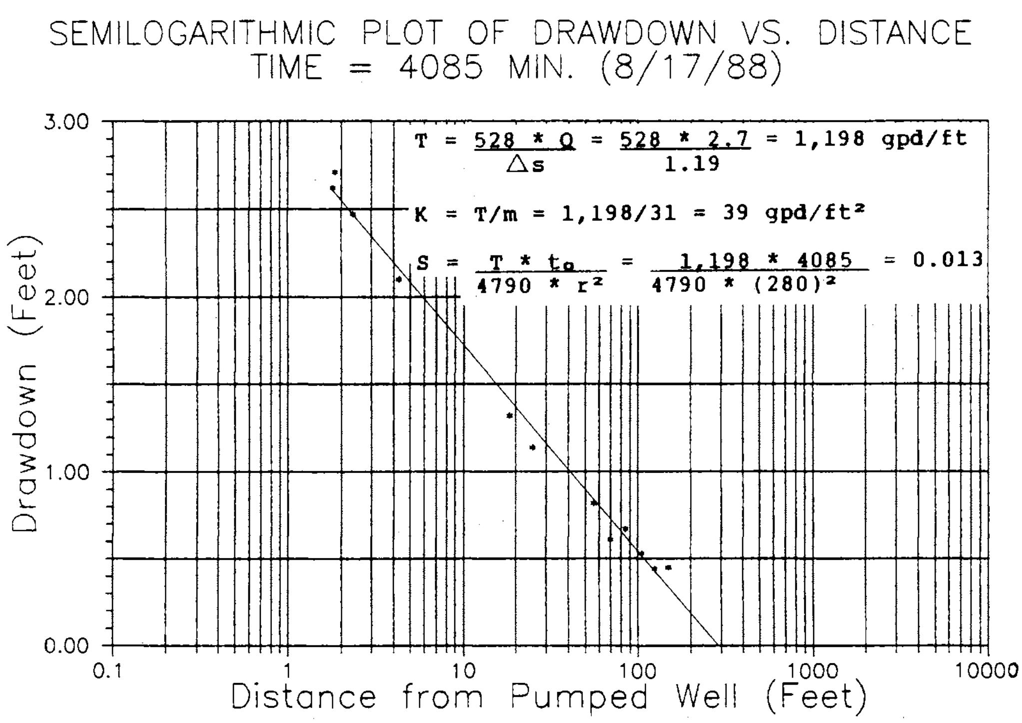


Cooper and Jacob (1946) Distance-Drawdown Method






SEMILOGARITHMIC PLOT OF DRAWDOWN VS. DISTANCE
TIME = 3021 MIN. (8/15/88)
T = 528 * Q / △s = 528 * 2.7 / 1.17 = 1,218 gpd/ft
K = T/m = 1,218/31 = 39 gpd/ft²
S = T * t₀ / 4790 * r² = 1,218 * 3021 / 4790 * (260)² = 0.011
3.00
2.00
1.00
0.00
Drawdown (Feet)
10⁻¹
1
10
10²
10³
10⁴
Distance from Pumped Well (Feet)


SEMILOGARITHMIC PLOT OF DRAWDOWN VS. DISTANCE
TIME = 4085 MIN. (8/17/88)
T = 528 * Q / △s = 528 * 2.7 / 1.19 = 1,198 gpd/ft
K = T/m = 1,198/31 = 39 gpd/ft²
S = T * t₀ / 4790 * r² = 1,198 * 4085 / 4790 * (280)² = 0.013
3.00
2.00
1.00
0.00
Drawdown (Feet)
0.1
1
10
100
1000
10000
Distance from Pumped Well (Feet)

Theis (1935) Recovery Method

Well A5 Recovery
Distance to pumped well = 18.3 feet.
Pumped well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM).

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4343	23	188.83	13.12	1.02
4351	31	140.35	13.05	0.95
4362.5	42.5	102.65	12.99	0.89
4372	52	84.08	12.94	0.84
4377	57	76.79	12.93	0.83
4382	62	70.68	12.91	0.81
4392	72	61.00	12.88	0.78
4402	82	53.68	12.86	0.76
4428	108	41.00	12.81	0.71
4462	142	31.42	12.77	0.67
4513	193	23.38	12.73	0.63
4551	231	19.70	12.70	0.59
4572	252	18.14	12.69	0.58
4598	278	16.54	12.67	0.56
4634	314	14.76	12.66	0.55
4656	336	13.86	12.65	0.54
4693	373	12.58	12.63	0.52
4817	497	9.69	12.61	0.50
4877	557	8.76	12.59	0.48
4993	673	7.42	12.57	0.45
5111	791	6.46	12.54	0.42
5121	801	6.39	12.51	0.39
5478	1158	4.73	12.48	0.35
5596	1276	4.39	12.47	0.34
5715	1395	4.10	12.45	0.32
6152	1832	3.36	12.45	0.31
7049	2729	2.58	12.41	0.25
7541	3221	2.34	12.44	0.26
8590	4270	2.01	12.41	0.21

Well B7 Recovery
Distance to pumped well = 2.3 feet.
Pumped well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM).

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4372	52	84.08	13.82	1.92
4377.5	57.5	76.13	13.77	1.87
4383	63	69.57	13.73	1.83
4399	79	55.68	13.60	1.70
4413	93	47.45	13.48	1.58
4423	103	42.94	13.22	1.32
4437	117	37.92	12.79	0.89
4447	127	35.02	12.69	0.79
4476	156	28.69	12.59	0.69
4496	176	25.55	12.58	0.68
4537	217	20.91	12.53	0.62
4566	246	18.56	12.49	0.58
4600	280	16.43	12.47	0.56
4624	304	15.21	12.46	0.55
4659	339	13.74	12.44	0.53
4686	366	12.80	12.43	0.52
4808	488	9.85	12.39	0.48
4867	547	8.90	12.38	0.47
4996	676	7.39	12.36	0.44
5113	793	6.45	12.33	0.41
5230	910	5.75	12.31	0.39
5468	1148	4.76	12.28	0.35
5587	1267	4.41	12.26	0.33
5708	1388	4.11	12.24	0.31
6141	1821	3.37	12.23	0.29
7040	2720	2.59	12.20	0.24
7543	3223	2.34	12.23	0.25
8505	4185	2.03	12.21	0.21

Well B8 Recovery
Distance to pumped well = 2.3 feet.
Pumped well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM).

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4359	39	111.77	13.07	1.20
4364	44	99.18	12.95	1.08
4369	49	89.16	12.90	1.03
4373	53	82.51	12.87	1.00
4378	58	75.48	12.82	0.95
4384	64	68.50	12.79	0.92
4402	82	53.68	12.71	0.84
4414	94	46.96	12.67	0.80
4424	104	42.54	12.64	0.77
4434	114	38.89	12.62	0.75
4448	128	34.75	12.59	0.72
4477	157	28.52	12.53	0.66
4497	177	25.41	12.52	0.65
4538	218	20.82	12.48	0.60
4567	247	18.49	12.45	0.57
4602	282	16.32	12.43	0.55
4625	305	15.16	12.42	0.54
4660	340	13.71	12.40	0.52
4687	367	12.77	12.38	0.50
4809	489	9.83	12.35	0.47
4869	549	8.87	12.33	0.45
4997	677	7.38	12.30	0.41
5115	795	6.43	12.28	0.39
5232	912	5.74	12.27	0.38
5469	1149	4.76	12.23	0.33
5589	1269	4.40	12.22	0.32
5709	1389	4.11	12.20	0.30
6143	1823	3.37	12.20	0.29
7042	2722	2.59	12.16	0.23
7545	3225	2.34	12.19	0.24
8510	4190	2.03	12.16	0.19

Well B9 Recovery
Distance to pumped well = 1.8 feet.
Pumped well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM).

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4352	32	136.00	12.91	0.99
4356.5	36.5	119.36	12.88	0.96
4363	43	101.47	12.85	0.93
4368	48	91.00	12.82	0.90
4374	54	81.00	12.80	0.88
4378.5	58.5	74.85	12.77	0.85
4387	67	65.48	12.75	0.83
4403	83	53.05	12.71	0.79
4415	95	46.47	12.68	0.76
4425	105	42.14	12.66	0.74
4435	115	38.57	12.64	0.72
4449	129	34.49	12.62	0.70
4477	157	28.52	12.59	0.67
4498	178	25.27	12.57	0.65
4538	218	20.82	12.53	0.60
4568	248	18.42	12.50	0.57
4603	283	16.27	12.49	0.56
4626	306	15.12	12.48	0.55
4661	341	13.67	12.46	0.53
4688	368	12.74	12.44	0.51
4811	491	9.80	12.42	0.49
4870	550	8.85	12.41	0.48
4999	679	7.36	12.37	0.43
5116	796	6.43	12.35	0.41
5234	914	5.73	12.34	0.40
5471	1151	4.75	12.30	0.35
5590	1270	4.40	12.28	0.33
5710	1390	4.11	12.27	0.32
6145	1825	3.37	12.27	0.31
7043	2723	2.59	12.23	0.25
7547	3227	2.34	12.26	0.26
8512	4192	2.03	12.24	0.22

Well B10
Distance from pumping well = 1.7 feet.
Pumped Well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM).

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4353	33	131.91	12.86	0.99
4357.5	37.5	116.20	12.82	0.95
4362	42	103.86	12.80	0.93
4367	47	92.91	12.78	0.91
4374.5	54.5	80.27	12.74	0.87
4379	59	74.22	12.72	0.85
4386	66	66.45	12.70	0.83
4403.5	83.5	52.74	12.65	0.78
4416	96	46.00	12.63	0.76
4426	106	41.75	12.61	0.74
4436	116	38.24	12.59	0.72
4450	130	34.23	12.57	0.70
4479.5	159.5	28.08	12.54	0.67
4499	179	25.13	12.51	0.64
4540	220	20.64	12.48	0.60
4569	249	18.35	12.45	0.57
4604	284	16.21	12.43	0.55
4627	307	15.07	12.42	0.54
4662	342	13.63	12.41	0.53
4689	369	12.71	12.39	0.51
4813	493	9.76	12.37	0.49
4872	552	8.83	12.35	0.47
5001	681	7.34	12.32	0.43
5118	798	6.41	12.30	0.41
5236	916	5.72	12.29	0.40
5472	1152	4.75	12.25	0.35
5592	1272	4.40	12.22	0.32
5711	1391	4.11	12.20	0.30
6146	1826	3.37	12.19	0.28
7045	2725	2.59	12.17	0.24
7549	3229	2.34	12.18	0.23
8513	4193	2.03	12.17	0.20

Well B12 Recovery
Pumped well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM).

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4326.5	6.5	665.62	14.33	1.81
4331	11	393.73	13.90	1.38
4333	13	333.31	13.81	1.29
4335	15	289.00	13.76	1.24
4337	17	255.12	13.71	1.19
4339	19	228.37	13.68	1.16
4341	21	206.71	13.65	1.13
4343	23	188.83	13.62	1.10
4345	25	173.80	13.60	1.08
4347	27	161.00	13.58	1.06
4349	29	149.97	13.56	1.04
4351	31	140.35	13.54	1.02
4356	36	121.00	13.50	0.98
4361	41	106.37	13.48	0.96
4366	46	94.91	13.45	0.93
4371	51	85.71	13.43	0.91
4376	56	78.14	13.41	0.89
4381	61	71.82	13.39	0.87
4391	71	61.85	13.35	0.83
4401	81	54.33	13.33	0.81
4411	91	48.47	13.31	0.79
4421	101	43.77	13.29	0.77
4432	112	39.57	13.27	0.75
4445	125	35.56	13.24	0.72
4461	141	31.64	13.22	0.70
4485	165	27.18	13.19	0.67
4503	183	24.61	13.17	0.65
4530	210	21.57	13.14	0.61
4563	243	18.78	13.13	0.60
4593	273	16.82	13.12	0.59
4622	302	15.30	13.10	0.57
4652	332	14.01	13.07	0.54
4684	364	12.87	13.07	0.54
4805	485	9.91	13.04	0.51
4864	544	8.94	13.03	0.50
4986	666	7.49	13.00	0.46
5106	786	6.50	12.97	0.43
5226	906	5.77	12.96	0.42

5465	1145	4.77	12.93	0.38
5585	1265	4.42	12.91	0.36
5704	1384	4.12	12.89	0.34
6138	1818	3.38	12.88	0.32
7036	2716	2.59	12.85	0.27
7536	3216	2.34	12.87	0.27
8499	4179	2.03	12.85	0.23

Well C5 Recovery
Distance from pumped well = 85 feet.
Pumped well B12 at 2.7 gpm.
Pump stopped 8/17/88 (1:00 PM)

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4422	102	43.35	12.78	0.60
4517	197	22.93	12.74	0.56
5483	1163	4.71	12.53	0.32
7557	3237	2.33	12.51	0.25
8523	4203	2.03	12.46	0.18

Well D5 Recovery
Distance from pumped well = 150 feet.
Pumped Well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM).

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4416.5	96.5	45.77	12.87	0.47
4520	200	22.60	12.87	0.47
5516	1196	4.61	12.74	0.31
7560	3240	2.33	12.72	0.24
8526	4206	2.03	12.68	0.18

Well E5 Recovery
Distance from pumped well = 105 feet.
Pumped Well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM)

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4414	94	46.96	12.84	0.54
4524	204	22.18	12.80	0.50
5511	1191	4.63	12.67	0.34
7564	3244	2.33	12.63	0.25
8529	4209	2.03	12.61	0.21

Well F1 Recovery
Distance from pumped well = 25 feet.
Pumped well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM).

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4320.5	0.5	8641.00	13.64	1.24
4321	1	4321.00	13.64	1.24
4321.5	1.5	2881.00	13.64	1.24
4322	2	2161.00	13.63	1.23
4322.5	2.5	1729.00	13.62	1.22
4323	3	1441.00	13.62	1.22
4323.5	3.5	1235.29	13.60	1.20
4324	4	1081.00	13.60	1.20
4324.5	4.5	961.00	13.59	1.19
4325	5	865.00	13.58	1.18
4326	6	721.00	13.56	1.16
4327	7	618.14	13.54	1.14
4328	8	541.00	13.52	1.12
4329	9	481.00	13.51	1.11
4330	10	433.00	13.50	1.10
4332	12	361.00	13.48	1.08
4334	14	309.57	13.45	1.05
4336	16	271.00	13.42	1.02
4338	18	241.00	13.41	1.01
4340	20	217.00	13.39	0.99
4342	22	197.36	13.38	0.98
4344	24	181.00	13.36	0.96
4346	26	167.15	13.35	0.95
4348	28	155.29	13.34	0.94
4350	30	145.00	13.32	0.92
4355	35	124.43	13.29	0.89
4360	40	109.00	13.27	0.87
4365	45	97.00	13.25	0.85
4370	50	87.40	13.23	0.83
4375	55	79.55	13.22	0.82
4380	60	73.00	13.20	0.80
4390	70	62.71	13.17	0.77
4400	80	55.00	13.15	0.75
4410	90	49.00	13.13	0.73
4420	100	44.20	13.11	0.71
4430	110	40.27	13.10	0.70
4443	123	36.12	13.10	0.70

Well F1 Recovery (Continued)

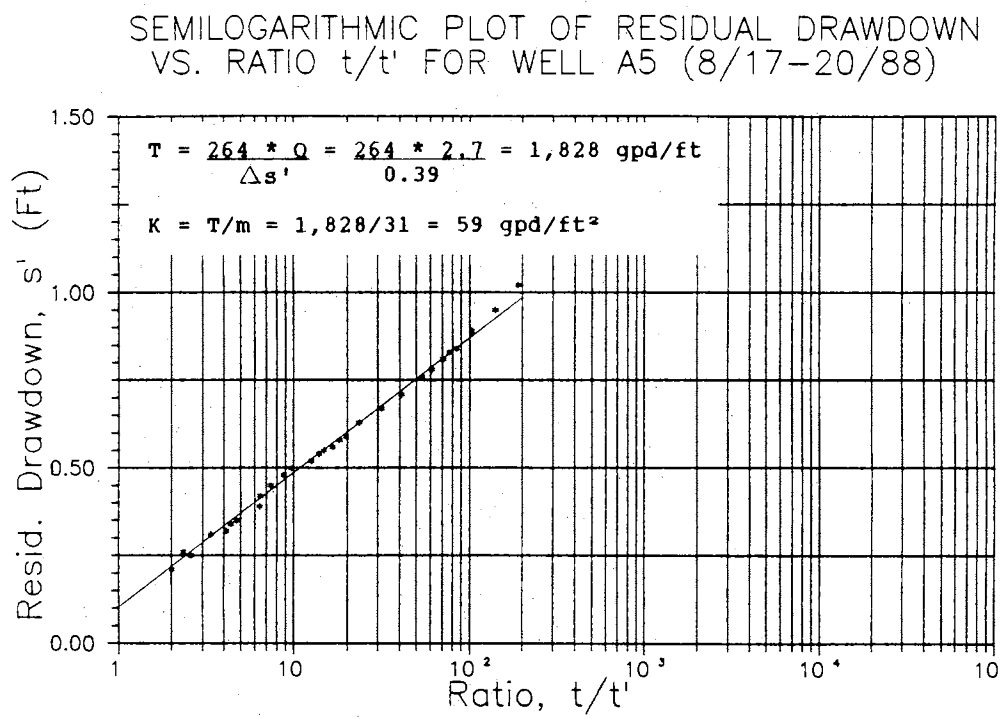
Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4460	140	31.86	13.07	0.67
4481.5	161.5	27.75	13.06	0.66
4501	181	24.87	13.04	0.64
4534	214	21.19	13.01	0.60
4562	242	18.85	12.99	0.58
4591	271	16.94	12.98	0.57
4621	301	15.35	12.96	0.55
4651	331	14.05	12.95	0.54
4682	362	12.93	12.94	0.53
4802	482	9.96	12.91	0.50
4862	542	8.97	12.90	0.49
4983	663	7.52	12.88	0.46
5103	783	6.52	12.85	0.43
5223	903	5.78	12.82	0.40
5463	1143	4.78	12.79	0.36
5582	1262	4.42	12.78	0.35
5701	1381	4.13	12.77	0.34
6149	1829	3.36	12.76	0.32
7020	2731	2.57	12.73	0.26
7530	3210	2.35	12.76	0.28
8519	4199	2.03	12.74	0.24

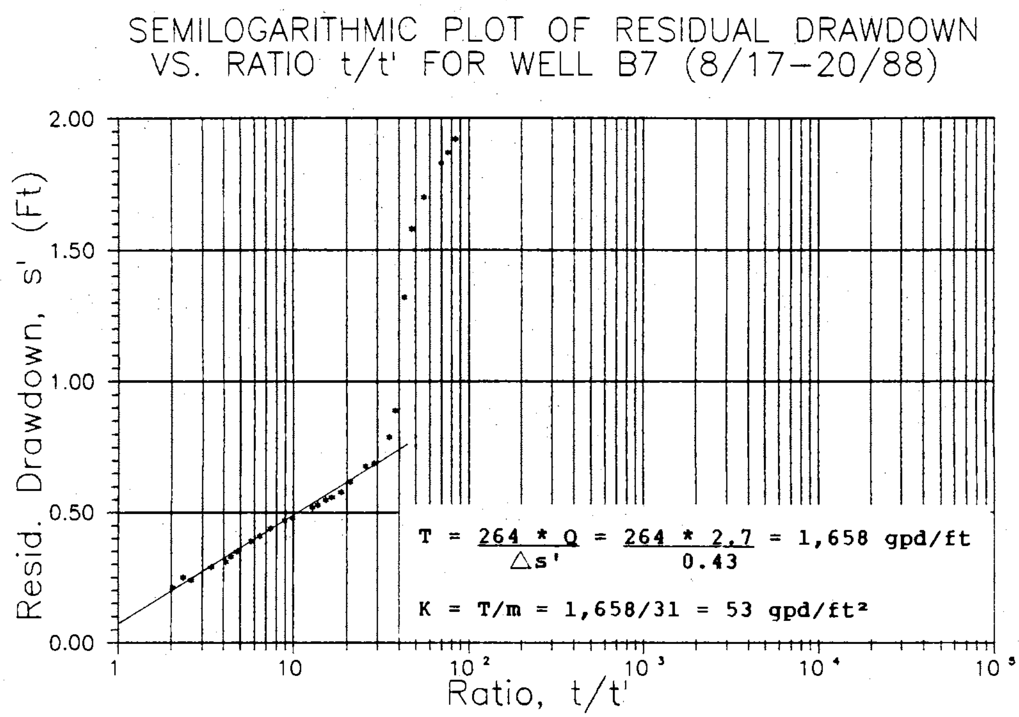
Well G2 Recovery
Distance from pumped well = 70 feet.
Pumped Well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM)

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t'	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4384	64	68.50	10.97	0.67
4394	74	59.38	10.95	0.65
4529.5	209.5	21.62	10.87	0.57
5502	1182	4.65	10.70	0.37
7571	3251	2.33	10.67	0.29
8536	4216	2.02	10.69	0.29

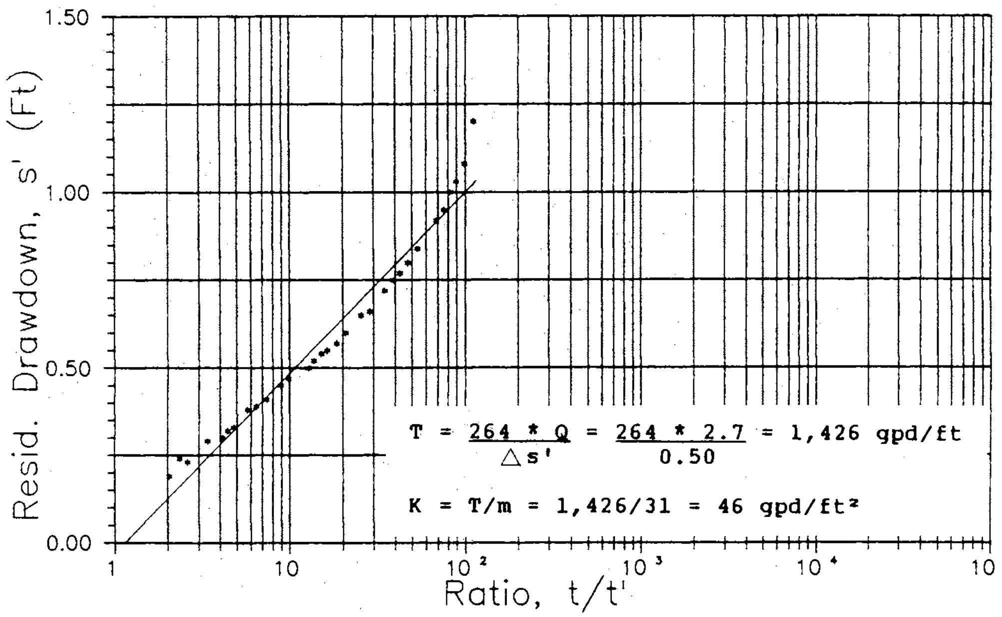
Well H2 Recovery
Distance from pumped well = 130 feet.
Pumped Well B12 at 2.7 gpm for 72 hours.
Pump stopped 8/17/88 (1:00 PM).

Time Since Pump Started t (Min.)	Time Since Pump Stopped t' (Min.)	Ratio t/t' (Min.)	Depth to Water (Feet)	Residual Drawdown s' (Feet)
4387	67	65.48	11.42	0.50
4528	208	21.77	11.39	0.47
5505	1185	4.65	11.32	0.37
7568	3248	2.33	11.30	0.30
8534	4214	2.03	11.34	0.32

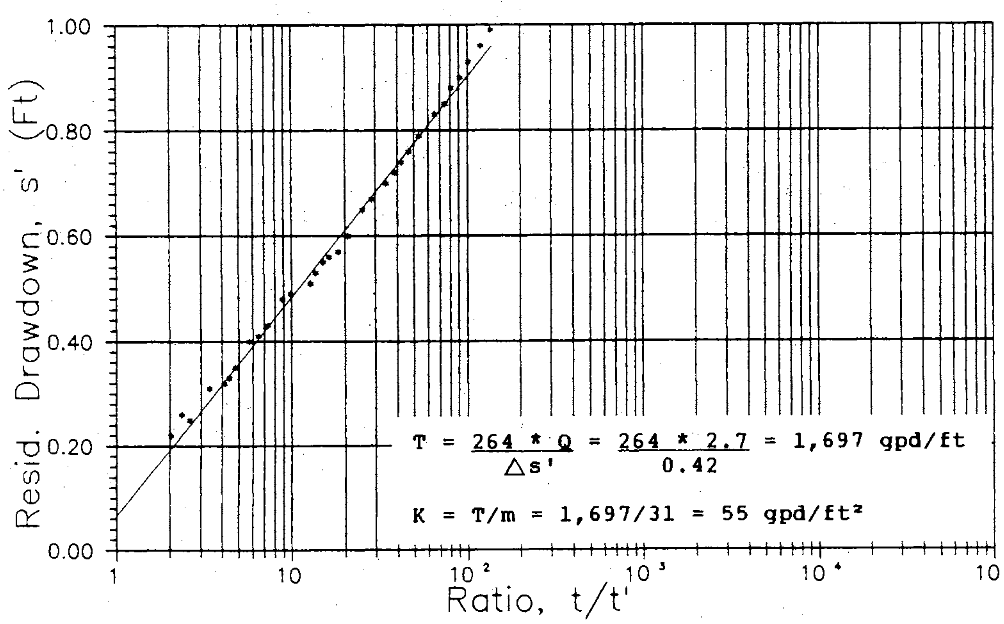

SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN
VS. RATIO t/t' FOR WELL A5 (8/17-20/88)
T = 264 * Q / Δs' = 264 * 2.7 / 0.39 = 1,828 gpd/ft
K = T/m = 1,828/31 = 59 gpd/ft²
Resid. Drawdown, s' (Ft)
1.50
1.00
0.50
0.00
1
10
10²
10³
10⁴
10⁵
Ratio, t/t'


SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN
VS. RATIO t/t' FOR WELL B7 (8/17-20/88)
T = 264 * Q / Δs' = 264 * 2.7 / 0.43 = 1,658 gpd/ft
K = T/m = 1,658/31 = 53 gpd/ft²
Resid. Drawdown, s' (Ft)
2.00
1.50
1.00
0.50
0.00
1
10
10²
10³
10⁴
10⁵
Ratio, t/t'

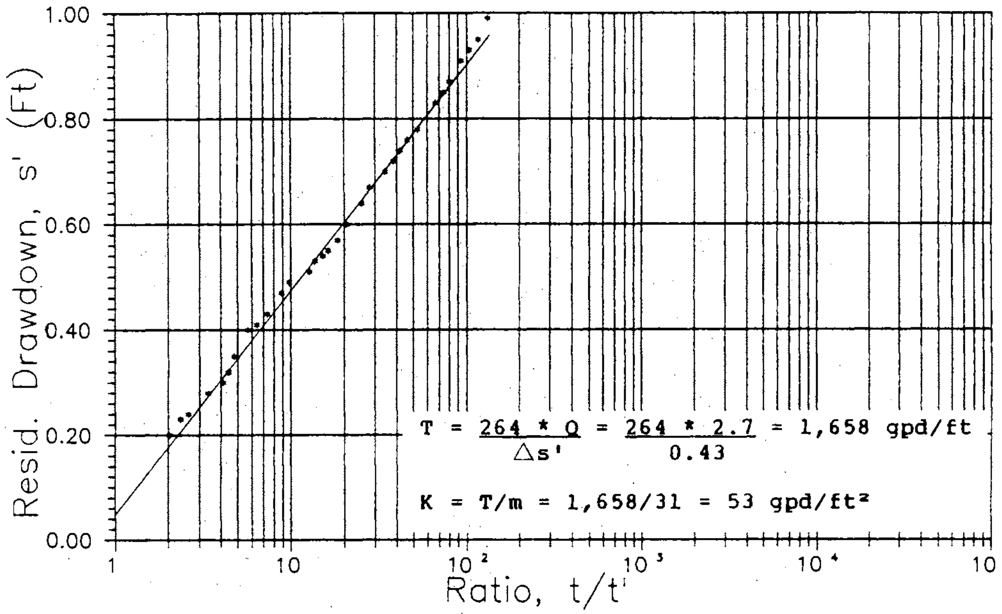
SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN
VS. RATIO t/t' FOR WELL B8 (8/17-20/88)



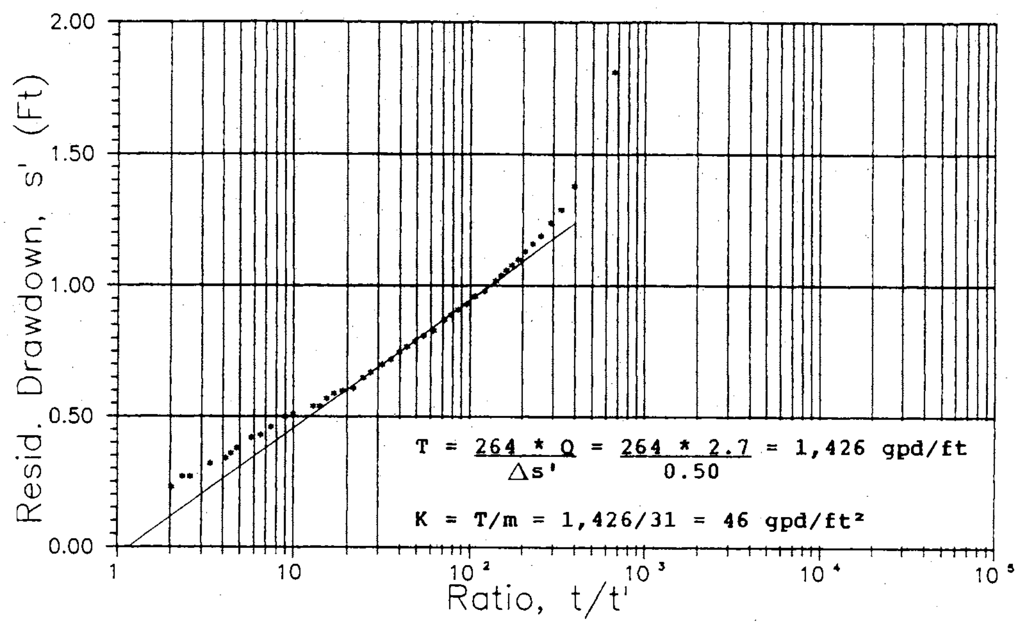
SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN
VS. RATIO t/t' FOR WELL B9 (8/17-20/88)



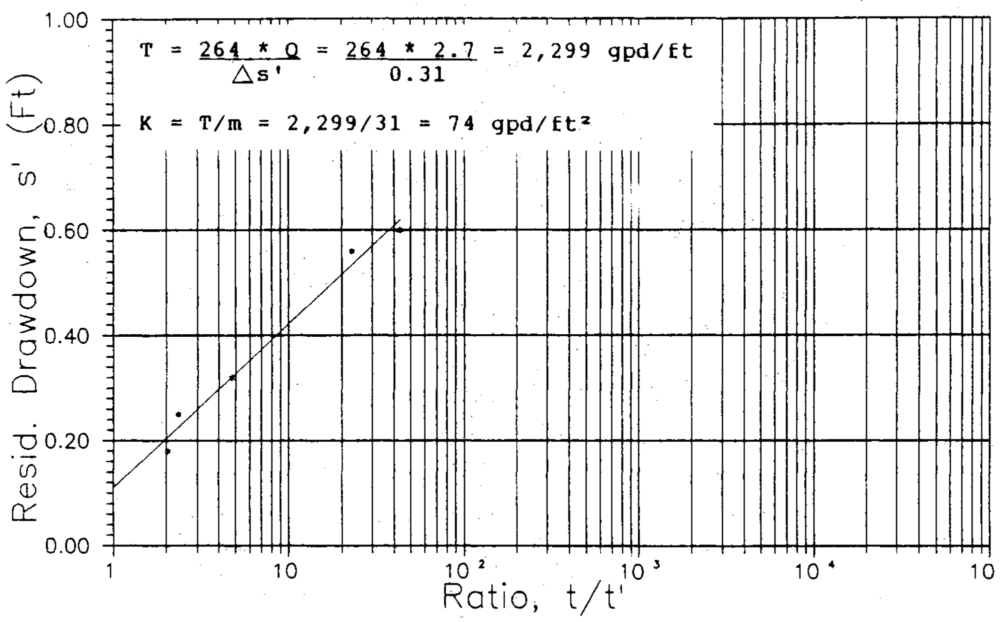
SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN VS. RATIO t/t' FOR WELL B10 (8/17-20/88)



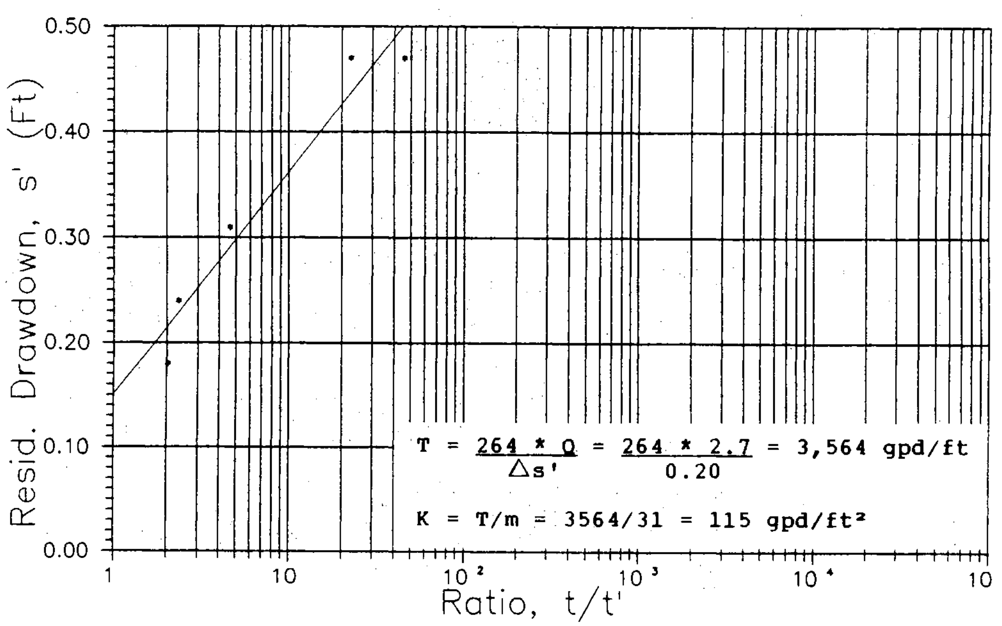
SEMILOGARTHMIC PLOT OF RESIDUAL DRAWDOWN VS. RATIO t/t' FOR WELL B12 (8/17-20/88)



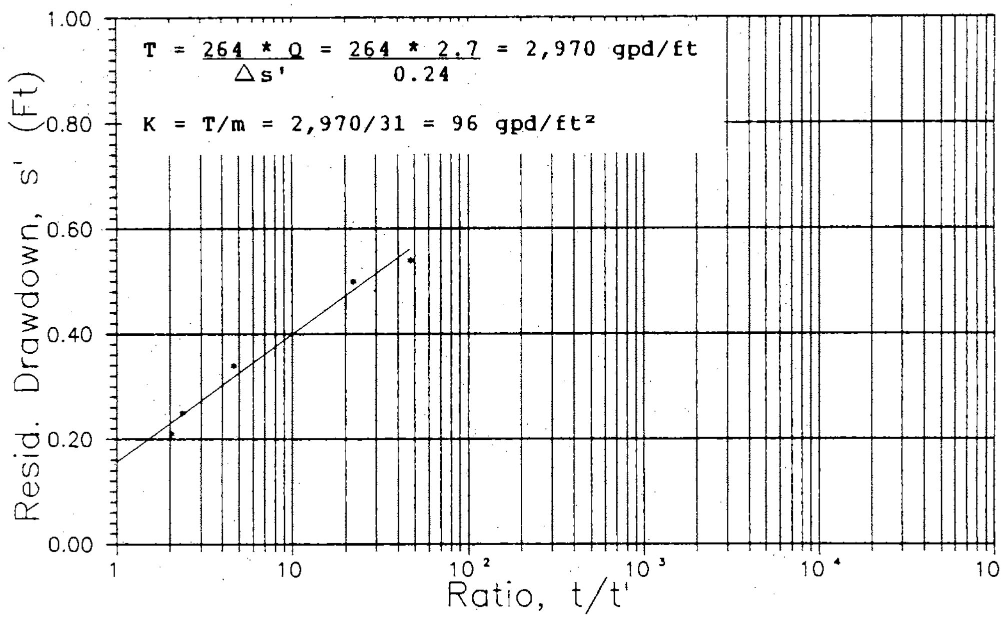
SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN VS. RATIO t/t' FOR WELL C5 (8/17-20/88)



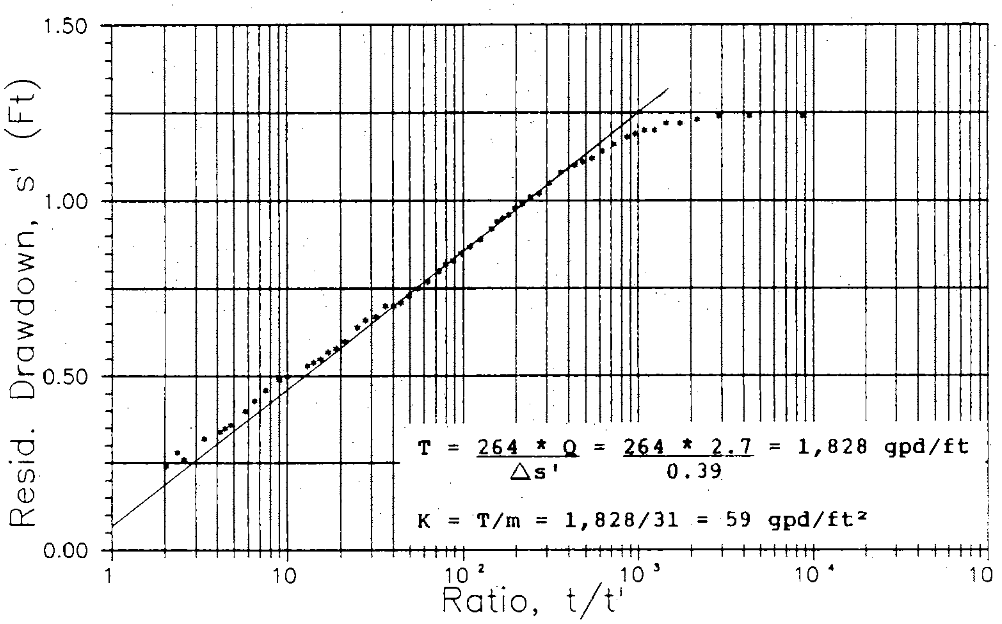
SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN VS. RATIO t/t' FOR WELL D5 (8/17-20/88)



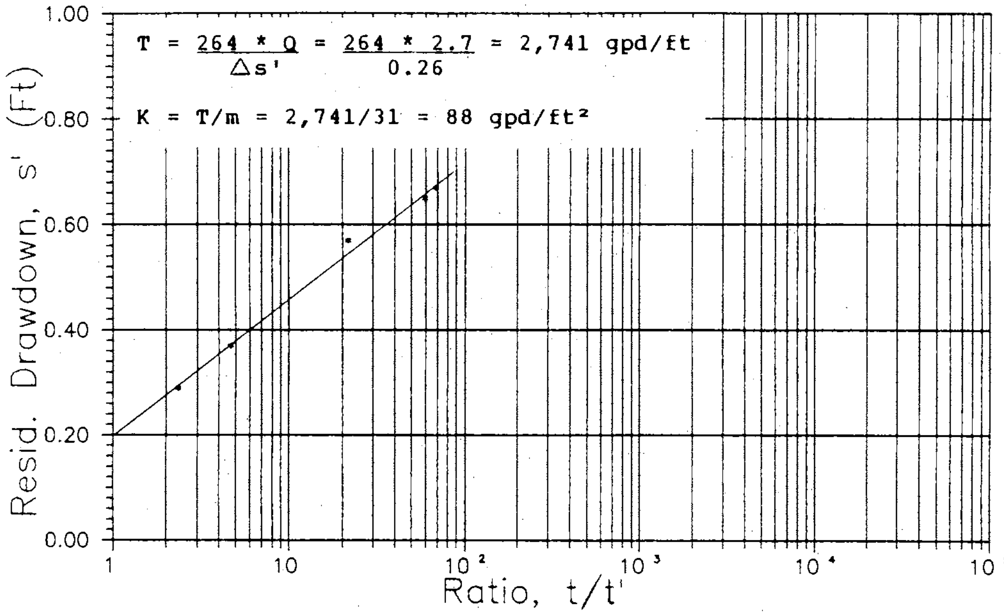
SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN VS. RATIO t/t' FOR WELL E5 (8/17-20/88)



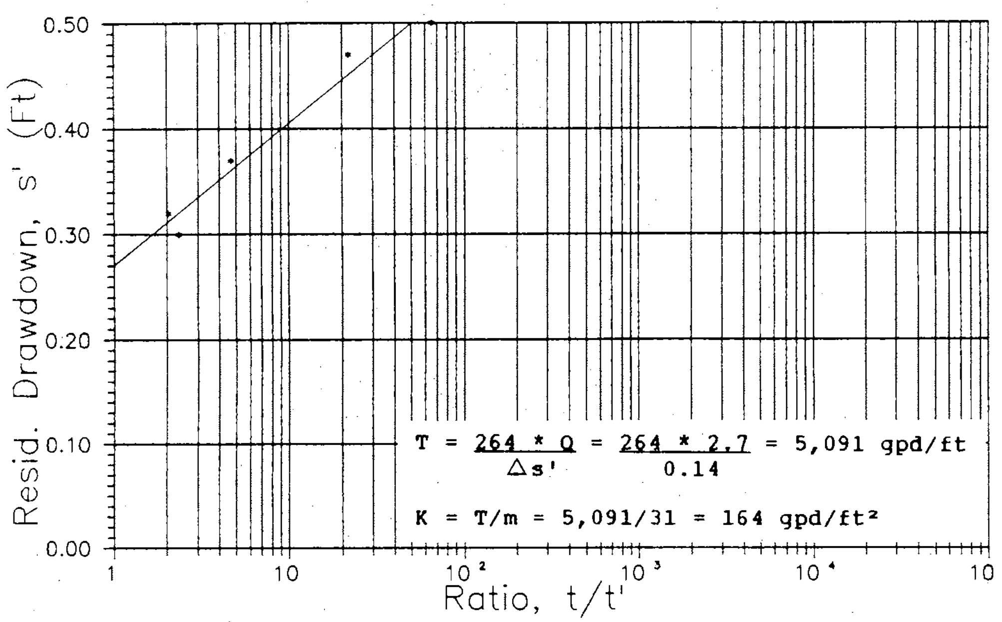
SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN VS. RATIO t/t' FOR WELL F1 (8/14-20/88)



SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN
VS. RATIO t/t' FOR WELL G2 (8/17-20/88)



SEMILOGARITHMIC PLOT OF RESIDUAL DRAWDOWN
VS. RATIO t/t' FOR WELL H2 (8/17-20/88)



APPENDIX D

SLUG TEST DATA AND ANALYSES

Well F1 Slug Test (8/13/88)
0.29 gal. removed with bailer.

Elapsed Time, t (sec)	Depth to Water (m)	Change in Water Level, H or y (m)	H/H(0)	Alternate H/H(0)
-1	3.8191			
0.2	4.0782	0.2591	1.0001	
0.6	4.0142	0.1951	0.7531	
0.8	3.9990	0.1799	0.6942	
1	3.9959	0.1768	0.6825	
1.2	3.9929	0.1738	0.6707	0.9999
1.4	3.9929	0.1738	0.6707	0.9999
1.6	3.9929	0.1738	0.6707	0.9999
1.8	3.9929	0.1738	0.6707	0.9999
2	3.9898	0.1707	0.6589	0.9823
3	3.9837	0.1646	0.6354	0.9473
4	3.9776	0.1585	0.6119	0.9122
5	3.9746	0.1555	0.6001	0.8947
6	3.9685	0.1494	0.5766	0.8596
7	3.9624	0.1433	0.5531	0.8245
8	3.9594	0.1403	0.5413	0.8070
9	3.9563	0.1372	0.5295	0.7894
10	3.9533	0.1342	0.5178	0.7719
11	3.9472	0.1281	0.4942	0.7368
12	3.9441	0.1250	0.4825	0.7193
13	3.9411	0.1220	0.4707	0.7017
14	3.9380	0.1189	0.4590	0.6842
15	3.9350	0.1159	0.4472	0.6667
16	3.9319	0.1128	0.4354	0.6491
17	3.9289	0.1098	0.4237	0.6316
18	3.9258	0.1067	0.4119	0.6141
19	3.9228	0.1037	0.4001	0.5965
20	3.9228	0.1037	0.4001	0.5965
25	3.9106	0.0915	0.3531	0.5264
30	3.9045	0.0854	0.3296	0.4913
35	3.8953	0.0762	0.2943	0.4387
40	3.8923	0.0732	0.2825	0.4212
45	3.8862	0.0671	0.2590	0.3861
50	3.8832	0.0641	0.2472	0.3685
55	3.8771	0.0580	0.2237	0.3335
60	3.8771	0.0580	0.2237	0.3335
65	3.8740	0.0549	0.2119	0.3159
70	3.8710	0.0519	0.2002	0.2984
75	3.8710	0.0519	0.2002	0.2984
80	3.8679	0.0488	0.1884	0.2809

85	3.8649	0.0458	0.1766	0.2633
90	3.8649	0.0458	0.1766	0.2633
95	3.8649	0.0458	0.1766	0.2633
100	3.8649	0.0458	0.1766	0.2633
105	3.8618	0.0427	0.1649	0.2458
110	3.8618	0.0427	0.1649	0.2458
115	3.8618	0.0427	0.1649	0.2458
120	3.8618	0.0427	0.1649	0.2458
150	3.8588	0.0397	0.1531	0.2282
180	3.8557	0.0366	0.1413	0.2107
210	3.8557	0.0366	0.1413	0.2107
240	3.8557	0.0366	0.1413	0.2107
270	3.8557	0.0366	0.1413	0.2107
300	3.8557	0.0366	0.1413	0.2107
330	3.8557	0.0366	0.1413	0.2107
360	3.8557	0.0366	0.1413	0.2107
390	3.8557	0.0366	0.1413	0.2107
420	3.8557	0.0366	0.1413	0.2107
450	3.8496	0.0305	0.1178	0.1756
480	3.8496	0.0305	0.1178	0.1756
510	3.8496	0.0305	0.1178	0.1756
540	3.8496	0.0305	0.1178	0.1756
570	3.8466	0.0275	0.1060	0.1581
600	3.8466	0.0275	0.1060	0.1581
720	3.8466	0.0275	0.1060	0.1581
840	3.8466	0.0275	0.1060	0.1581
960	3.8466	0.0275	0.1060	0.1581
1080	3.8466	0.0275	0.1060	0.1581

Well F1 Slug Test (9/15/88)
0.79 gal. removed with bailer.

Elapsed Time, t (sec)	Depth to Water (m)	Change in Water Level, H or y (m)	H/H(0)	Alternate H/H(0)
-1	3.8801			
0.2	4.2581	0.3780	0.9999	
0.4	4.2489	0.3688	0.9757	
0.6	4.2306	0.3505	0.9273	
0.8	4.2184	0.3383	0.8951	
1	4.2093	0.3292	0.8709	1.0000
1.2	4.2062	0.3261	0.8628	0.9907
1.4	4.2032	0.3231	0.8547	0.9814
1.6	4.2032	0.3231	0.8547	0.9814
1.8	4.2001	0.3200	0.8467	0.9722
2	4.1971	0.3170	0.8386	0.9629
3	4.1880	0.3079	0.8144	0.9352
4	4.1758	0.2957	0.7822	0.8981
5	4.1666	0.2865	0.7580	0.8703
6	4.1575	0.2774	0.7338	0.8426
7	4.1483	0.2682	0.7096	0.8148
8	4.1392	0.2591	0.6854	0.7870
9	4.1300	0.2499	0.6612	0.7592
10	4.1239	0.2438	0.6451	0.7407
11	4.1178	0.2377	0.6290	0.7222
12	4.1118	0.2317	0.6128	0.7037
13	4.1026	0.2225	0.5886	0.6759
14	4.0965	0.2164	0.5725	0.6574
15	4.0904	0.2103	0.5564	0.6389
16	4.0843	0.2042	0.5403	0.6204
17	4.0782	0.1981	0.5241	0.6018
18	4.0721	0.1920	0.5080	0.5833
19	4.0691	0.1890	0.4999	0.5741
20	4.0630	0.1829	0.4838	0.5555
25	4.0447	0.1646	0.4354	0.5000
30	4.0264	0.1463	0.3871	0.4444
35	4.0112	0.1311	0.3467	0.3981
40	3.9959	0.1158	0.3064	0.3518
45	3.9868	0.1067	0.2822	0.3241
50	3.9746	0.0945	0.2500	0.2870
55	3.9654	0.0853	0.2258	0.2593
60	3.9594	0.0793	0.2097	0.2407
65	3.9502	0.0701	0.1855	0.2130
70	3.9441	0.0640	0.1693	0.1944
75	3.9380	0.0579	0.1532	0.1759

80	3.9350	0.0549	0.1452	0.1667
85	3.9289	0.0488	0.1290	0.1482
90	3.9258	0.0457	0.1210	0.1389
95	3.9228	0.0427	0.1129	0.1296
100	3.9167	0.0366	0.0968	0.1111
105	3.9167	0.0366	0.0968	0.1111
110	3.9136	0.0335	0.0887	0.1019
115	3.9106	0.0305	0.0806	0.0926
120	3.9075	0.0274	0.0726	0.0833
150	3.8984	0.0183	0.0484	0.0556
180	3.8892	0.0091	0.0242	0.0278
210	3.8862	0.0061	0.0161	0.0185
240	3.8801	0.0000	0.0000	0.0000

Well B12 Slug Test (9/14/88, 7:00 PM)
0.29 gal. removed with bailer.

Elapsed Time, t (sec)	Depth to Water (m)	Change in Water Level, H or y (m)	H/H(0)	Alternate H/H(0)
-1	3.9228			
0.4	4.1666	0.2438	1.0002	
0.6	4.1422	0.2194	0.9000	
1.4	4.0935	0.1707	0.7000	0.9998
1.6	4.0904	0.1676	0.6875	0.9819
1.8	4.0904	0.1676	0.6875	0.9819
2	4.0874	0.1646	0.6750	0.9641
3	4.0874	0.1646	0.6750	0.9641
4	4.0813	0.1585	0.6500	0.9284
5	4.0782	0.1554	0.6375	0.9105
6	4.0752	0.1524	0.6250	0.8927
7	4.0721	0.1493	0.6125	0.8748
8	4.0691	0.1463	0.6000	0.8569
9	4.0660	0.1432	0.5875	0.8391
10	4.0660	0.1432	0.5875	0.8391
11	4.0630	0.1402	0.5750	0.8212
12	4.0599	0.1371	0.5625	0.8034
13	4.0569	0.1341	0.5500	0.7855
14	4.0538	0.1310	0.5375	0.7677
15	4.0508	0.1280	0.5250	0.7498
16	4.0508	0.1280	0.5250	0.7498
17	4.0477	0.1249	0.5125	0.7320
18	4.0477	0.1249	0.5125	0.7320
19	4.0447	0.1219	0.5000	0.7141
20	4.0416	0.1188	0.4875	0.6962
25	4.0325	0.1097	0.4500	0.6427
30	4.0264	0.1036	0.4250	0.6070
35	4.0203	0.0975	0.4000	0.5712
40	4.0142	0.0914	0.3750	0.5355
45	4.0081	0.0853	0.3500	0.4998
50	4.0020	0.0792	0.3250	0.4641
55	3.9990	0.0762	0.3125	0.4463
60	3.9929	0.0701	0.2874	0.4105
65	3.9898	0.0670	0.2749	0.3927
70	3.9868	0.0640	0.2624	0.3748
75	3.9807	0.0579	0.2374	0.3391
80	3.9776	0.0548	0.2249	0.3213
85	3.9746	0.0518	0.2124	0.3034
90	3.9715	0.0487	0.1999	0.2856
95	3.9685	0.0457	0.1874	0.2677

100	3.9685	0.0457	0.1874	0.2677
105	3.9654	0.0426	0.1749	0.2498
110	3.9624	0.0396	0.1624	0.2320
115	3.9594	0.0366	0.1499	0.2141
120	3.9594	0.0366	0.1499	0.2141
150	3.9472	0.0244	0.0999	0.1427
180	3.9411	0.0183	0.0749	0.1070
210	3.9350	0.0122	0.0499	0.0713
240	3.9319	0.0091	0.0374	0.0534
270	3.9289	0.0061	0.0249	0.0356
300	3.9289	0.0061	0.0249	0.0356
330	3.9258	0.0030	0.0124	0.0177
360	3.9228	-0.0000	-0.0001	-0.0001

Well B12 Slug Test (9/14/88, 8:00 PM)
0.79 gal. removed with bailer.

Elapsed Time, t (sec)	Depth to Water (m)	Change in Water Level, H or y (m)	H/H(0)	Alternate H/H(0)
-1	3.9228			
0	4.4379	0.5151	1.0000	
0.4	4.3007	0.3779	0.7337	
0.6	4.2824	0.3596	0.6982	
0.8	4.2642	0.3414	0.6627	0.9999
1.4	4.2611	0.3383	0.6568	0.9909
1.6	4.2611	0.3383	0.6568	0.9909
1.8	4.2611	0.3383	0.6568	0.9909
2	4.2581	0.3353	0.6509	0.9820
3	4.2489	0.3261	0.6331	0.9552
4	4.2398	0.3170	0.6154	0.9284
5	4.2337	0.3109	0.6035	0.9106
6	4.2276	0.3048	0.5917	0.8927
7	4.2215	0.2987	0.5798	0.8749
8	4.2154	0.2926	0.5680	0.8570
9	4.2123	0.2895	0.5621	0.8481
10	4.2062	0.2834	0.5503	0.8302
11	4.2001	0.2773	0.5384	0.8124
12	4.1940	0.2712	0.5266	0.7945
13	4.1910	0.2682	0.5207	0.7856
14	4.1849	0.2621	0.5088	0.7677
15	4.1819	0.2591	0.5029	0.7588
16	4.1758	0.2530	0.4911	0.7409
17	4.1727	0.2499	0.4852	0.7320
18	4.1666	0.2438	0.4733	0.7142
19	4.1636	0.2408	0.4674	0.7052
20	4.1575	0.2347	0.4556	0.6874
25	4.1422	0.2194	0.4260	0.6427
30	4.1239	0.2011	0.3905	0.5892
35	4.1118	0.1890	0.3668	0.5535
40	4.0996	0.1768	0.3432	0.5178
45	4.0874	0.1646	0.3195	0.4820
50	4.0752	0.1524	0.2958	0.4463
55	4.0660	0.1432	0.2781	0.4195
60	4.0569	0.1341	0.2603	0.3928
65	4.0477	0.1249	0.2426	0.3660
70	4.0386	0.1158	0.2248	0.3392
75	4.0325	0.1097	0.2130	0.3213
80	4.0264	0.1036	0.2011	0.3035
85	4.0203	0.0975	0.1893	0.2856

90	4.0142	0.0914	0.1775	0.2678
95	4.0081	0.0853	0.1656	0.2499
100	4.0020	0.0792	0.1538	0.2321
105	3.9990	0.0762	0.1479	0.2231
110	3.9929	0.0701	0.1361	0.2053
115	3.9898	0.0670	0.1301	0.1963
120	3.9868	0.0640	0.1242	0.1874
150	3.9685	0.0457	0.0887	0.1338
180	3.9563	0.0335	0.0650	0.0981
210	3.9472	0.0244	0.0473	0.0714
240	3.9411	0.0183	0.0355	0.0535
270	3.9350	0.0122	0.0236	0.0356
300	3.9319	0.0091	0.0177	0.0267
330	3.9289	0.0061	0.0118	0.0178
360	3.9289	0.0061	0.0118	0.0178
390	3.9258	0.0030	0.0059	0.0089
420	3.9258	0.0030	0.0059	0.0089
450	3.9228	-0.0000	-0.0000	-0.0001

Well B12 Slug Test (1/27/89)
1.75 gals. removed with bailer.

Elapsed Time, t (sec)	Depth to Water (m)	Change in Water Level, H or y (m)	H/H(0)	Alternate H/H(0)
-1	2.7127			
0.6	3.7003	0.9876	1.0000	
0.8	3.6210	0.9083	0.9197	
1.4	3.5022	0.7895	0.7994	1.0000
1.6	3.5022	0.7895	0.7994	1.0000
1.8	3.5022	0.7895	0.7994	1.0000
2	3.5022	0.7895	0.7994	1.0000
3	3.4930	0.7803	0.7901	0.9883
4	3.4778	0.7651	0.7747	0.9691
5	3.4656	0.7529	0.7624	0.9536
6	3.4534	0.7407	0.7500	0.9382
7	3.4412	0.7285	0.7376	0.9227
8	3.4290	0.7163	0.7253	0.9073
9	3.4168	0.7041	0.7129	0.8918
10	3.4077	0.6950	0.7037	0.8803
11	3.3955	0.6828	0.6914	0.8649
12	3.3863	0.6736	0.6821	0.8532
13	3.3741	0.6614	0.6697	0.8377
14	3.3650	0.6523	0.6605	0.8262
15	3.3558	0.6431	0.6512	0.8146
16	3.3437	0.6310	0.6389	0.7992
17	3.3345	0.6218	0.6296	0.7876
18	3.3254	0.6127	0.6204	0.7761
19	3.3162	0.6035	0.6111	0.7644
20	3.3071	0.5944	0.6019	0.7529
25	3.2705	0.5578	0.5648	0.7065
30	3.2339	0.5212	0.5277	0.6602
35	3.2034	0.4907	0.4969	0.6215
40	3.1760	0.4633	0.4691	0.5868
45	3.1486	0.4359	0.4414	0.5521
50	3.1242	0.4115	0.4167	0.5212
55	3.0998	0.3871	0.3920	0.4903
60	3.0754	0.3627	0.3673	0.4594
65	3.0571	0.3444	0.3487	0.4362
70	3.0389	0.3262	0.3303	0.4132
75	3.0206	0.3079	0.3118	0.3900
80	3.0023	0.2896	0.2932	0.3668
85	2.9870	0.2743	0.2777	0.3474
90	2.9718	0.2591	0.2624	0.3282
95	2.9596	0.2469	0.2500	0.3127

100	2.9474	0.2347	0.2376	0.2973
105	2.9322	0.2195	0.2223	0.2780
110	2.9230	0.2103	0.2129	0.2664
115	2.9108	0.1981	0.2006	0.2509
120	2.9017	0.1890	0.1914	0.2394
150	2.8529	0.1402	0.1420	0.1776
180	2.8194	0.1067	0.1080	0.1351
210	2.7920	0.0793	0.0803	0.1004
240	2.7767	0.0640	0.0648	0.0811
270	2.7615	0.0488	0.0494	0.0618
300	2.7523	0.0396	0.0401	0.0502
330	2.7462	0.0335	0.0339	0.0424
360	2.7371	0.0244	0.0247	0.0309
390	2.7310	0.0183	0.0185	0.0232
420	2.7280	0.0153	0.0155	0.0194
450	2.7249	0.0122	0.0124	0.0155
480	2.7219	0.0092	0.0093	0.0117
510	2.7219	0.0092	0.0093	0.0117
540	2.7249	0.0122	0.0124	0.0155
570	2.7249	0.0122	0.0124	0.0155
600	2.7219	0.0092	0.0093	0.0117
720	2.7219	0.0092	0.0093	0.0117
840	2.7219	0.0092	0.0093	0.0117
960	2.7219	0.0092	0.0093	0.0117
1080	2.7127	0.0000	0.0000	0.0000

Hvorslev (1951) Method

The following is an example of the methodology used to calculate hydraulic conductivity using the method devised by Hvorslev (1951), as described by Fetter (1988). Water-level data from a slug test on well B12 on January 27, 1989 was plotted with H/H(0), on a logarithmic axis, versus time, in seconds, on an arithmetic axis, as shown in this appendix. A straight-line segment of the data was chosen in order to determine T_0, and values of R, r, and L, as shown on Figure 12, were determined for substitution into equation 6.10.

As explained by Fetter (1988), the radius of the well screen, R, should include the sand pack zone, as shown on Figure 12. Therefore, with an 8-inch borehole, the value of R is 4 inches, or 0.33 foot. The determination of the radius of the well screen, r, is complicated by the fact that in this slug test the water level rose in the sreened portion of the well with a sand pack around it. In this situation, as explained by Bouwer (1989), the thickness and porosity of the sand pack should be taken into account when calculating the effective value of r. This slug test was further complicated because two wells, the 4-inch-diameter well B12 and the 2-inch-diameter well B13, are installed in the same borehole. It was apparent during aquifer testing that the water-level response in each well is the same when water is removed from one of the wells. Therefore, the two wells effectively behave as one well. In order to compensate for these situations, the following calculations were used to determine the effective value of r:

Area of 4-inch-diameter well	= 12.5664 $in.^2$
Area of 2-inch-diameter well	=+ 3.1416 $in.^2$
Area of the 2 wells together	= 15.7080 $in.^2$

Area of 8-inch-diam. borehole = 50.2655 $in.^2$

Area of surrounding sand pack	= 50.2655 $in.^2$
	-15.7080 $in.^2$
	= 34.5575 $in.^2$

Assuming 30% porosity (0.30) for sand pack, effective area of sand pack	= 34.5575 * 0.3
	= 10.3672 in^2

Area of the 2 wells together	= 15.7080 $in.^2$
Effective area of sand pack	=+10.3672 $in.^2$
Effective area of wells + pack	= 26.0752 $in.^2$

$\Pi r^2 = 26.0752\ in.^2$

$r = 2.8810\ in. = 0.2401\ ft.$

The length of the well screen, L, was not considered to be the actual length of the screen because the water table was below the top of the screen during the slug test. The length, L, was calculated by subtracting the depth to the water table (9 ft.) from the depth of the well (34 ft.), which equals 25 feet. The time required for the water level to rise to 37 percent of the initial change, T_0, was obtained from the plot of H/H(0) vs. Time, and equals 60 seconds.

Hydraulic conductivity was solved for by substituting these values into equation 6.10:

$$K = \frac{r^2 * \ln(L/R)}{2 * L * T_0}$$

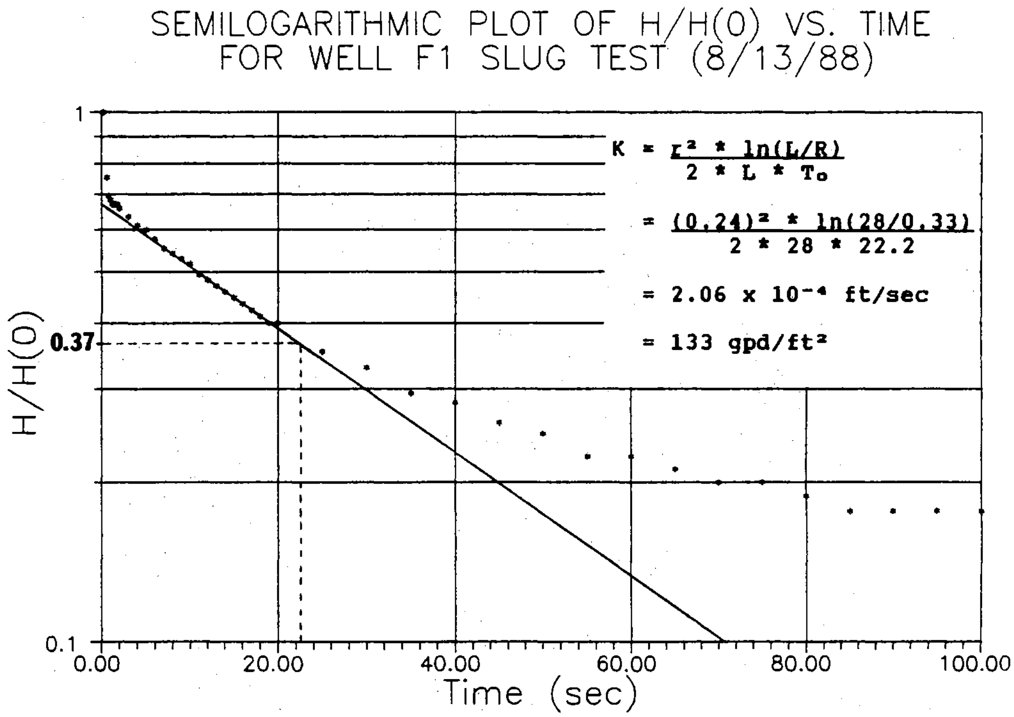
$$= \frac{(0.24)^2 * \ln(25/0.33)}{2 * 25 * 60}$$

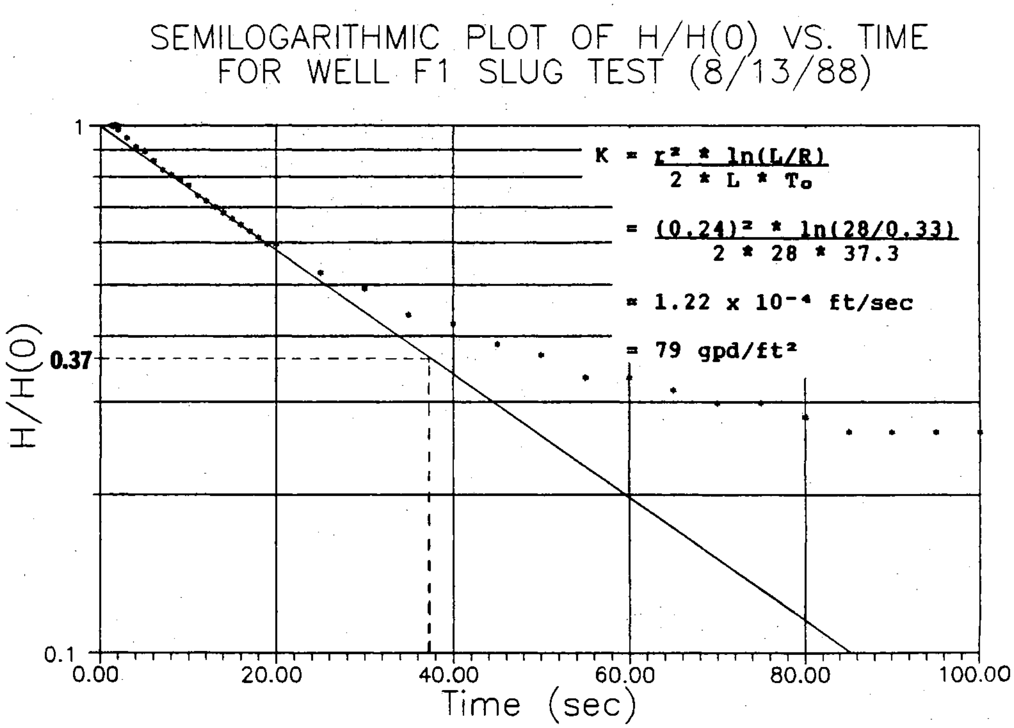
$$K = 8.31 \times 10^{-5} \text{ ft/sec}$$

$= 2.53 \times 10^{-3}$ cm/sec

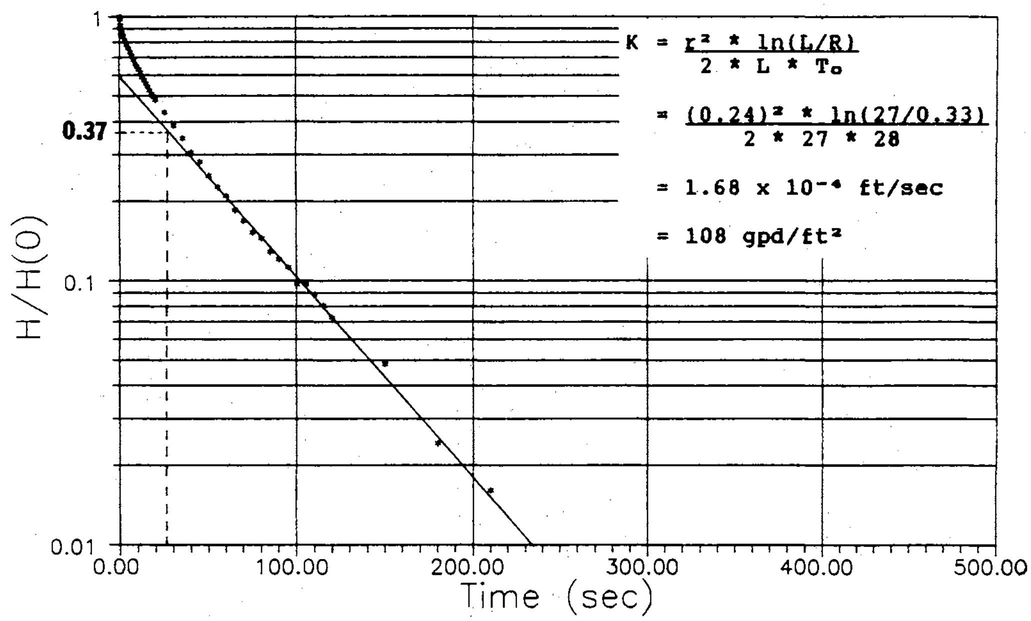
$= 53.7$ gpd/ft^2

It was observed on the plot of H/H(0) vs. Time that the data showed an initial steep decline during the first few seconds. It was hypothesized that this response was due to water quickly entering the well from storage in the sand pack when a bail of water is removed from the well. In an attempt to distinguish between the effect of the sand pack on the water-level response and that due to the surrounding formation, a different value for the initial head change, H(0), was subjectively chosen. Consequently, two analyses are shown in the appendix for each slug test. As previously discussed, the alternate values reported in Table VI were calculated using these different values of H(0).

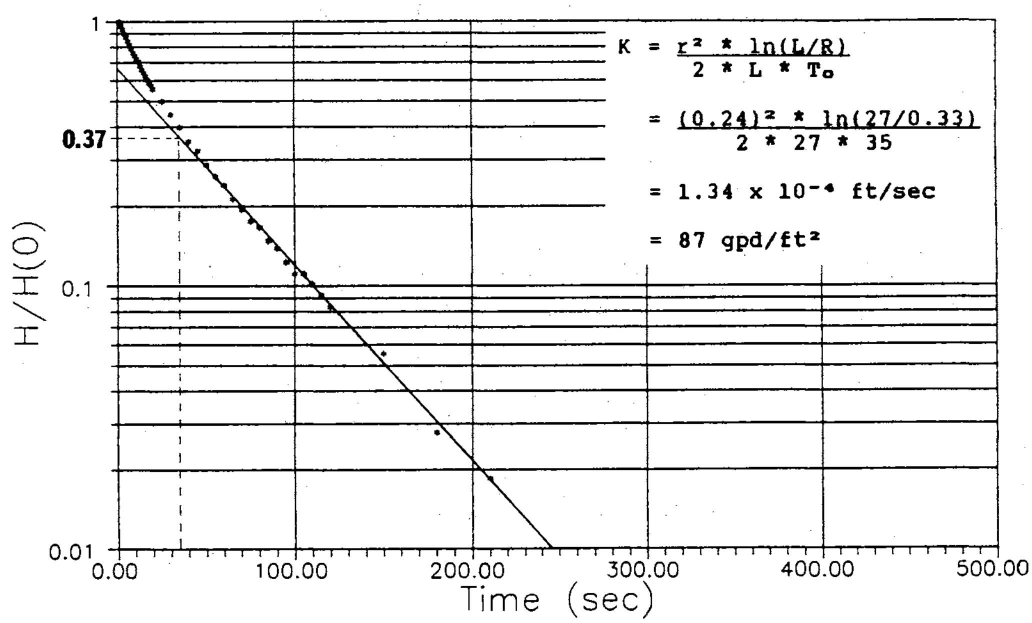

SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL F1 SLUG TEST (8/13/88)
K = r² * ln(L/R) / 2 * L * To
= (0.24)² * ln(28/0.33) / 2 * 28 * 22.2
= 2.06 x 10⁻⁴ ft/sec
= 133 gpd/ft²
H/H(0)
0.37
1
0.1
0.00
20.00
40.00
60.00
80.00
100.00
Time (sec)


SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL F1 SLUG TEST (8/13/88)
K = r² * ln(L/R) / 2 * L * To
= (0.24)² * ln(28/0.33) / 2 * 28 * 37.3
= 1.22 x 10⁻⁴ ft/sec
= 79 gpd/ft²
H/H(0)
0.37
1
0.1
0.00
20.00
40.00
60.00
80.00
100.00
Time (sec)

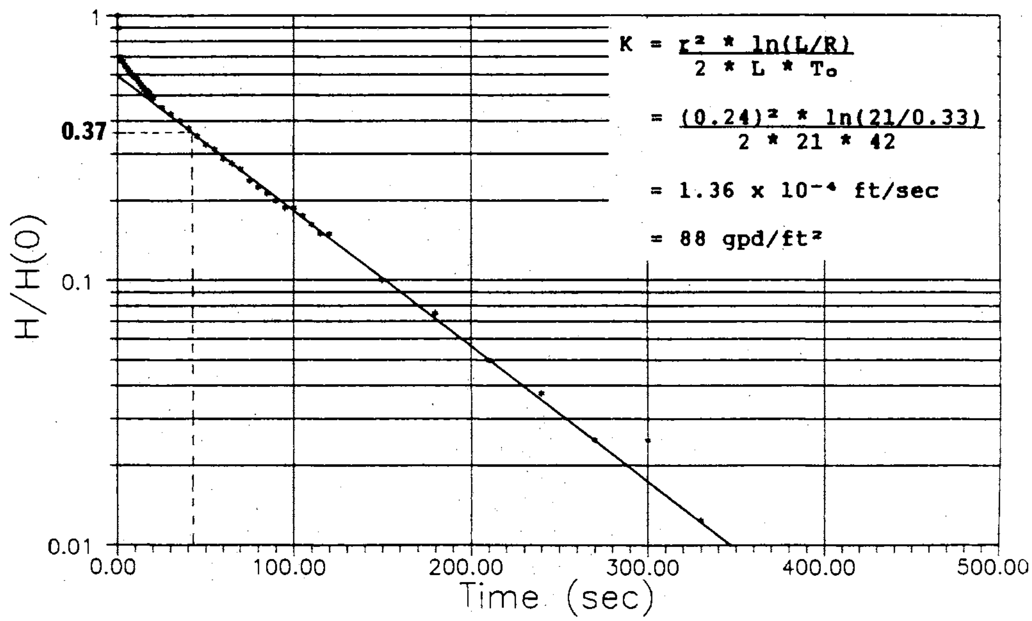
SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL F1 SLUG TEST (9/15/88)



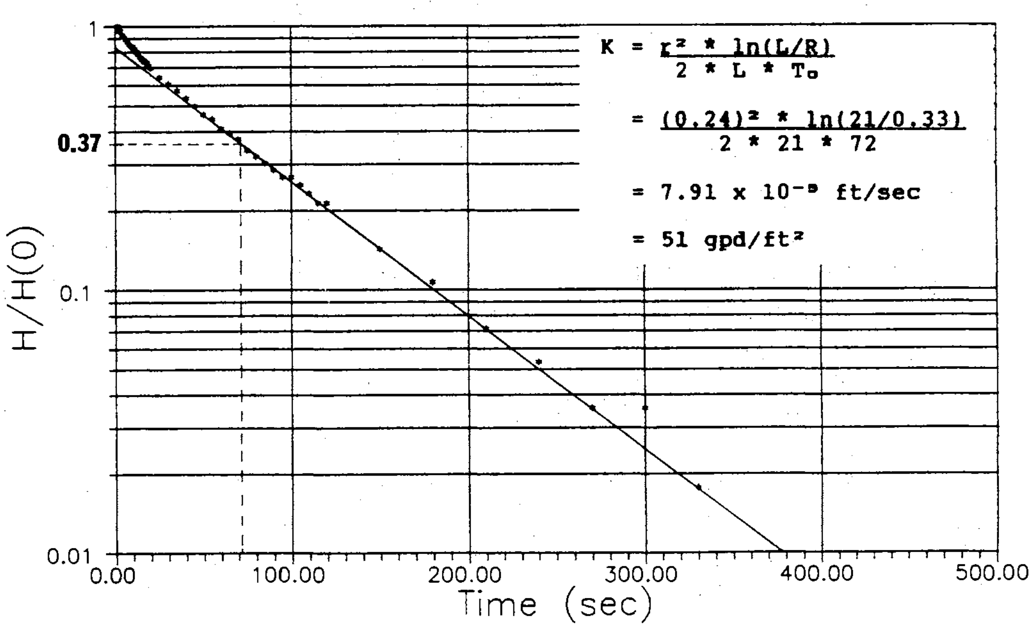
SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL F1 SLUG TEST (9/15/88)

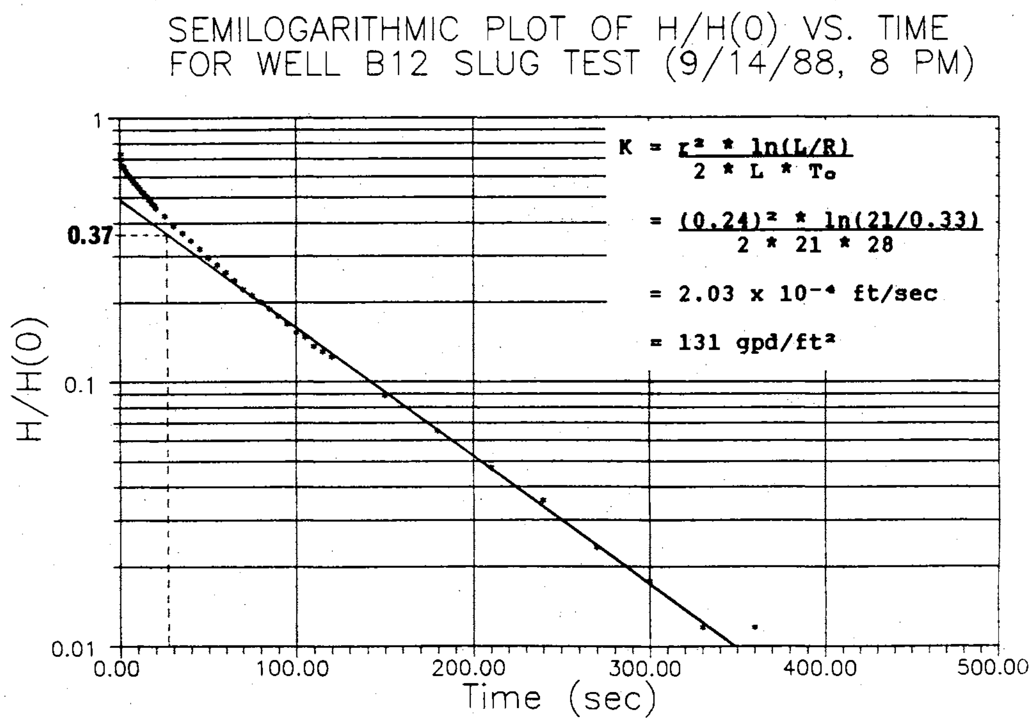


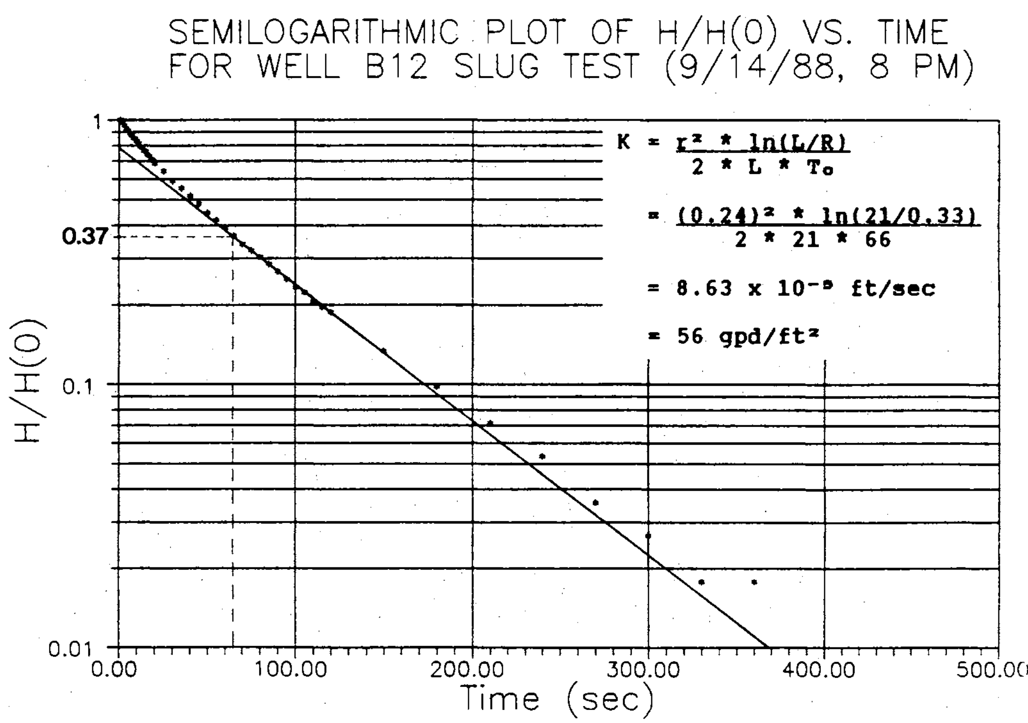
SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL B12 SLUG TEST (9/14/88, 7 PM)

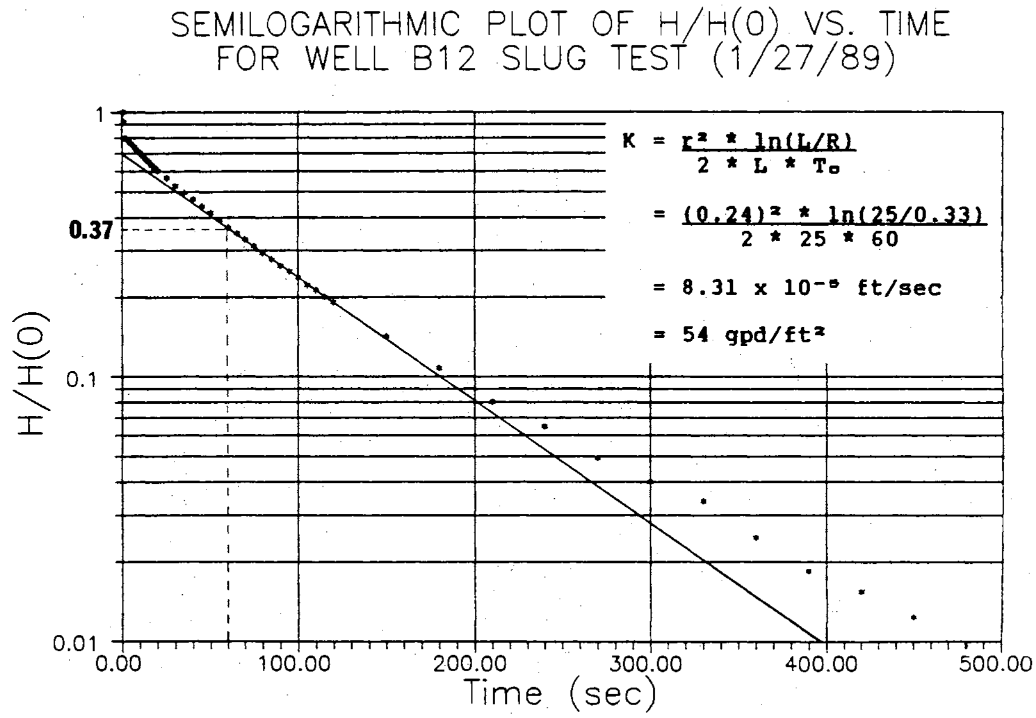


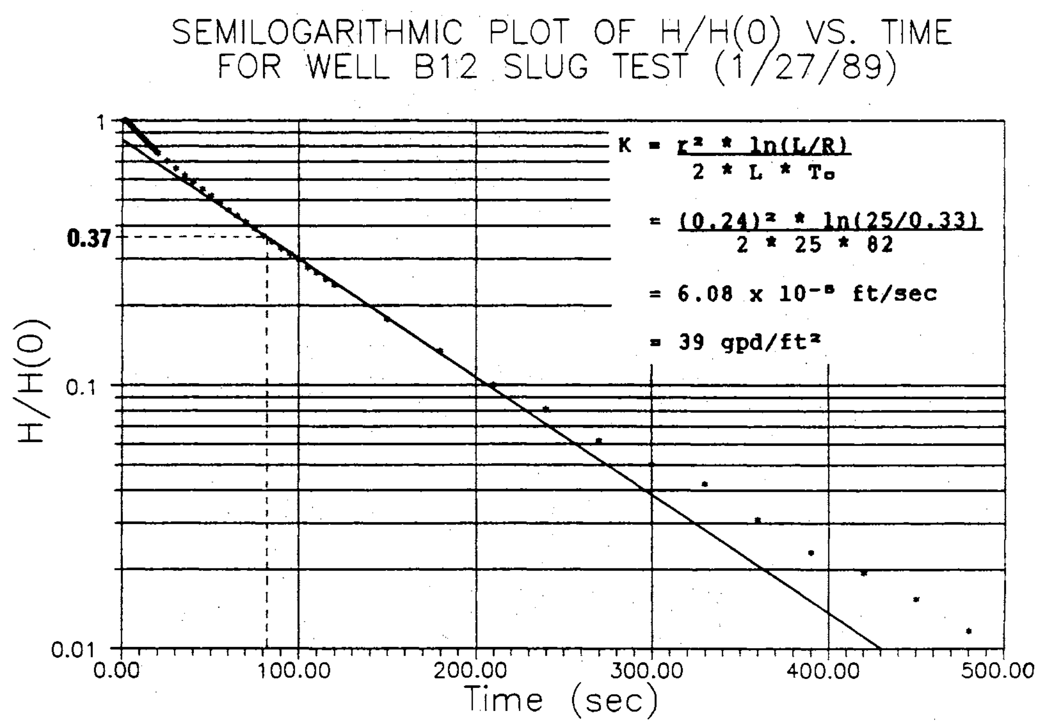
SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL B12 SLUG TEST (9/14/88, 7 PM)




SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL B12 SLUG TEST (9/14/88, 8 PM)
K = r² * ln(L/R) / 2 * L * To
= (0.24)² * ln(21/0.33) / 2 * 21 * 28
= 2.03 x 10⁻⁴ ft/sec
= 131 gpd/ft²
H/H(0)
1
0.37
0.1
0.01
0.00
100.00
200.00
300.00
400.00
500.00
Time (sec)


SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL B12 SLUG TEST (9/14/88, 8 PM)
K = r² * ln(L/R) / 2 * L * To
= (0.24)² * ln(21/0.33) / 2 * 21 * 66
= 8.63 x 10⁻⁵ ft/sec
= 56 gpd/ft²
H/H(0)
1
0.37
0.1
0.01
0.00
100.00
200.00
300.00
400.00
500.00
Time (sec)


SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL B12 SLUG TEST (1/27/89)
K = r² * ln(L/R) / 2 * L * To
= (0.24)² * ln(25/0.33) / 2 * 25 * 60
= 8.31 x 10⁻⁵ ft/sec
= 54 gpd/ft²
0.37
H/H(0)
1
0.1
0.01
0.00
100.00
200.00
300.00
400.00
500.00
Time (sec)


SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL B12 SLUG TEST (1/27/89)
K = r² * ln(L/R) / 2 * L * To
= (0.24)² * ln(25/0.33) / 2 * 25 * 82
= 6.08 x 10⁻⁵ ft/sec
= 39 gpd/ft²
0.37
H/H(0)
1
0.1
0.01
0.00
100.00
200.00
300.00
400.00
500.00
Time (sec)

Cooper and others (1967) Method

The following is an example of the Cooper and others (1967) method used to analyze data from the slug test on well B12 on January 27, 1989. This method is also decribed by Fetter (1989). Values of H/H(0) were plotted, on an arithmetic scale, versus Time, on a logarithmic scale, as shown on the figure in this appendix. Type curves presented by Papadopulos and others, shown on Figure 14, were overlain on top of this plot and the data were matched to one of the type curves by moving the type curves horizontally, while keeping the arithmetic axes coincident. The vertical time-axis, t_1, which is overlain by the vertical axis for $Tt/r_c^2 = 1.0$ for the type curves, was then selected. This value was determined to be 41 seconds.

As explained in the section of the appendix which discusses the Hvorslev (1951) method, the radius of the well casing, r_c should incorporate the influence of the sand pack because the water level during the slug test was in the screened zone of the well. Also, the 2-inch well in the same borehole must be compensated for. Taking these considerations into account, the effective radius of the well screen/casing was found to be 0.24 ft. or 7.32 cm. Plugging these values into equation 6.11, we obtain:

$$K = \frac{1.0 * r_c^2}{t_1}$$

$$= \frac{1.0\ (7.32\ \text{cm})^2}{41\ \text{sec}}$$

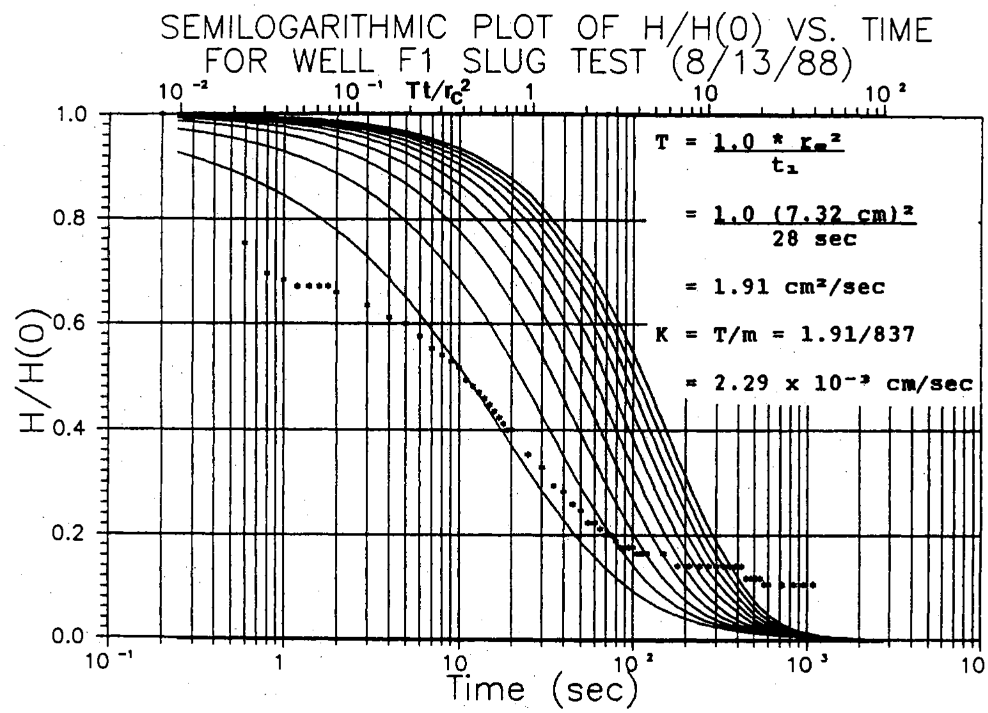
$$K = 1.31\ \text{cm}^2/\text{sec}$$

K = T/aquifer thickness, m

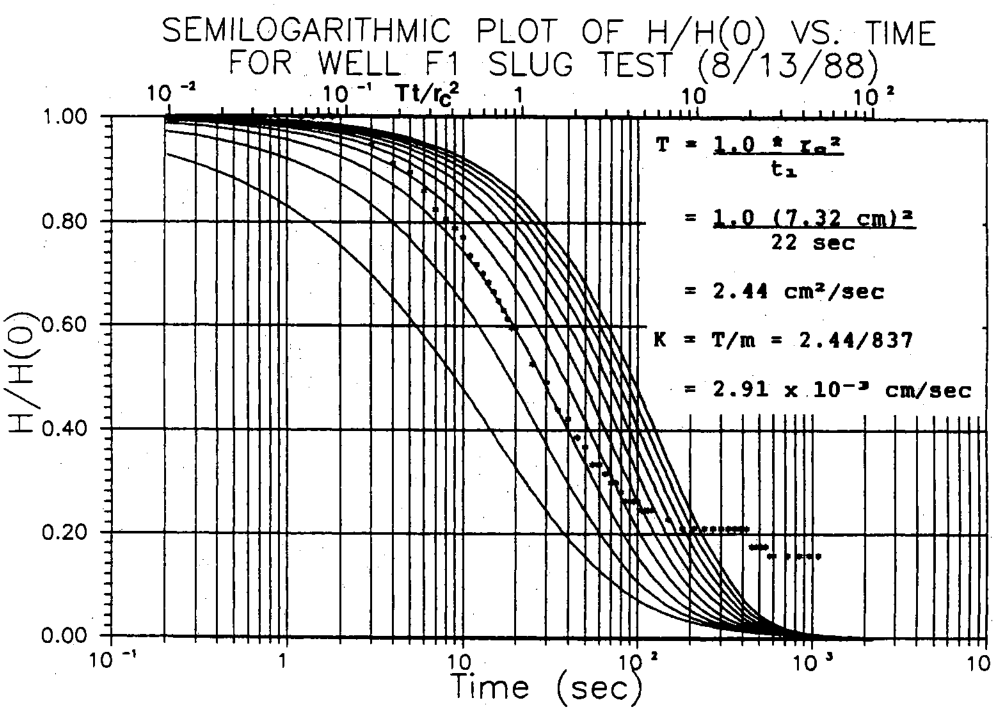
K = 1.31/765 cm

$K = 1.71 \times 10^{-3}$ cm/sec

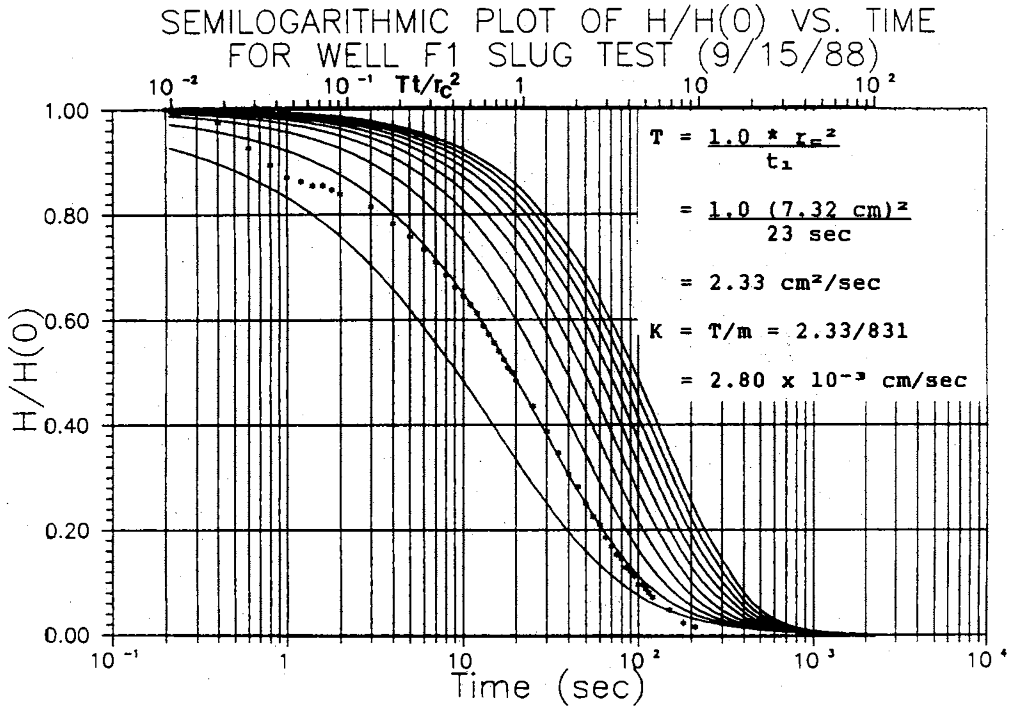
As explained in the discussion of the Hvorslev (1951) method in this appendix, an alternate value of H/H(0) also was chosen for each slug test. The analyses of the slug tests using the Cooper and others (1967) method are presented on the following pages.

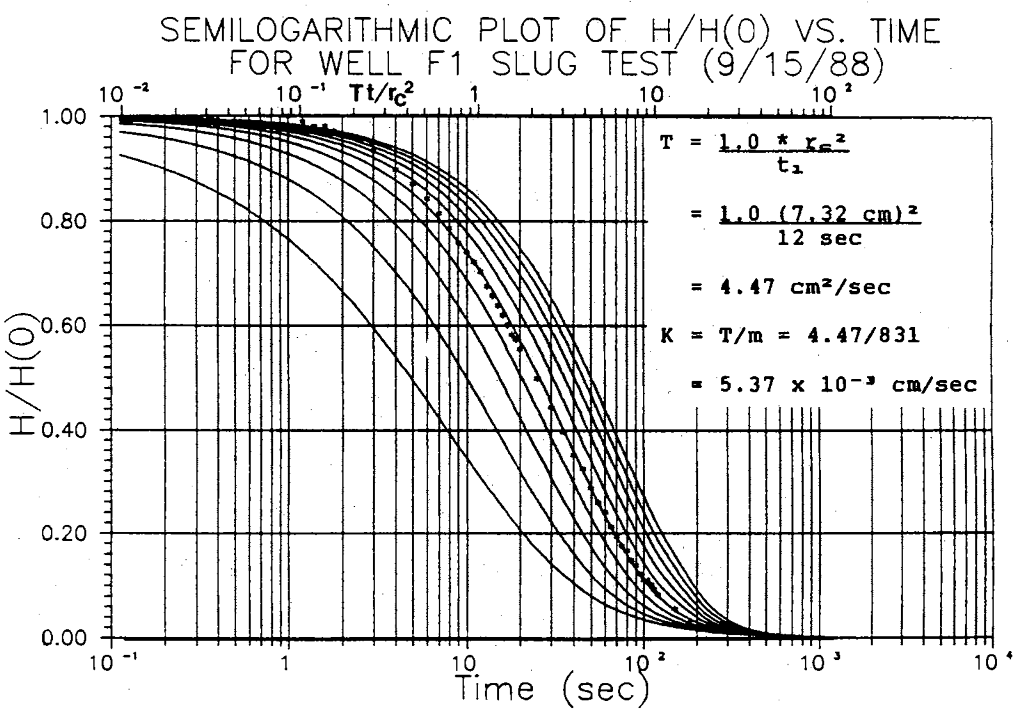


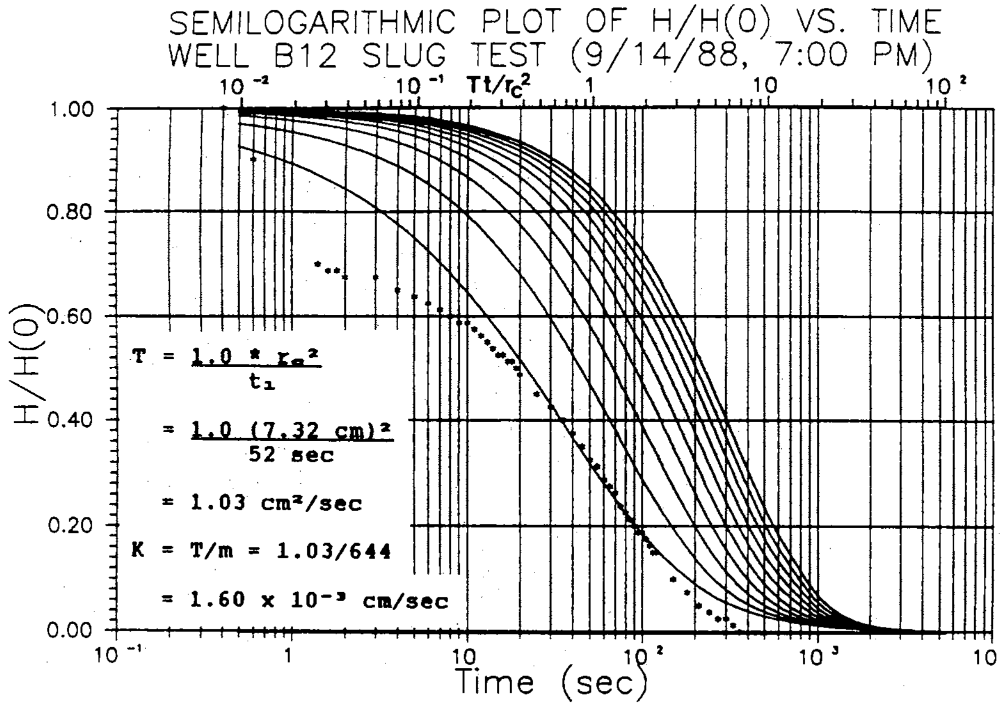
SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL F1 SLUG TEST (8/13/88)
Tt/rc²
T = 1.0 * rc² / t₁
= 1.0 (7.32 cm)² / 28 sec
= 1.91 cm²/sec
K = T/m = 1.91/837
= 2.29 x 10⁻³ cm/sec
H/H(0)
Time (sec)

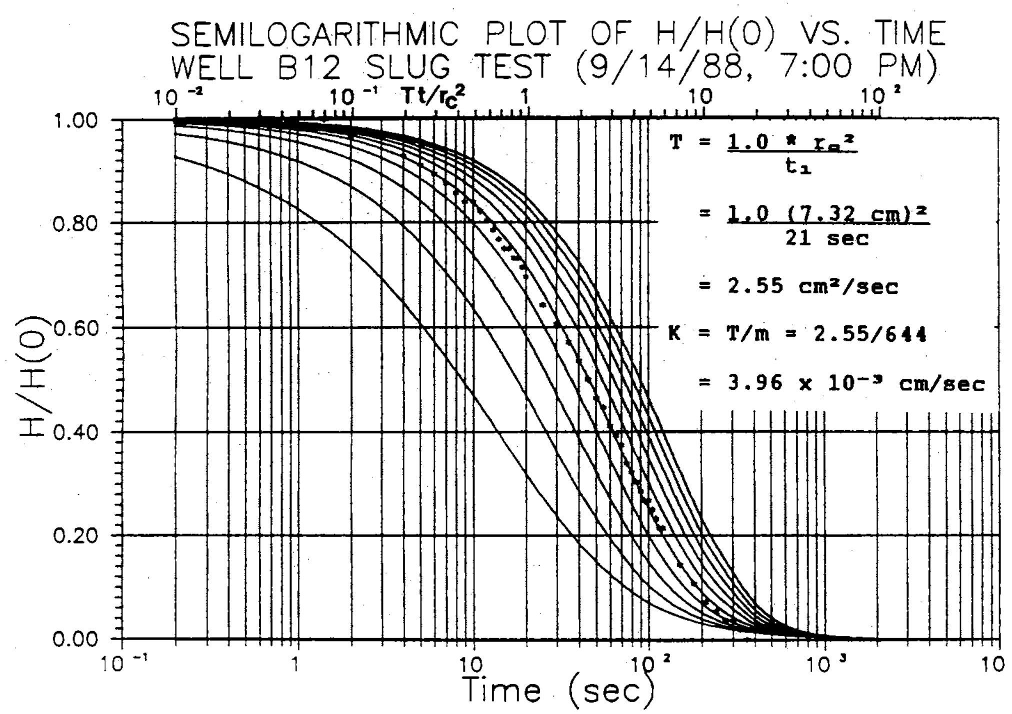


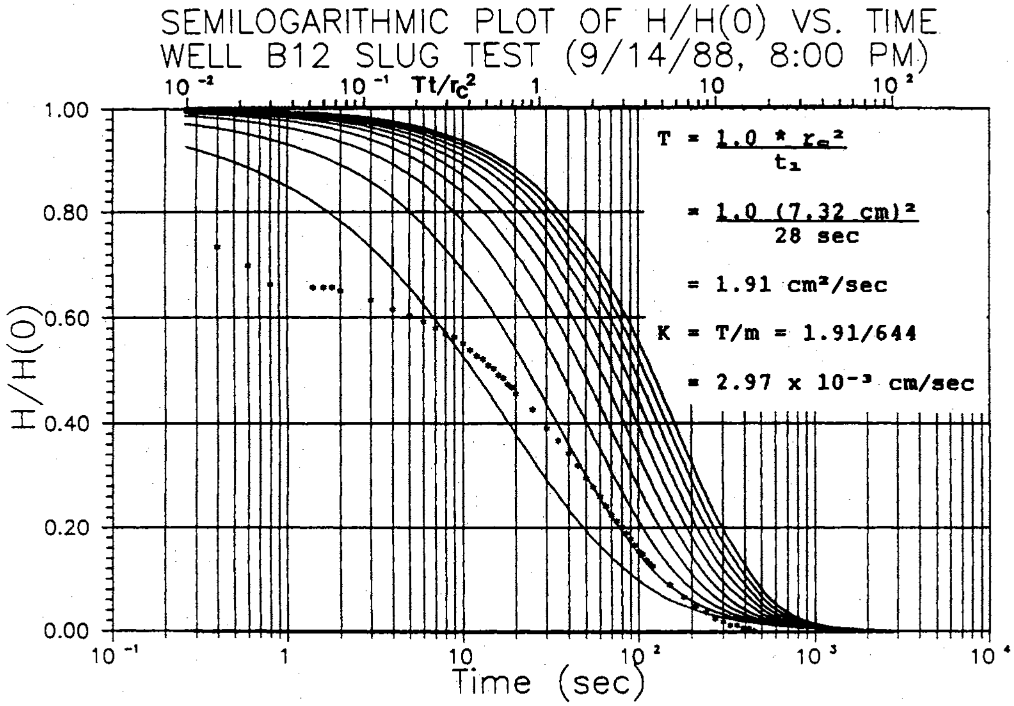
SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL F1 SLUG TEST (8/13/88)
Tt/rc²
T = 1.0 * rc² / t₁
= 1.0 (7.32 cm)² / 22 sec
= 2.44 cm²/sec
K = T/m = 2.44/837
= 2.91 x 10⁻³ cm/sec
H/H(0)
Time (sec)

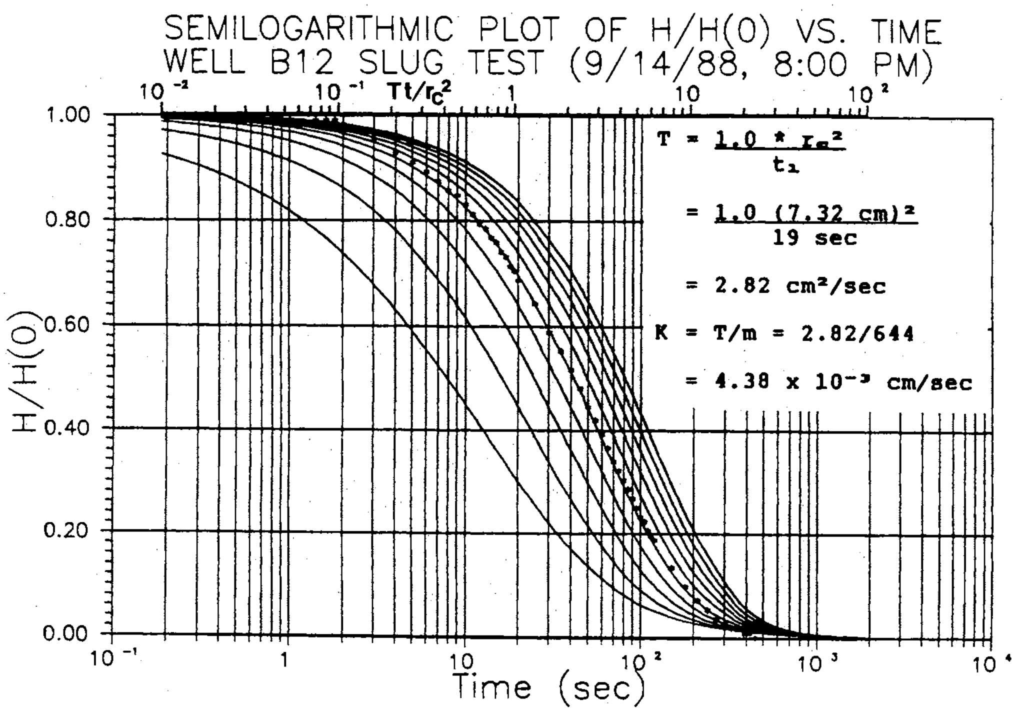

SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL F1 SLUG TEST (9/15/88)
Tt/rc²
H/H(0)
Time (sec)
T = 1.0 * rc² / t1
= 1.0 (7.32 cm)² / 23 sec
= 2.33 cm²/sec
K = T/m = 2.33/831
= 2.80 x 10⁻³ cm/sec

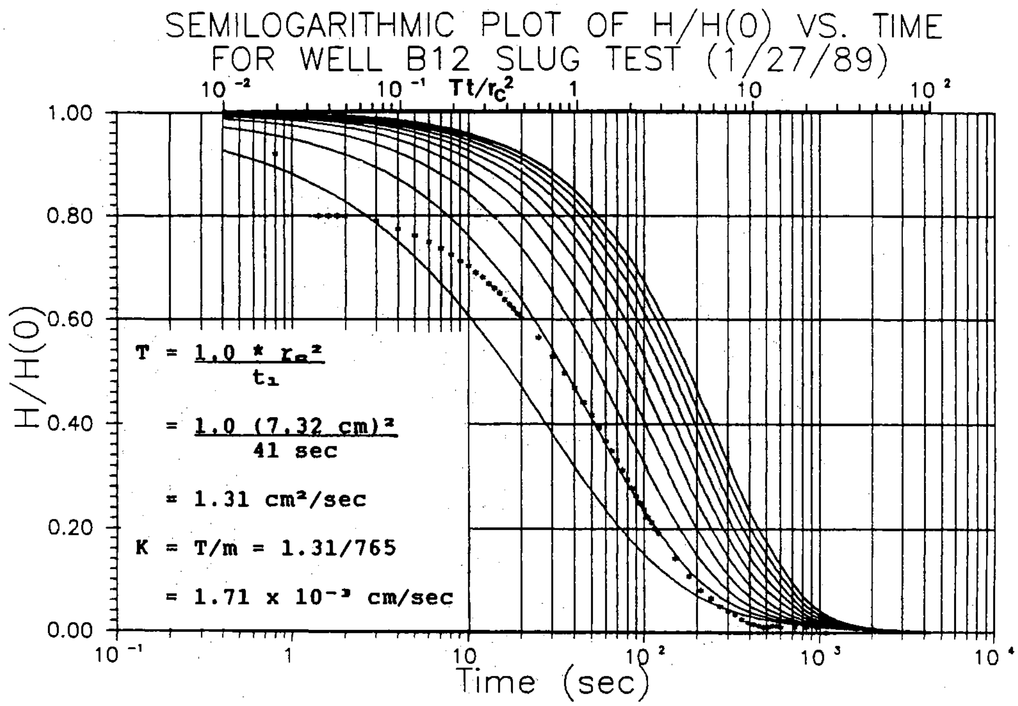

SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL F1 SLUG TEST (9/15/88)
Tt/rc²
H/H(0)
Time (sec)
T = 1.0 * rc² / t1
= 1.0 (7.32 cm)² / 12 sec
= 4.47 cm²/sec
K = T/m = 4.47/831
= 5.37 x 10⁻³ cm/sec

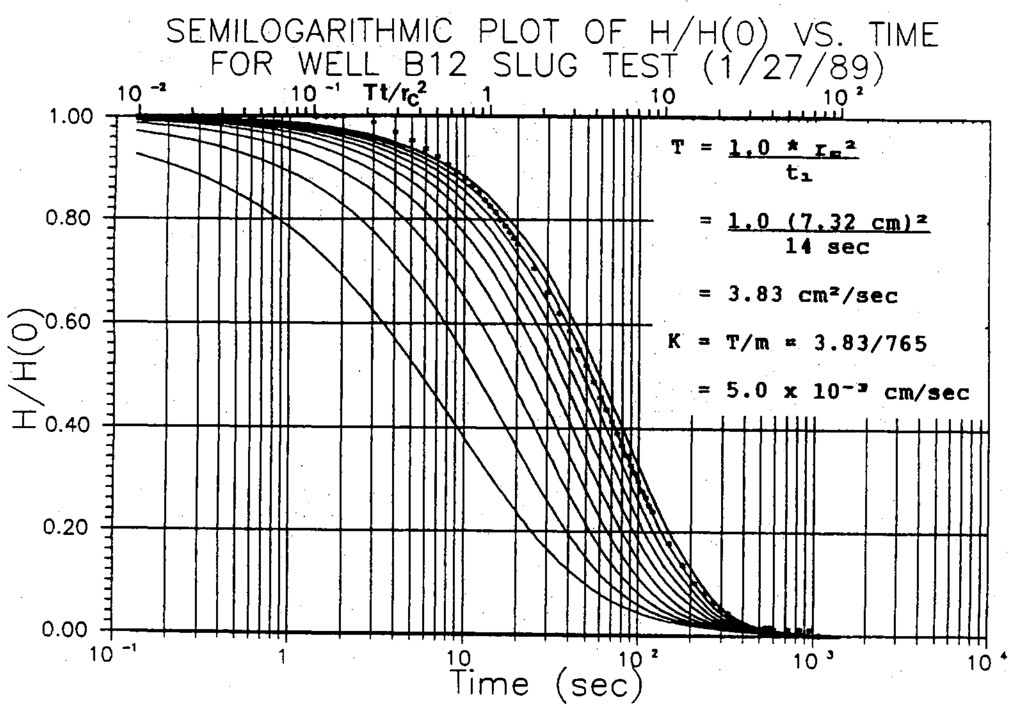

SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
WELL B12 SLUG TEST (9/14/88, 7:00 PM)
Tt/rc²
H/H(0)
Time (sec)
T = 1.0 * rc² / t₁
= 1.0 (7.32 cm)² / 52 sec
= 1.03 cm²/sec
K = T/m = 1.03/644
= 1.60 x 10⁻³ cm/sec


SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
WELL B12 SLUG TEST (9/14/88, 7:00 PM)
Tt/rc²
H/H(0)
Time (sec)
T = 1.0 * rc² / t₁
= 1.0 (7.32 cm)² / 21 sec
= 2.55 cm²/sec
K = T/m = 2.55/644
= 3.96 x 10⁻³ cm/sec


SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
WELL B12 SLUG TEST (9/14/88, 8:00 PM)
Tt/rc²
H/H(0)
Time (sec)
T = 1.0 * rc² / t1
= 1.0 (7.32 cm)² / 28 sec
= 1.91 cm²/sec
K = T/m = 1.91/644
= 2.97 x 10⁻³ cm/sec


SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
WELL B12 SLUG TEST (9/14/88, 8:00 PM)
Tt/rc²
H/H(0)
Time (sec)
T = 1.0 * rc² / t1
= 1.0 (7.32 cm)² / 19 sec
= 2.82 cm²/sec
K = T/m = 2.82/644
= 4.38 x 10⁻³ cm/sec


SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL B12 SLUG TEST (1/27/89)
Tt/r_c^2
H/H(0)
Time (sec)
T = 1.0 * r_c^2 / t_1
= 1.0 (7.32 cm)^2 / 41 sec
= 1.31 cm^2/sec
K = T/m = 1.31/765
= 1.71 x 10^-3 cm/sec


SEMILOGARITHMIC PLOT OF H/H(0) VS. TIME
FOR WELL B12 SLUG TEST (1/27/89)
Tt/r_c^2
H/H(0)
Time (sec)
T = 1.0 * r_c^2 / t_1
= 1.0 (7.32 cm)^2 / 14 sec
= 3.83 cm^2/sec
K = T/m = 3.83/765
= 5.0 x 10^-3 cm/sec

Bouwer and Rice (1976) Method

The following is an example of the methodology used to calculate hydraulic conductivity using the procedure described by Bouwer and Rice (1976). Water-level recovery data from a slug test on well B12 on January 27, 1989 was plotted with y_t, in meters, on a logarithmic axis, versus t, in seconds, on an arithmetic axis, as shown in this section of appendix D. Bouwer (1989) explains that the sand pack around a well screen can cause a double straight line effect in which there are two straight line portions to the graph. The first straight line portion at large y and small t is probably due to water quickly entering the well from the sand pack and should be ignored when choosing the appropriate straight line portion. In addition, the author explains that the data points typically deviate from a straight line for large t and small y because drawdown of the water-table around the well becomes increasingly significant as the test progresses. Therefore, only the straight line segment of the data points should be used to determine $[\ln(y_0/y_t)]/t$ for calculation of K with equation 6.12. In consideration of these factors a straight line portion of the graph was chosen as shown on the appendix figure.

In order to calculate $1/t \ln(y_0/y_t)$ for the straight line portion chosen, two values of y on the straight line and their corresponding values of t were read from the plot. The coordinates chosen were ($t = 0$, $y_t = 0.72$) and

(t = 382, y_t = 0.01). Then, the natural logarithm of the ratio y_0/y_t was calculated and divided by the difference between the two values of t as follows:

$$1/t \ln(y_0/y_t) = 1/382 \ln(0.72/0.01) = 0.0112 \text{ m/sec}$$

The value of $\ln(R_e/r_w)$ was calculated using equation 6.13,

where (see Figure 15):

$H = 43 \text{ ft} - 8.90 \text{ ft} = 34.10 \text{ ft} = 10.3937 \text{ m}$

$L_w = 34 \text{ ft} - 8.90 \text{ ft} = 25.10 \text{ ft} = 7.6505 \text{ m}$

$L_e = 34 \text{ ft} - 8.90 \text{ ft} = 25.10 \text{ ft} = 7.6505 \text{ m}$

$r_w = 0.1016 \text{ m}$ (4 inches)

$L_e/r_w = 7.6505/0.1016 = 75.30$

The dimensionless parameters, A and B were then obtained from Figure 16,

where:

A = 1.2

B = 0.63

Plugging the above values into equation 6.13, we obtain:

$$\ln R_e/r_w = \cfrac{1}{\cfrac{1.1}{\ln 75.3} + \cfrac{1.2 + 0.63\ln[(10.3937-7.6505)/0.0106]}{75.30}}$$

$$= 3.3556$$

Finally, solving for K with equation 6.12,

where

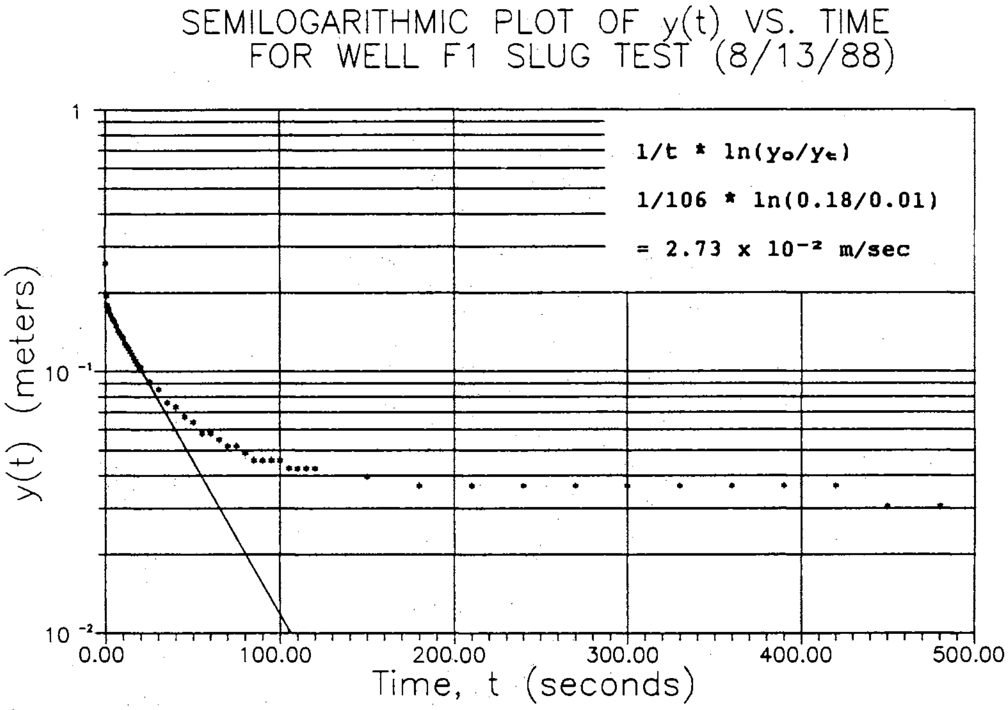
r_c = 0.0732 m (0.24 ft, as explained in Hvorslev (1951) section of this appendix)

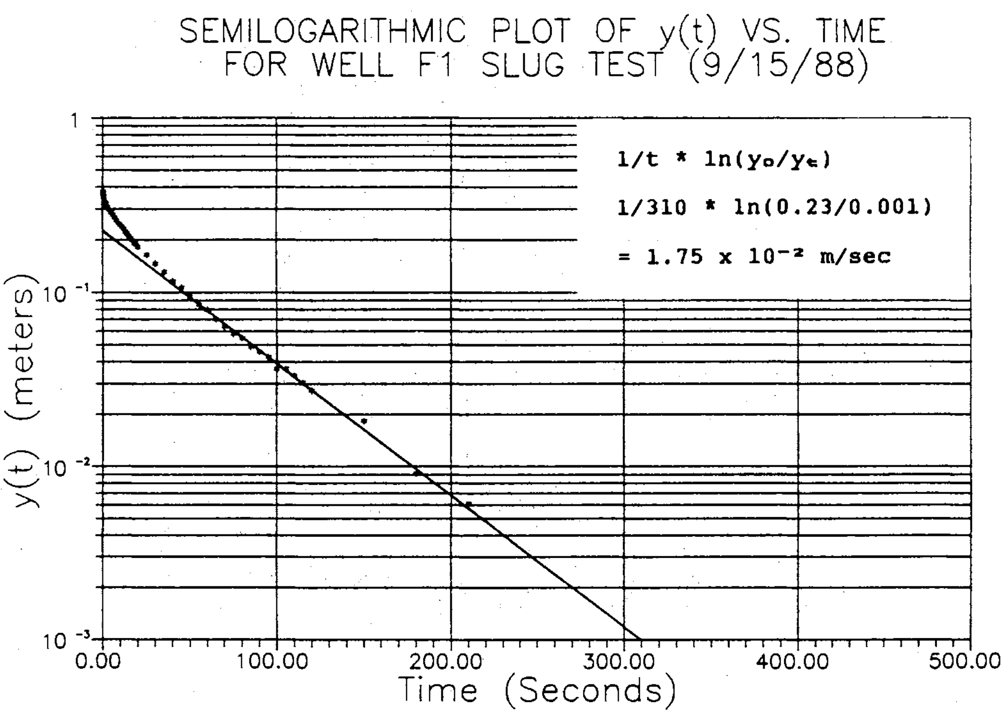
$$K = \frac{(0.0732)^2\ (3.3556)}{2\ (7.6505)} * 0.0112$$

$$= 1.32 \times 10^{-5} \text{ m/sec}$$

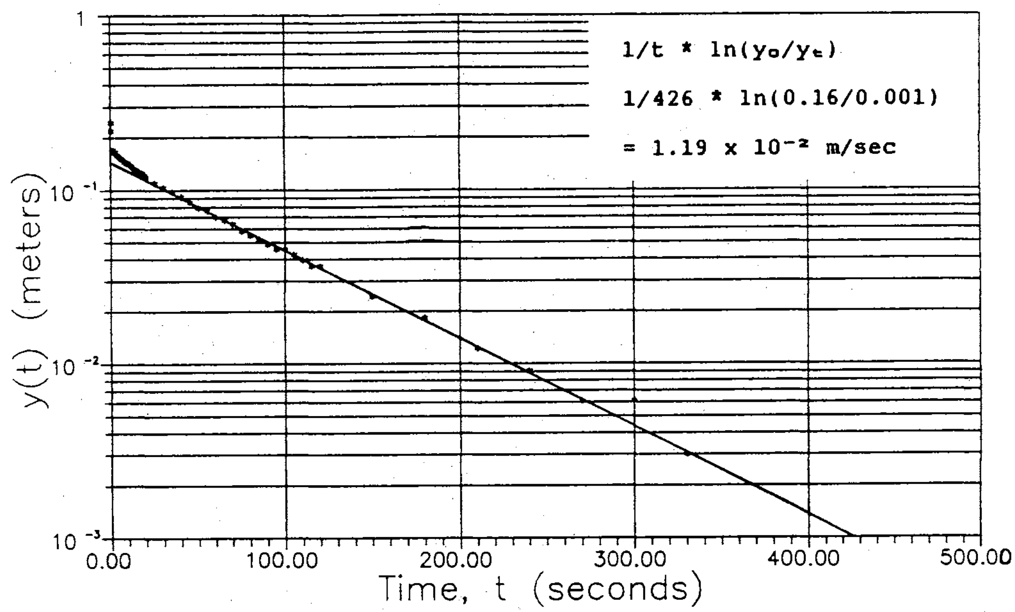
$= 1.32 \times 10^{-3}$ cm/sec

$= 27.90$ gpd/ft^2

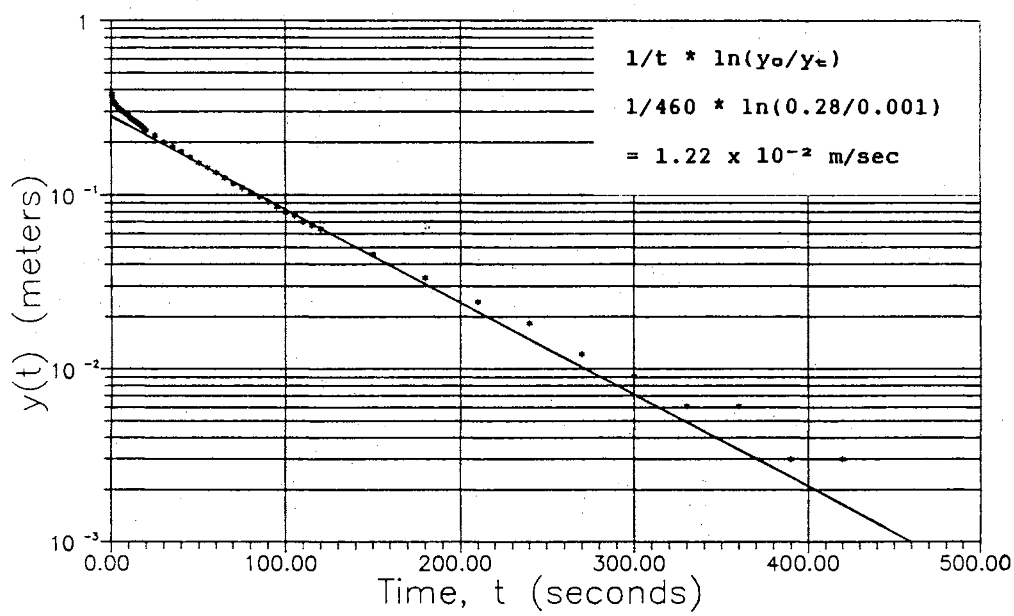

SEMILOGARITHMIC PLOT OF y(t) VS. TIME
FOR WELL F1 SLUG TEST (8/13/88)
1/t * ln(yo/yt)
1/106 * ln(0.18/0.01)
= 2.73 x 10⁻² m/sec
y(t) (meters)
1
10 ⁻¹
10 ⁻²
0.00
100.00
200.00
300.00
400.00
500.00
Time, t (seconds)


SEMILOGARITHMIC PLOT OF y(t) VS. TIME
FOR WELL F1 SLUG TEST (9/15/88)
1/t * ln(yo/yt)
1/310 * ln(0.23/0.001)
= 1.75 x 10⁻² m/sec
y(t) (meters)
1
10 ⁻¹
10 ⁻²
10 ⁻³
0.00
100.00
200.00
300.00
400.00
500.00
Time (Seconds)

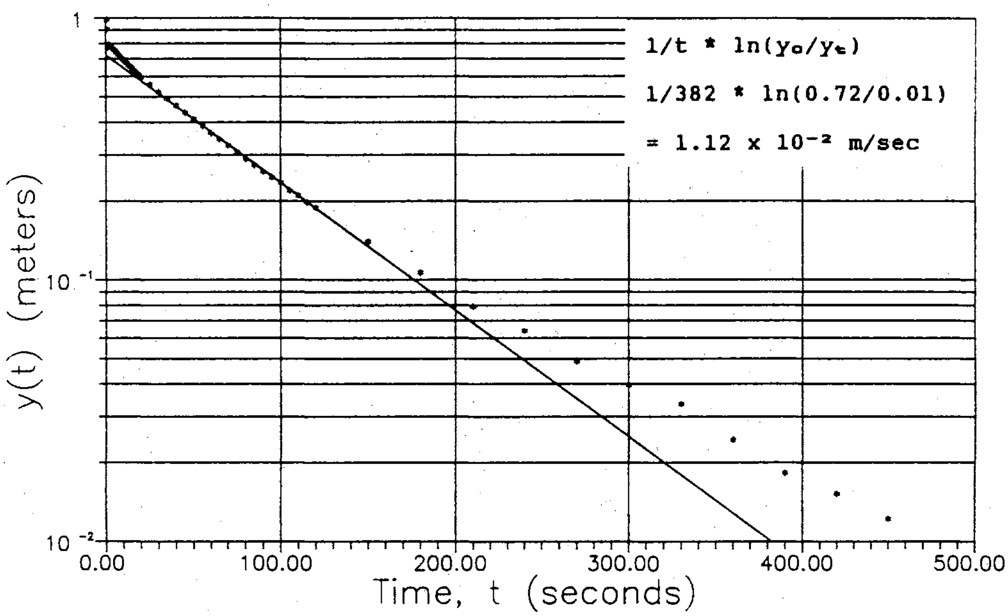
SEMILOGARITHMIC PLOT OF y(t) VS. TIME
WELL B12 SLUG TEST (9/14/88, 7 PM)



SEMILOGARITHMIC PLOT OF Y(t) VS. TIME
WELL B12 SLUG TEST (9/14/88, 8 PM)



SEMILOGARITHMIC PLOT OF Y(t) VS. TIME
FOR WELL B12 SLUG TEST (1/27/89)



Nguyen and Pinder (1984) Method

The following is an example of the methodology used for the Nguyen and Pinder (1984) analyses. Data from a slug test on Well B12 on January 27, 1989 was tabulated with columns for time, t (sec), H(t) (cm), $\Delta H/\Delta t$, and 1/t (1/sec), as shown in the table in this section of the appendix. Plots of log h(t) versus log t and log $-\Delta H/\Delta t$ versus 1/t were created, as shown in this appendix. The slopes, C_1 and C_2 were determined to be -1.02×10^{-2} and 2.17, respectively. The effective distance, r_c, was determined to be 7.32 cm (0.24 ft., taking into account the sand pack and the 2-inch well in the same borehole, as explained in the Hvorslev (1951) method section of appendix D. The lengths, z_1 and z_2, were 271 cm and 1,036 cm, respectively. Plugging these values into equation 6.14:

$$K = \frac{(7.32)^2\ (1.02 \times 10^{-2})}{4\ (2.17)\ (1{,}036 - 271)}$$

$$= 8.23 \times 10^{-5} \text{ cm/sec}$$

$$= 1.74 \text{ gpd/ft}^2$$

Well F1 Slug Test (8/13/88)
0.29 gal. removed with bailer.
Nguyen and Pinder (1984) Analysis

Elapsed Time, t (sec)	Depth to Water, H(t) (cm)	ΔH/Δt (cm/sec)	1/t (1/sec)
0.2	407.82		5.0000
0.6	401.42	-16.0000	1.6667
0.8	399.90	-7.6000	1.2500
1	399.59	-1.5500	1.0000
1.2	399.29	-1.5000	0.8333
1.4	399.29	0.0000	0.7143
1.6	399.29	0.0000	0.6250
1.8	399.29	0.0000	0.5556
2	398.98	-1.5500	0.5000
3	398.37	-0.6100	0.3333
4	397.76	-0.6100	0.2500
5	397.46	-0.3000	0.2000
6	396.85	-0.6100	0.1667
7	396.24	-0.6100	0.1429
8	395.94	-0.3000	0.1250
9	395.63	-0.3100	0.1111
10	395.33	-0.3000	0.1000
11	394.72	-0.6100	0.0909
12	394.41	-0.3100	0.0833
13	394.11	-0.3000	0.0769
14	393.80	-0.3100	0.0714
15	393.50	-0.3000	0.0667
16	393.19	-0.3100	0.0625
17	392.89	-0.3000	0.0588
18	392.58	-0.3100	0.0556
19	392.28	-0.3000	0.0526
20	392.28	0.0000	0.0500
25	391.06	-0.2440	0.0400
30	390.45	-0.1220	0.0333
35	389.53	-0.1840	0.0286
40	389.23	-0.0600	0.0250
45	388.62	-0.1220	0.0222
50	388.32	-0.0600	0.0200
55	387.71	-0.1220	0.0182
60	387.71	0.0000	0.0167
65	387.40	-0.0620	0.0154
70	387.10	-0.0600	0.0143
75	387.10	0.0000	0.0133
80	386.79	-0.0620	0.0125
85	386.49	-0.0600	0.0118
90	386.49	0.0000	0.0111

95	386.49	0.0000	0.0105
100	386.49	0.0000	0.0100
105	386.18	-0.0620	0.0095
110	386.18	0.0000	0.0091
115	386.18	0.0000	0.0087
120	386.18	0.0000	0.0083
150	385.88	-0.0100	0.0067
180	385.57	-0.0103	0.0056
210	385.57	0.0000	0.0048
240	385.57	0.0000	0.0042
270	385.57	0.0000	0.0037
300	385.57	0.0000	0.0033
330	385.57	0.0000	0.0030
360	385.57	0.0000	0.0028
390	385.57	0.0000	0.0026
420	385.57	0.0000	0.0024
450	384.96	-0.0203	0.0022
480	384.96	0.0000	0.0021
510	384.96	0.0000	0.0020
540	384.96	0.0000	0.0019
570	384.66	-0.0100	0.0018
600	384.66	0.0000	0.0017
720	384.66	0.0000	0.0014
840	384.66	0.0000	0.0012
960	384.66	0.0000	0.0010
1080	384.66	0.0000	0.0009

Well F1 Slug Test (9/15/88)
0.79 gal. removed with bailer.
Nguyen and Pinder (1984) Analysis

Elapsed Time, t (sec)	Depth to Water H(t) (cm)	$\Delta H/\Delta t$ (cm/sec)	1/t (1/sec)
0.2	425.81		5.0000
0.4	424.89	-4.6000	2.5000
0.6	423.06	-9.1500	1.6667
0.8	421.84	-6.1000	1.2500
1	420.93	-4.5500	1.0000
1.2	420.62	-1.5500	0.8333
1.4	420.32	-1.5000	0.7143
1.6	420.32	0.0000	0.6250
1.8	420.01	-1.5500	0.5556
2	419.71	-1.5000	0.5000
3	418.80	-0.9100	0.3333
4	417.58	-1.2200	0.2500
5	416.66	-0.9200	0.2000
6	415.75	-0.9100	0.1667
7	414.83	-0.9200	0.1429
8	413.92	-0.9100	0.1250
9	413.00	-0.9200	0.1111
10	412.39	-0.6100	0.1000
11	411.78	-0.6100	0.0909
12	411.18	-0.6000	0.0833
13	410.26	-0.9200	0.0769
14	409.65	-0.6100	0.0714
15	409.04	-0.6100	0.0667
16	408.43	-0.6100	0.0625
17	407.82	-0.6100	0.0588
18	407.21	-0.6100	0.0556
19	406.91	-0.3000	0.0526
20	406.30	-0.6100	0.0500
25	404.47	-0.3660	0.0400
30	402.64	-0.3660	0.0333
35	401.12	-0.3040	0.0286
40	399.59	-0.3060	0.0250
45	398.68	-0.1820	0.0222
50	397.46	-0.2440	0.0200
55	396.54	-0.1840	0.0182
60	395.94	-0.1200	0.0167
65	395.02	-0.1840	0.0154
70	394.41	-0.1220	0.0143
75	393.80	-0.1220	0.0133
80	393.50	-0.0600	0.0125
85	392.89	-0.1220	0.0118

90	392.58	-0.0620	0.0111
95	392.28	-0.0600	0.0105
100	391.67	-0.1220	0.0100
105	391.67	0.0000	0.0095
110	391.36	-0.0620	0.0091
115	391.06	-0.0600	0.0087
120	390.75	-0.0620	0.0083
150	389.84	-0.0303	0.0067
180	388.92	-0.0307	0.0056
210	388.62	-0.0100	0.0048
240	388.01	-0.0203	0.0042

Well B12 Slug Test (9/14/88, 7:00 PM)
0.29 gal. removed with bailer.
Nguyen and Pinder (1984) Analysis

Elapsed Time, t (sec)	Depth to Water, H(t) (cm)	△H/△t (cm/sec)	1/t (1/sec)
0.4	416.66		2.5000
0.6	414.22	-12.2000	1.6667
1.4	409.35	-6.0875	0.7143
1.6	409.04	-1.5500	0.6250
1.8	409.04	0.0000	0.5556
2	408.74	-1.5000	0.5000
3	408.74	0.0000	0.3333
4	408.13	-0.6100	0.2500
5	407.82	-0.3100	0.2000
6	407.52	-0.3000	0.1667
7	407.21	-0.3100	0.1429
8	406.91	-0.3000	0.1250
9	406.60	-0.3100	0.1111
10	406.60	0.0000	0.1000
11	406.30	-0.3000	0.0909
12	405.99	-0.3100	0.0833
13	405.69	-0.3000	0.0769
14	405.38	-0.3100	0.0714
15	405.08	-0.3000	0.0667
16	405.08	0.0000	0.0625
17	404.77	-0.3100	0.0588
18	404.77	0.0000	0.0556
19	404.47	-0.3000	0.0526
20	404.16	-0.3100	0.0500
25	403.25	-0.1820	0.0400
30	402.64	-0.1220	0.0333
35	402.03	-0.1220	0.0286
40	401.42	-0.1220	0.0250
45	400.81	-0.1220	0.0222
50	400.20	-0.1220	0.0200
55	399.90	-0.0600	0.0182
60	399.29	-0.1220	0.0167
65	398.98	-0.0620	0.0154
70	398.68	-0.0600	0.0143
75	398.07	-0.1220	0.0133
80	397.76	-0.0620	0.0125
85	397.46	-0.0600	0.0118
90	397.15	-0.0620	0.0111
95	396.85	-0.0600	0.0105
100	396.85	0.0000	0.0100

105	396.54	-0.0620	0.0095
110	396.24	-0.0600	0.0091
115	395.94	-0.0600	0.0087
120	395.94	0.0000	0.0083
150	394.72	-0.0407	0.0067
180	394.11	-0.0203	0.0056
210	393.50	-0.0203	0.0048
240	393.19	-0.0103	0.0042
270	392.89	-0.0100	0.0037
300	392.89	0.0000	0.0033
330	392.58	-0.0103	0.0030
360	392.28	-0.0100	0.0028

Well B12 Slug Test (9/14/88, 8:00 PM)
0.79 gal. removed with bailer.
Nguyen and Pinder (1984) Analysis

Elapsed Time, t (sec)	Depth to Water, H(t) (cm)	ΔH/Δt (cm/sec)	1/t (1/sec)
0.4	430.07		2.5000
0.6	428.24	-9.1500	1.6667
0.8	426.42	-9.1000	1.2500
1.4	426.11	-0.5167	0.7143
1.6	426.11	0.0000	0.6250
1.8	426.11	0.0000	0.5556
2	425.81	-1.5000	0.5000
3	424.89	-0.9200	0.3333
4	423.98	-0.9100	0.2500
5	423.37	-0.6100	0.2000
6	422.76	-0.6100	0.1667
7	422.15	-0.6100	0.1429
8	421.54	-0.6100	0.1250
9	421.23	-0.3100	0.1111
10	420.62	-0.6100	0.1000
11	420.01	-0.6100	0.0909
12	419.40	-0.6100	0.0833
13	419.10	-0.3000	0.0769
14	418.49	-0.6100	0.0714
15	418.19	-0.3000	0.0667
16	417.58	-0.6100	0.0625
17	417.27	-0.3100	0.0588
18	416.66	-0.6100	0.0556
19	416.36	-0.3000	0.0526
20	415.75	-0.6100	0.0500
25	414.22	-0.3060	0.0400
30	412.39	-0.3660	0.0333
35	411.18	-0.2420	0.0286
40	409.96	-0.2440	0.0250
45	408.74	-0.2440	0.0222
50	407.52	-0.2440	0.0200
55	406.60	-0.1840	0.0182
60	405.69	-0.1820	0.0167
65	404.77	-0.1840	0.0154
70	403.86	-0.1820	0.0143
75	403.25	-0.1220	0.0133
80	402.64	-0.1220	0.0125
85	402.03	-0.1220	0.0118
90	401.42	-0.1220	0.0111
95	400.81	-0.1220	0.0105

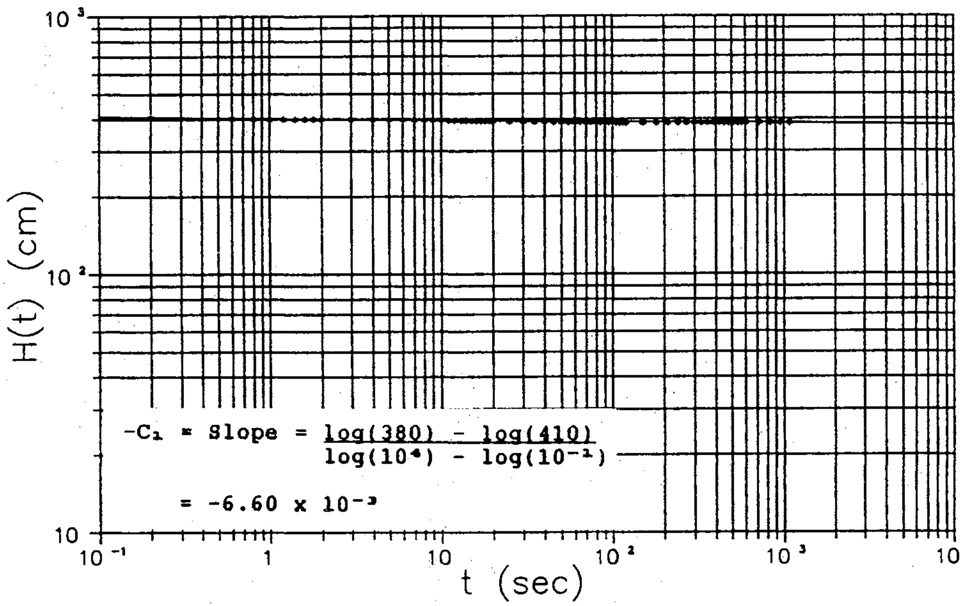
100	400.20	-0.1220	0.0100
105	399.90	-0.0600	0.0095
110	399.29	-0.1220	0.0091
115	398.98	-0.0620	0.0087
120	398.68	-0.0600	0.0083
150	396.85	-0.0610	0.0067
180	395.63	-0.0407	0.0056
210	394.72	-0.0303	0.0048
240	394.11	-0.0203	0.0042
270	393.50	-0.0203	0.0037
300	393.19	-0.0103	0.0033
330	392.89	-0.0100	0.0030
360	392.89	0.0000	0.0028
390	392.58	-0.0103	0.0026
420	392.58	0.0000	0.0024
450	392.28	-0.0100	0.0022

Well B12 Slug Test (1/27/89)
1.75 gals. removed with bailer.
Nguyen and Pinder (1984) Analysis

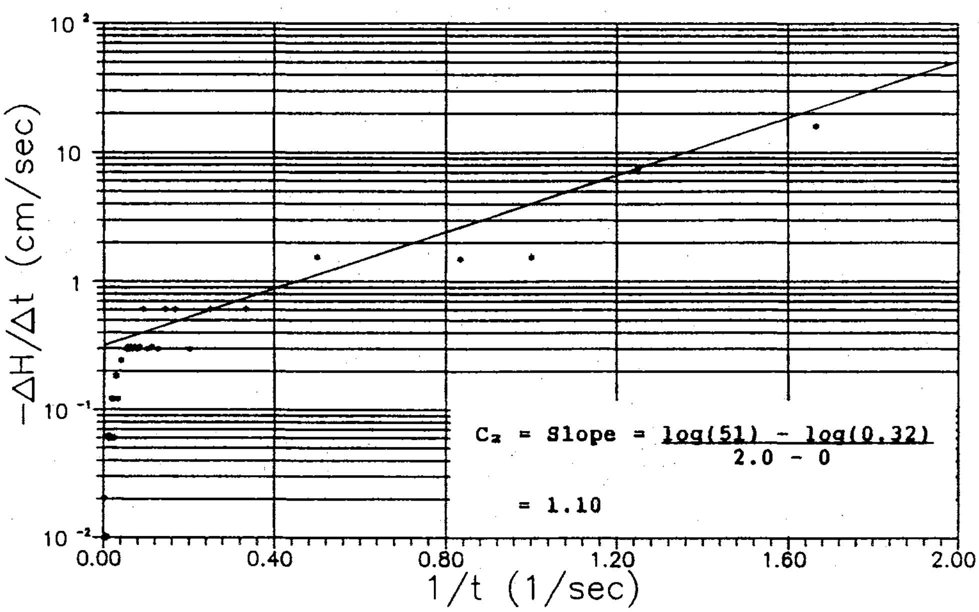
Elapsed Time, t (sec)	Depth to Water, H(t) (cm)	△H/△t (cm/sec)	1/t (1/sec)
0.2	290.17		5.0000
0.4	340.46	251.4520	2.5000
0.6	370.03	147.8500	1.6667
0.8	362.10	-39.6500	1.2500
1	349.00	-65.5000	1.0000
1.2	348.69	-1.5500	0.8333
1.4	350.22	7.6500	0.7143
1.6	350.22	0.0000	0.6250
1.8	350.22	0.0000	0.5556
2	350.22	0.0000	0.5000
3	349.30	-0.9200	0.3333
4	347.78	-1.5200	0.2500
5	346.56	-1.2200	0.2000
6	345.34	-1.2200	0.1667
7	344.12	-1.2200	0.1429
8	342.90	-1.2200	0.1250
9	341.68	-1.2200	0.1111
10	340.77	-0.9100	0.1000
11	339.55	-1.2200	0.0909
12	338.63	-0.9200	0.0833
13	337.41	-1.2200	0.0769
14	336.50	-0.9100	0.0714
15	335.58	-0.9200	0.0667
16	334.37	-1.2100	0.0625
17	333.45	-0.9200	0.0588
18	332.54	-0.9100	0.0556
19	331.62	-0.9200	0.0526
20	330.71	-0.9100	0.0500
25	327.05	-0.7320	0.0400
30	323.39	-0.7320	0.0333
35	320.34	-0.6100	0.0286
40	317.60	-0.5480	0.0250
45	314.86	-0.5480	0.0222
50	312.42	-0.4880	0.0200
55	309.98	-0.4880	0.0182
60	307.54	-0.4880	0.0167
65	305.71	-0.3660	0.0154
70	303.89	-0.3640	0.0143
75	302.06	-0.3660	0.0133
80	300.23	-0.3660	0.0125

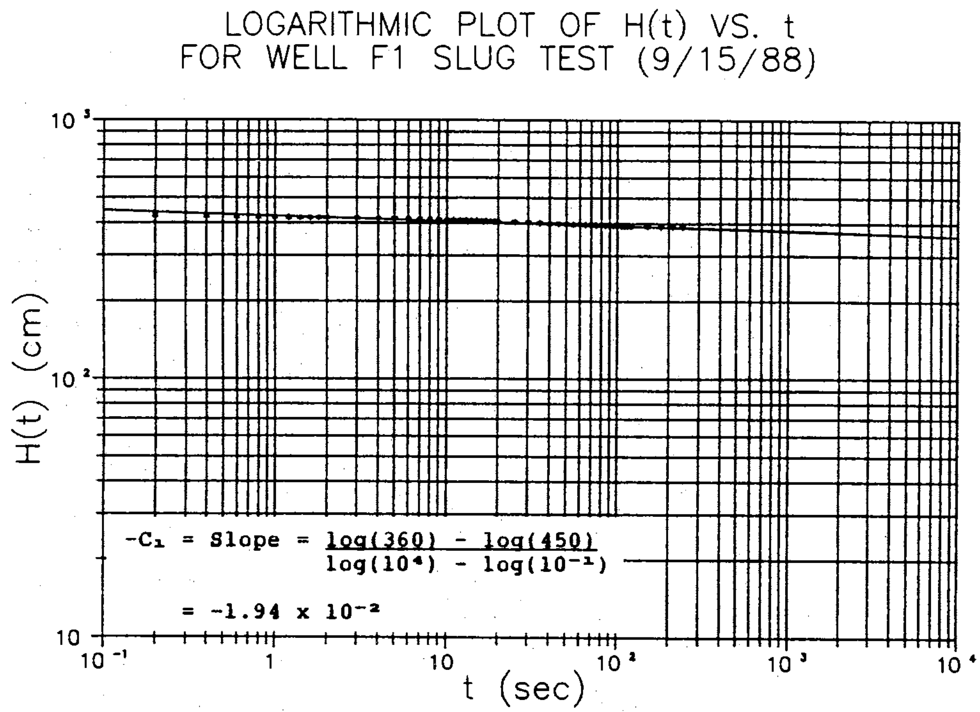
85	298.70	-0.3060	0.0118
90	297.18	-0.3040	0.0111
95	295.96	-0.2440	0.0105
100	294.74	-0.2440	0.0100
105	293.22	-0.3040	0.0095
110	292.30	-0.1840	0.0091
115	291.08	-0.2440	0.0087
120	290.17	-0.1820	0.0083
150	285.29	-0.1627	0.0067
180	281.94	-0.1117	0.0056
210	279.20	-0.0913	0.0048
240	277.67	-0.0510	0.0042
270	276.15	-0.0507	0.0037
300	275.23	-0.0307	0.0033
330	274.62	-0.0203	0.0030
360	273.71	-0.0303	0.0028
390	273.10	-0.0203	0.0026
420	272.80	-0.0100	0.0024
450	272.49	-0.0103	0.0022
480	272.19	-0.0100	0.0021
510	272.19	0.0000	0.0020
540	272.49	0.0100	0.0019
570	272.49	0.0000	0.0018
600	272.19	-0.0100	0.0017
720	272.19	0.0000	0.0014
840	272.19	0.0000	0.0012
960	272.19	0.0000	0.0010
1080	271.27	-0.0077	0.0009

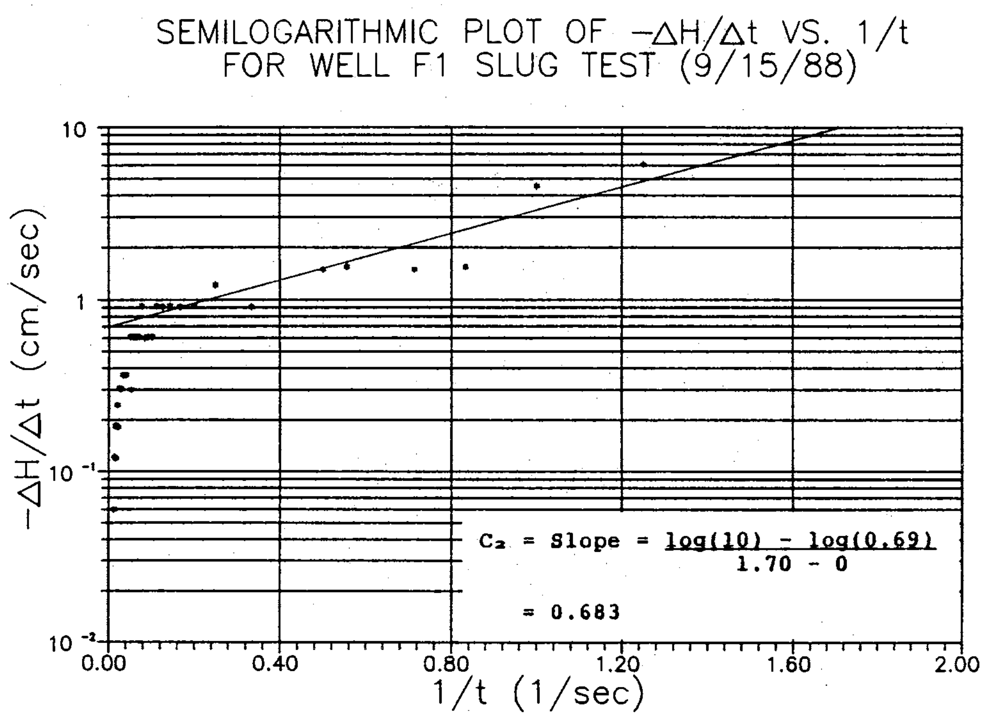
LOGARITHMIC PLOT OF H(t) VS. t
FOR WELL F1 SLUG TEST (8/13/88)

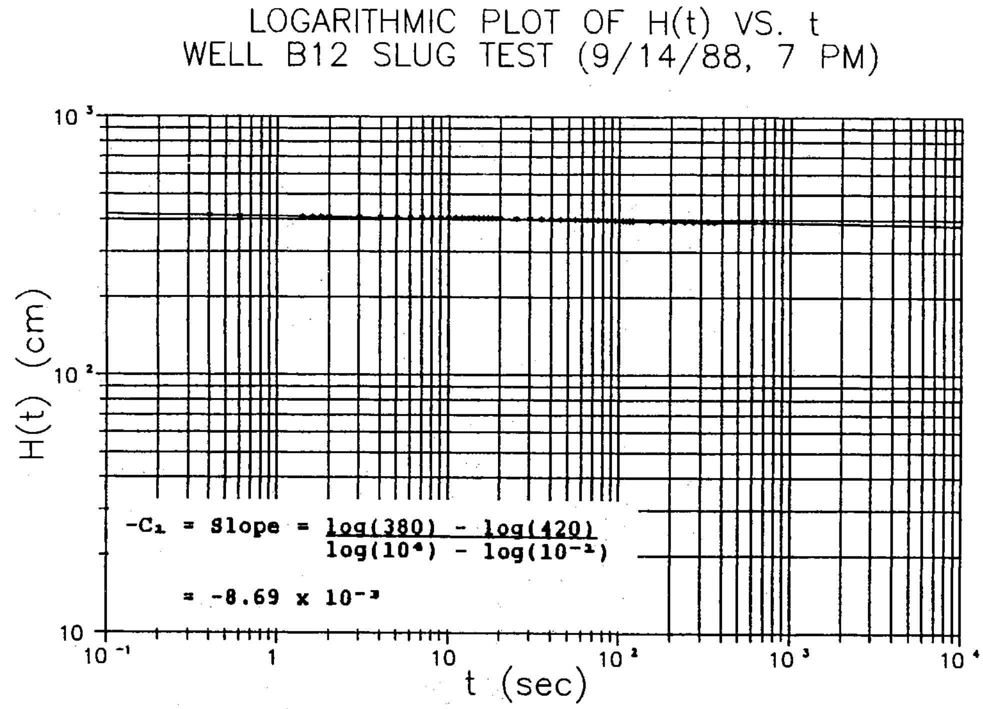


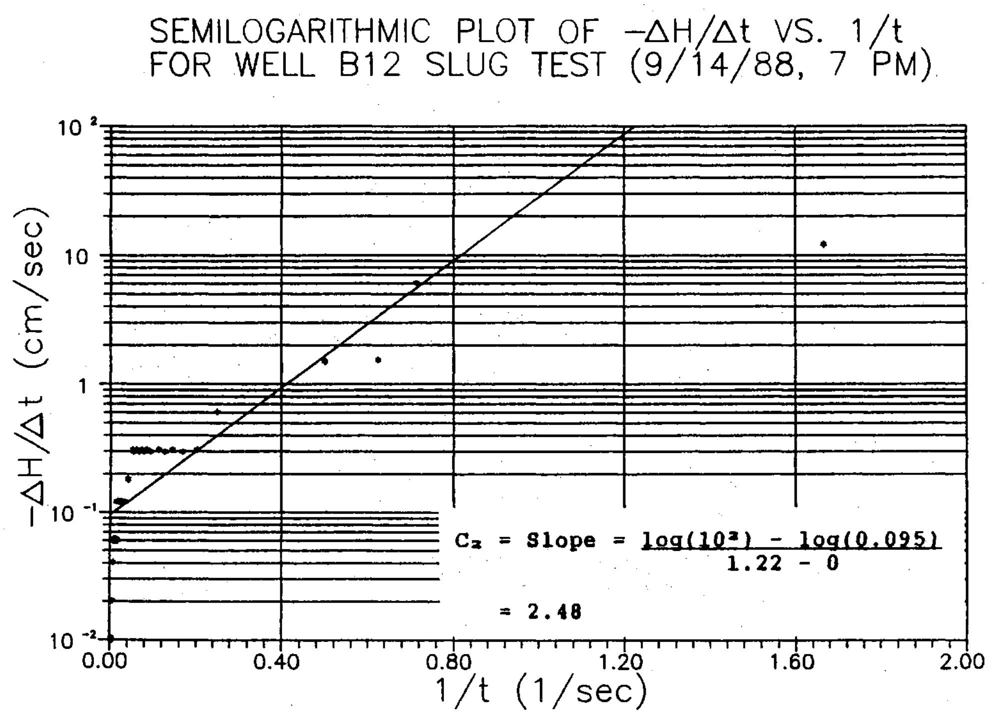
SEMILOGARITHMIC PLOT OF −ΔH/Δt VS. 1/t
FOR WELL F1 SLUG TEST (8/13/88)



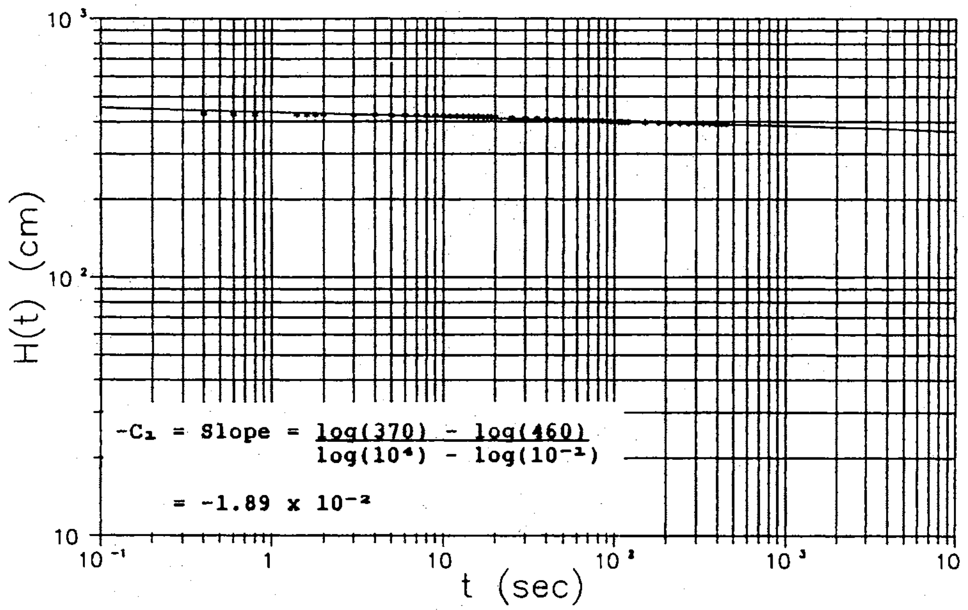

LOGARITHMIC PLOT OF H(t) VS. t
FOR WELL F1 SLUG TEST (9/15/88)
H(t) (cm)
t (sec)
$-C_1$ = Slope = $\frac{\log(360) - \log(450)}{\log(10^4) - \log(10^{-1})}$
= -1.94×10^{-2}


SEMILOGARITHMIC PLOT OF −ΔH/Δt VS. 1/t
FOR WELL F1 SLUG TEST (9/15/88)
−ΔH/Δt (cm/sec)
1/t (1/sec)
C_2 = Slope = $\frac{\log(10) - \log(0.69)}{1.70 - 0}$
= 0.683

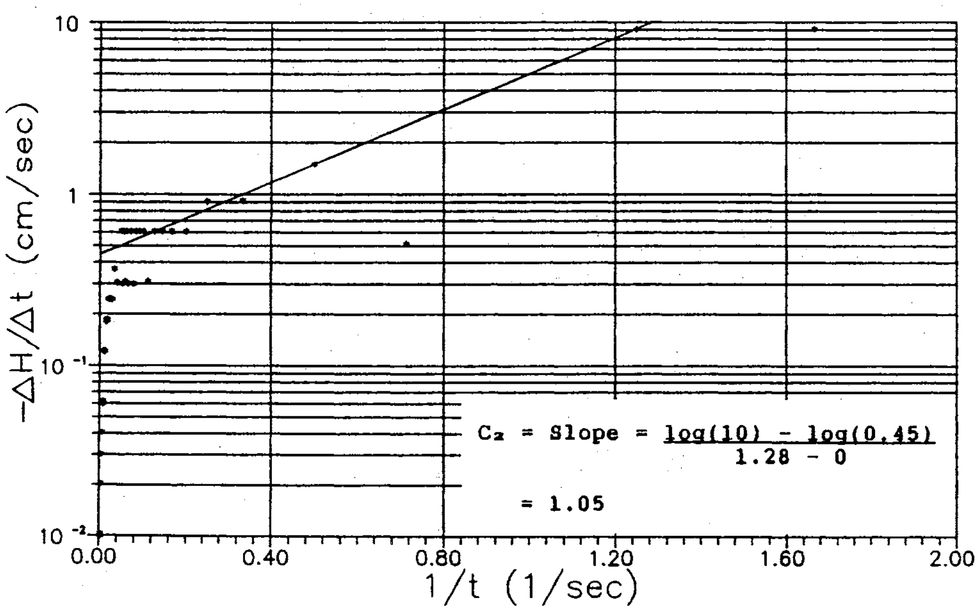

LOGARITHMIC PLOT OF H(t) VS. t
WELL B12 SLUG TEST (9/14/88, 7 PM)
H(t) (cm)
t (sec)
$-C_1$ = Slope = $\frac{\log(380) - \log(420)}{\log(10^4) - \log(10^{-1})}$
= -8.69×10^{-3}


SEMILOGARITHMIC PLOT OF −ΔH/Δt VS. 1/t
FOR WELL B12 SLUG TEST (9/14/88, 7 PM)
−ΔH/Δt (cm/sec)
1/t (1/sec)
C_2 = Slope = $\frac{\log(10^2) - \log(0.095)}{1.22 - 0}$
= 2.48

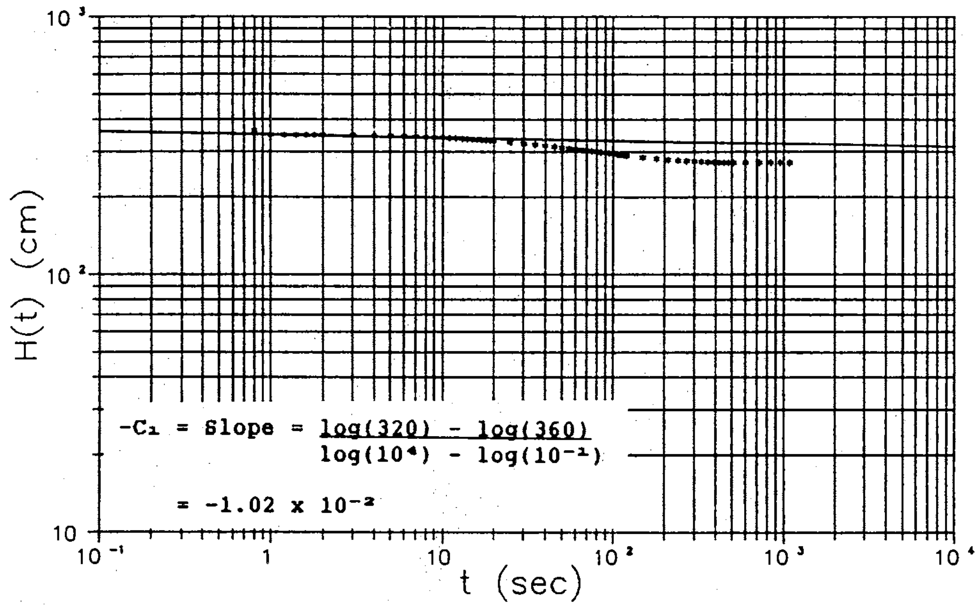
LOGARITHMIC PLOT OF H(t) VS. t
WELL B12 SLUG TEST (9/14/88, 8 PM)



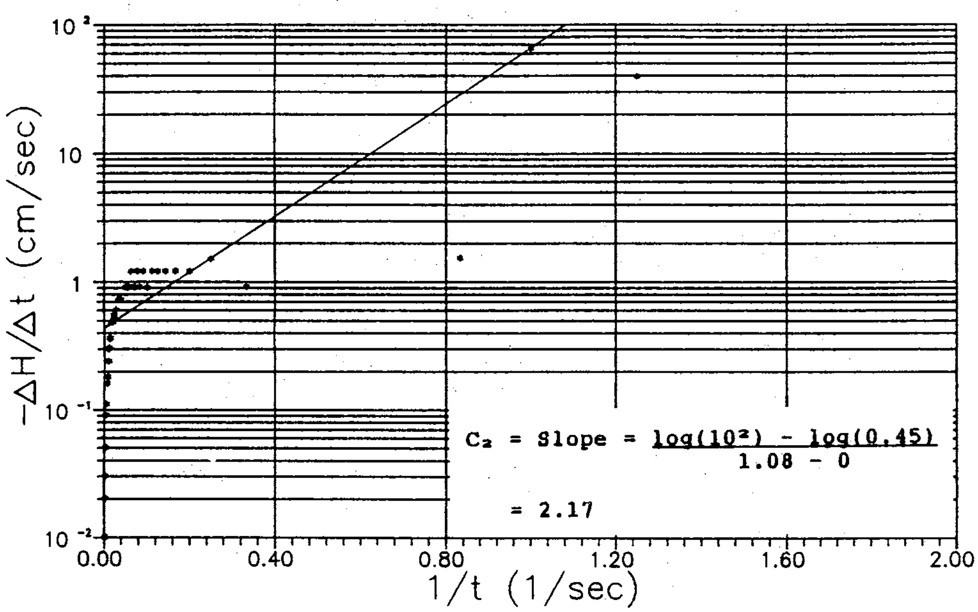
SEMILOGARITHMIC PLOT OF −ΔH/Δt VS. 1/t
FOR WELL B12 SLUG TEST (9/14/88, 8 PM)



LOGARITHMIC PLOT OF H(t) VS. t
FOR WELL B12 SLUG TEST (1/27/89)



SEMILOGARITHMIC PLOT OF −ΔH/Δt VS. 1/t
FOR WELL B12 SLUG TEST (1/27/89)



VITA

Jeffrey Thomas Melby

Candidate for the Degree of

Master of Science

Thesis: A COMPARATIVE STUDY OF HYDRAULIC CONDUCTIVITY DETERMINATIONS FOR A FINE-GRAINED ALLUVIUM AQUIFER

Major Field: Geology

Biographical:

Personal Data: Born in Middlebury, Vermont, March 18, 1961, the son of Dr. Edward C. and Jean F. Melby.

Education: Graduated from Ithaca High School, Ithaca, New York, in June 1979; Rotary International exchange student to Keuruu, Finland, July 1979 to July 1980; received Bachelor of Arts Degree in Geological Sciences from Cornell University in May 1984; completed requirements for the Master of Science degree at Oklahoma State University in December 1989.

Professional Experience: Scientist, Geraghty & Miller, Inc., Ground-Water Consultants, Hackensack, New Jersey, December 1984 to August 1987; Teaching Assistant, School of Geology, Oklahoma State University, August 1987 to May 1988; Presidential Fellow in Water Resources, July 1988 to August 1989. Hydrogeologist, ERM-Southwest, Inc., Houston, Texas, September 1989 to present.

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