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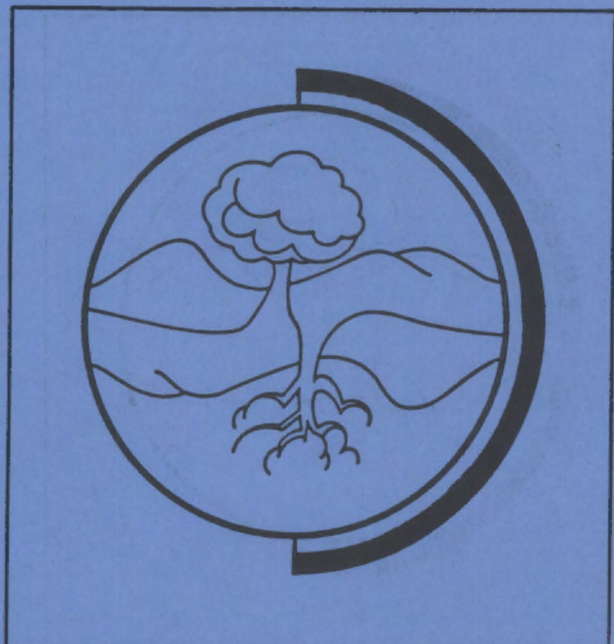
Aquifer Characterization at the Veterans Administration Hospital, Tuscaloosa, Alabama



October 1989

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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AQUIFER CHARACTERIZATION AT THE VETERANS ADMINISTRATION HOSPITAL, TUSCALOOSA, ALABAMA

W. E. Cronin
S. P. Luttrell
S. H. Hall

October 1989

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

FOREWORD

Seasonal thermal energy storage (STES) involves storing thermal energy, such as winter chill, summer heat, and industrial waste heat, for future use in heating and/or cooling buildings or for industrial processes. Widespread development and implementation of STES would significantly reduce the need to generate primary energy in the U.S. Recent data indicate that STES is technically suitable for providing 5% to 10% of the nation's energy, with major contributions in the commercial and industrial sectors and in district heating and cooling applications.

Aquifer thermal energy storage (ATES) is predicted to be the most cost-effective technology for seasonal storage of low-grade thermal energy. Approximately 60% of the U.S. is underlain by aquifers that are potentially suitable for underground energy storage. Chill ATES has the potential to substantially reduce energy consumption and, especially, summer peak cooling electrical demand. However, the geohydrologic environment that the system will use is a major element in system design and operation, and this environment must be characterized for development of efficient energy recovery.

This report describes aquifer characterization of a site proposed for an ATES chill system at the U.S. Veterans Administration Hospital facility in Tuscaloosa, Alabama. The aquifer characterization work was conducted by the U.S. Department of Energy's Pacific Northwest Laboratory (Seasonal Thermal Energy Storage Program) in cooperation with the University of Alabama to assess utilization of chill ATES for cooling large institutional buildings for the Veterans Administration. The Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the Department of Energy under contract DE-AC06-76RLO 1830. The project was managed by Dr. C. Everett Brett, Director of the University of Alabama Natural Resources Center.

Landis D. Kannberg, Manager
Seasonal Thermal Energy Storage Program

SUMMARY

The Veterans Administration (VA) is studying the feasibility of aquifer thermal energy storage (ATES) at their Tuscaloosa, Alabama, facility. To determine the characteristics of the aquifer underlying the facility, the Pacific Northwest Laboratory gathered information about the environment of the aquifer and conducted tests to estimate the aquifer's transmissivity, ground-water flow direction, and velocity.

Seven wells were drilled at the VA site. It was found that ground-water flow direction at the site is generally toward the southwest. The magnitude of the gradient is approximately 2.5×10^{-3} to 3×10^{-3} ft/ft. For six of the seven wells, clay lenses or thick clay layers appear to be acting locally as confining or semi-confining layers.

Three types of tests were conducted at the site: a step drawdown test, a constant discharge and recovery test, and a single-well tracer test. The data yielded responses suggesting leaky confined or delayed yield models for the aquifer. Drawdown and recovery versus time were matched to type curves for delayed yield to obtain estimates of transmissivity and storage. This recovery method gave the best fit to the drawdown-versus-time curves. Using this method it was found that transmissivity ranged from 500 to 9000 ft^2/day and storage ranged from 1.5×10^{-4} to 4.5×10^{-2} for the wells tested. Using the results of the pump and tracer tests simultaneously, ground-water velocity was estimated to be approximately 0.8 ft/day, with an effective porosity of approximately 12%.

CONTENTS

FIGURES

TABLES

INTRODUCTION

The Veterans Administration (VA) is studying the feasibility of aquifer thermal energy storage (ATES) for cooling purposes at their Tuscaloosa, Alabama, location. An understanding of aquifer characteristics and geometry, ground-water flow direction, and ground-water velocity are essential to determine the location and design of production and injection wells. The purpose of this study is to provide estimates of aquifer parameters, in order for feasibility studies to be conducted.

No previous hydrogeologic work has been conducted at the VA site. Previous work done by the Pacific Northwest Laboratory (PNL) staff[a] at the General Motors Harrison Division plant in Tuscaloosa and preliminary drilling directed by the University of Alabama were used as guides in planning aquifer tests at the VA site.[b]

Seven wells were drilled at the VA site, ranging from depths of 175 to 248 ft. The hydrogeologic setting of the site was determined, including the stratigraphy of the aquifer environment and the hydraulic gradient and flow direction. Then, three types of tests were performed: a step drawdown test, a continuous discharge and recovery test, and a single-well tracer test. The step drawdown test gave an estimate of the degree of efficiency of the pump well. The constant discharge and recovery test yielded estimates of transmissivity and storage properties. The single-well tracer test, using a lithium bromide (LiBr) solution, allowed an estimate of ground-water velocity. Results from these tests were used conjunctively in the calculation of ground-water velocity and effective porosity.

This report consists of chapters that describe the experimental method used and the hydrogeological setting of the VA site, describe the field tests and the experimental and calculated results, and finally summarize the findings. Appendixes contain the raw data of the field tests.

(a) Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.
(b) Letter report by S. P. Luttrell et al., Aquifer Characterization at the General Motors Harrison Division Plant, Tuscaloosa, Alabama, May 1989.

INTRODUCTION

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METHODS AND HYDROGEOLOGICAL SETTING

METHODS OF STUDY

All wells at the VA site were drilled for aquifer testing during May and June, 1989. Table 1 summarizes the construction of the wells and Figure 1 shows the locations of wells at the VA site.

Three types of tests were planned for the VA site: 1) a step drawdown test, 2) constant discharge and recovery test, and 3) single-well tracer injection/withdrawal test. Water levels in all wells were also measured for gradient analysis.

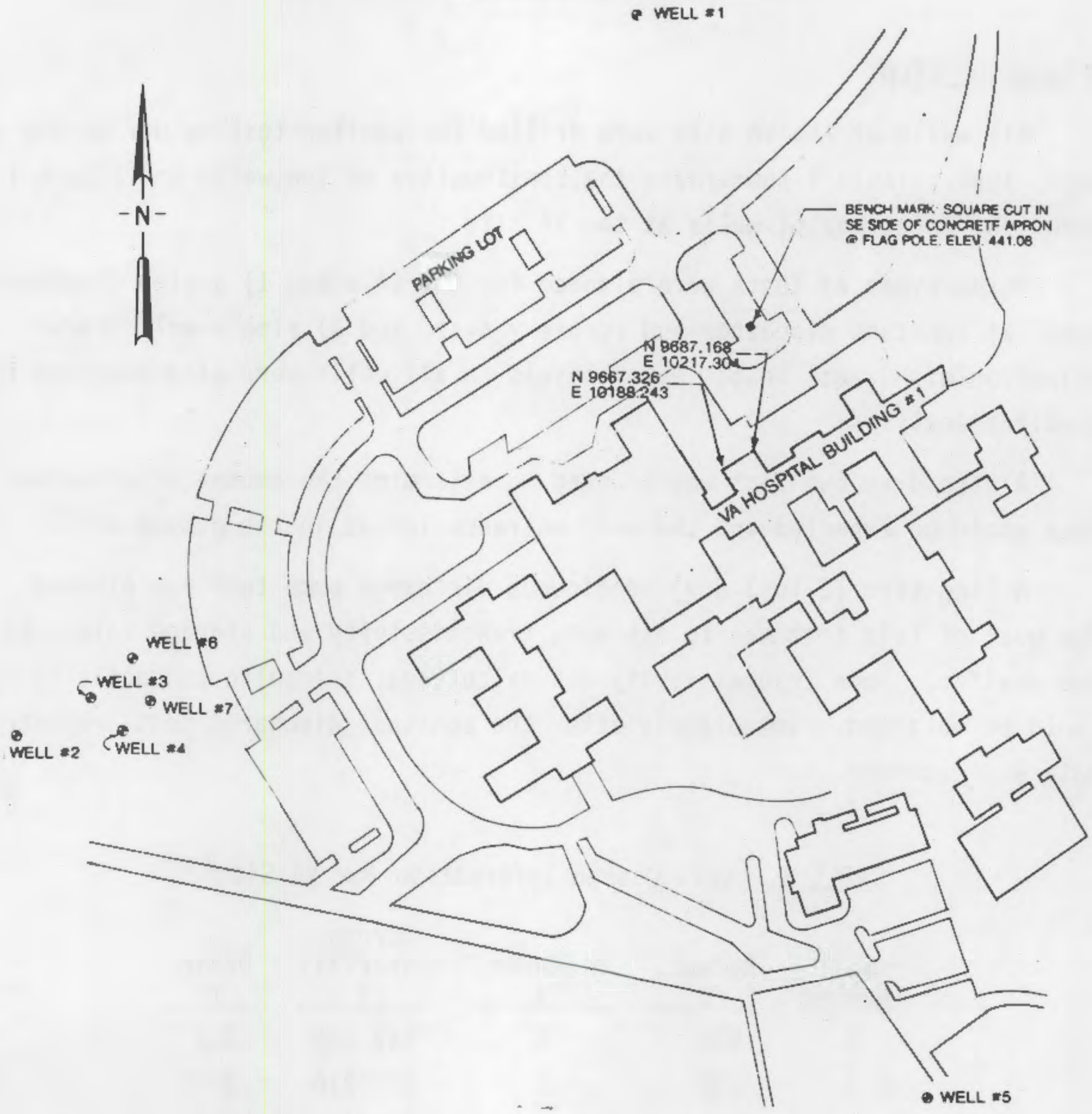
A step drawdown test was planned to determine the amount of drawdown that would be expected and the well entrance losses in the pumped well.

A long-term (2-to-3-day) continuous discharge pump test was planned. The goal of this test was to estimate transmissivity and storage values of the aquifer. Once transmissivity was calculated, hydraulic conductivity could be obtained. Immediately after the constant discharge test, recovery data was recorded.

TABLE 1. Well Design Information for VA Site[a]

Well Number	Radius, ft	Diameter, in.	Screen Interval, ft	Depth, ft
1	950	2	192-232	232
2	150	2	170-210	210
3	65	2	175-215	215
4	40	2	180-220	220
5	950	2	208-248	248
6	62	2	135-175	175
7	--	10	143-223	223

(a) All wells used 0.032-in. slotted PVC screen.



<u>FIGURE 1</u>. Locations of Wells at the VA Site

A single-well tracer injection/withdrawal drift and pumpback test was planned following full recovery from the aquifer pump test. The purpose of this test was to estimate ground-water velocity. A LiBr solution was mixed with aquifer water and injected into the pumping well. The residence time of the tracer in the aquifer was based on a velocity calculated from preliminary results of the aquifer test and gradient analyses. The tracer was removed four days later by pumping, and the concentration of the tracer was measured over the time of withdrawal.

HYDROGEOLOGIC SETTING

The hydrogeology of the setting can be described as comprising three elements: stratigraphy of the area, water levels and layers in the aquifer, and the hydraulic gradient and flow direction.

Stratigraphy

The stratigraphy in the vicinity of the VA site consists of unconsolidated sands, gravels, and clays of the Coker Formation (and/or Black Warrior River Valley deposits) which overlie the Pottsville Formation. The unconsolidated materials are about 220 ft thick near the VA site. The upper 15 to 20 ft of the materials consist mainly of red, sandy clay. The next approximately 125 ft of the formation consist of undifferentiated layers of sand and clay. The lower approximately 80 ft contain sands and gravels with scattered clay lenses present. The underlying Pottsville formation consists of shales and limestones with relatively low permeabilities compared to the unconsolidated sediments. The unconsolidated sediments offer the only unit in the vicinity that has potential for ATES use. Figure 2 shows stratigraphic diagrams for each well at the VA site. Appendix A contains geologic information from several drillers logs for the VA location.

Aquifer Hydrogeology

Undifferentiated sands and gravels overlying the Pottsville formation comprise the major aquifer in the vicinity of the site. Saturated thickness of the aquifer is approximately 75 ft. The depth to water at the VA site is about 145 ft for wells 2, 3, 4, 6, and 7. Depth to water at wells 1 and 5 is about 165 ft due to their topographically higher location. Results of this study indicate that clay lenses beneath the static water level may be acting as locally confining or semi-confining layers for wells 2, 3, 4, and 7. Well 6 shows no clay lenses below the static water level and appears to be

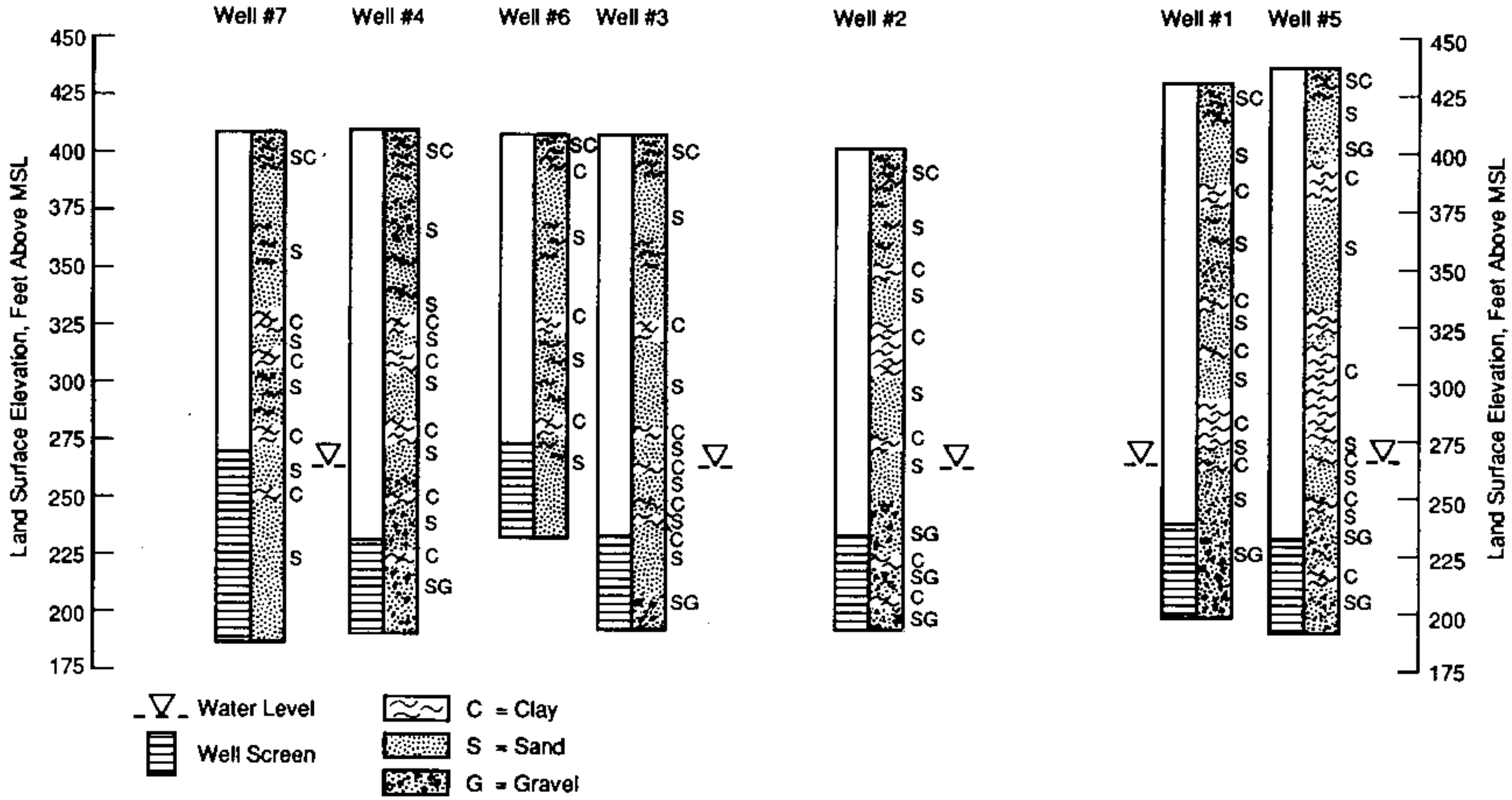


FIGURE 2. Stratigraphic Diagram of Wells at the VA Site

unconfined. A relatively thick clay layer is present at or near the static water level in wells 1 and 5, indicating possible confining conditions at these locations.

Hydraulic Gradient and Flow Direction

Water levels were measured in all wells to determine the direction and magnitude of the hydraulic gradient. Table 2 lists data from these measurements.

Ground-water flow direction at the VA site is generally towards the southwest. Magnitude of the gradient is approximately 2.5×10^{-3} to 3×10^{-3} ft/ft. Figure 3 shows a ground-water map of the VA site for water levels measured in wells 1, 2, 3, 4, and 5 on May 24, 1989.

TABLE 2. Casing Elevations, Depth-to-Water Measurements, and Water-Level Elevations for Wells at the VA Site

Well Number	Casing Elevation, ft	Date of Measurement	Depth to Water, ft	Water Level Elevation, ft
1	429.10	05/24/89	161.16	267.94
		06/20/89	161.22	267.88
		06/21/89	161.29	267.81
2	403.69	05/24/89	138.56	265.13
		06/20/89	138.44	265.25
		06/21/89	138.48	265.21
3	407.99	05/24/89	142.71	265.28
		06/20/89	142.75	265.24
		06/21/89	142.81	265.18
4	410.32	05/24/89	144.98	265.34
		06/20/89	144.85	265.47
		06/21/89	144.93	265.39
5	436.91	05/24/89	169.42	267.49
		06/20/89	169.30	267.61
		06/21/89	169.36	267.55
6	410.17	06/20/89	143.80	266.37
		06/21/89	143.49	266.68
7	414.02	06/20/89	148.44	265.58

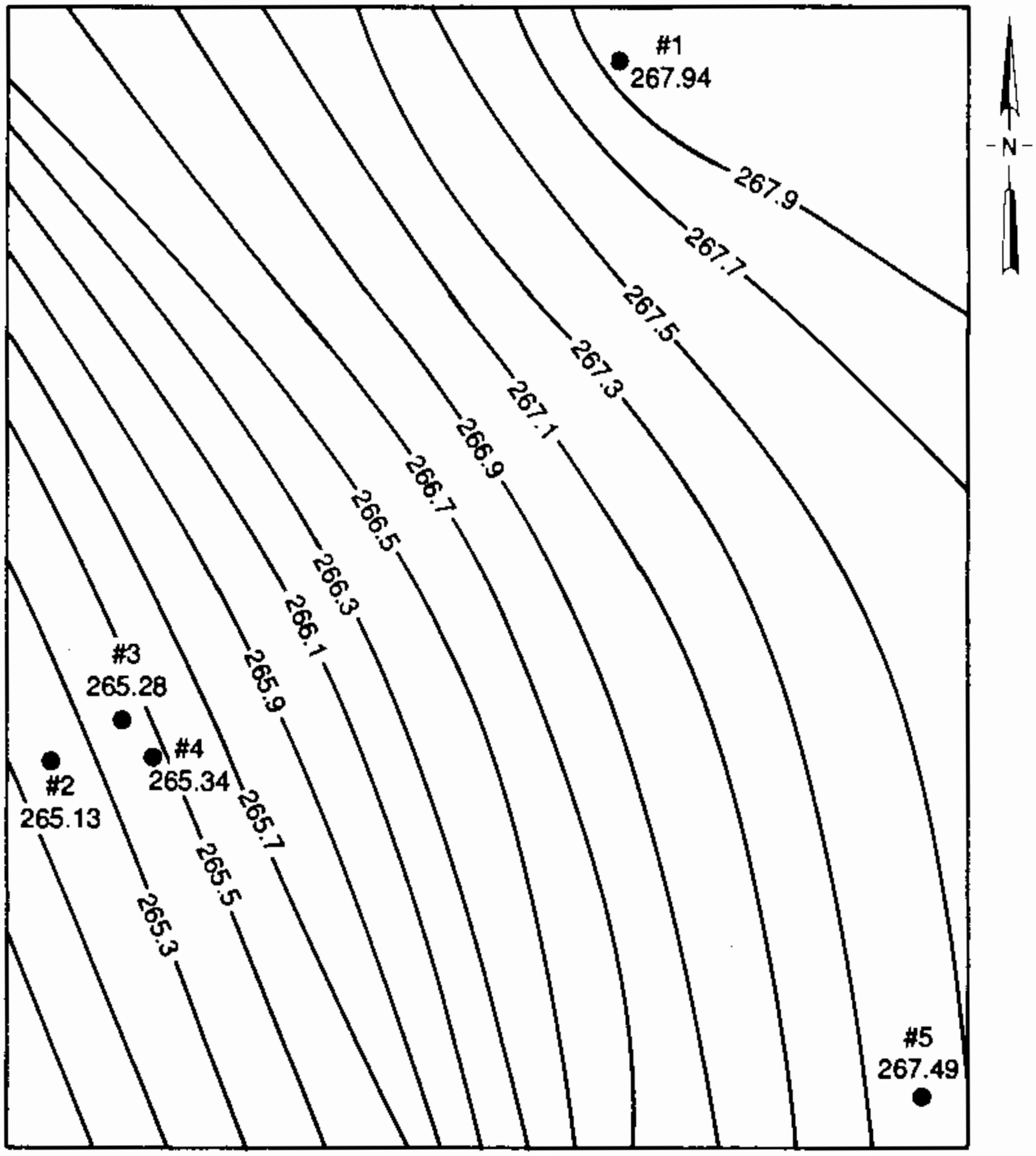


FIGURE 3. Water Table Elevation (ft) Map of the VA Site, Measured Measured May 24, 1989. Dot represents well locations.

TESTS AND RESULTS

STEP DRAWDOWN TEST

A step drawdown test was conducted from 1200 hr to 1652 hr on June 20, 1989. Well 7 was the pumping well, and the discharge rate was measured using an in-line pitot tube. Discharge was also measured by timing the discharge into a 26-qt pail. Steps of 60, 120, 180, and 230 gallons per minute (gpm) were originally planned for the test. Occasional malfunction of the pitot tube during the test warranted use of the 26-qt pail for several discharge measurements. Using the pail measurements, steps of 90, 140, 200, and 234 gpm were obtained. A 50-psi transducer was placed in pump well 7 to measure drawdown. Ten-psi transducers were placed in wells 6 and 3 to measure responses to pumping in the vicinity of the pump well.

Method of Analysis

The Jacob method of analysis (Todd 1980) was used to estimate values for the aquifer constant (B) and the well loss constant (C). A graph of drawdown/discharge versus discharge gives the well loss constant (slope) and the aquifer constant (intercept). Drawdown in the well due to entrance losses is then calculated using the equation

$$s = CQ^2 \tag{1}$$

where s is the well loss in ft, C is the well loss constant, and Q is the discharge during the constant discharge test. Appendix B contains graphs of the step drawdown analysis.

Data Discussion

A value of 7.1×10^{-3} min^2/ft^5 ($2.69\ min^2/m^5$) was calculated for the well loss constant in pump well 7. This value suggests severe clogging or improper well design (Todd 1980.). Using a constant discharge value of 235 gpm, the drawdown due to well loss was approximately 7 ft. Pump well 7 recovered approximately 90% within 3 minutes after turning off the pump, also indicating an inefficient well.

CONSTANT DISCHARGE AND RECOVERY TESTS

A constant discharge pumping test was conducted from April 21 at 1115 hr to April 23 at 1115 hr (48 hours). The discharge rate was measured at approximately 230 gpm using an in-line pitot tube. Timing the discharge into a 60-gallon steel drum gave an average value of 235 gpm, which was used in transmissivity and storage calculations. Discharged water flowed across the VA grounds into a nearby storm sewer.

Drawdown and recovery water-level data were collected in wells 3, 4, and 7 using 50-psi transducers and data loggers. Water-level data were collected in wells 2 and 6 using 10-psi transducers. Although a transducer had been set in well 1, difficulties with the data logger resulted in no data being recorded. Water-level measurements in all wells were also made periodically with electric and steel tapes.

Methods of Analysis

The data exhibited responses that appeared to follow leaky confined (Boulton 1963) or delayed yield aquifer model responses. Type curves of these are given in Lohman (1972). Use of either set of type curves results in similar values of transmissivity, which is the primary aquifer property of concern.

Logarithmic plots of drawdown versus time were matched to type curves for delayed yield to obtain estimates of transmissivity and storage.

Analysis of recovery data by the Cooper-Jacob method (Cooper and Jacob 1946) was used to estimate transmissivity. The Theis recovery method was also used to obtain estimates of transmissivity and storage using log-log curve-matching techniques with delayed-yield type curves.

Data Discussion and Analysis

Drawdown data from wells 2, 3, 4 and 7 are difficult to match completely to the Theis curve. Nearly all drawdown in these wells occurs within the first 2 minutes of pumping. This initial drawdown produces time/drawdown curves that are difficult to match for early times. Well 6 shows a much slower response to pumping.

Recovery analysis using the Theis method gave the best fit to delayed yield and leaky confined type curves, including early times. This method is presumed to give the most valid estimates of transmissivity and storage. Appendix C contains drawdown and recovery plots for the test at the VA site.

Data from the wells tested are discussed below.

Well 2

During the first 2 minutes of the pump test, aquifer response shows about 1.5 ft of drawdown. A maximum of approximately 4 ft of drawdown was reached at the end of the test.

Logarithmic curve matching of drawdown data resulted in a value of 1200 ft^2/day for transmissivity and a storage value of 1.5×10^{-4}. Logarithmic recovery curve matching resulted in a value of 2400 ft^2/day for transmissivity and a storage value of 1.5×10^{-4}. Cooper-Jacob analysis of recovery data gave a value of 3700 ft^2/day for transmissivity.

Well 3

Drawdown in well 3 reached a maximum of approximately 5 ft at the end of the pump test. Logarithmic curve matching of drawdown data resulted in a value of 900 ft^2/day for transmissivity and a storage value of 4×10^{-4}. Logarithmic recovery curve matching gave a transmissivity value of 1600 ft^2/day and a storage value of 3.5×10^{-4}. Cooper-Jacob analysis of recovery data resulted in a transmissivity value of 2600 ft^2/day.

Well 4

Drawdown in well 4 reached a maximum of approximately 7 ft at the end of the pump test. Logarithmic curve matching of drawdown data resulted in a value of 600 ft^2/day for transmissivity and a storage value of 5×10^{-4}. Logarithmic recovery curve matching gave a transmissivity value of 1300 ft^2/day and a storage value of 3.4×10^{-4}. Cooper-Jacob analysis of recovery data resulted in a transmissivity value of 2000 ft^2/day.

Well 6

Drawdown in well 6 reached a maximum of approximately 1.5 ft at the end of the pump test. Sharp increases in the water level at times of approximately 800 and 2000 minutes were probably caused by surface runoff entering the well during heavy rains.

Logarithmic curve matching of drawdown data resulted in a value of 6000 ft^2/day for transmissivity and a storage value of 3×10^{-2}. Logarithmic recovery curve matching gave a transmissivity value of 9000 ft^2/day and a storage value of 4.5×10^{-2}. Cooper-Jacob analysis of recovery data resulted in a transmissivity value of 9900 ft^2/day.

Transmissivity values for well 6 are considerably higher than the other wells. Storage values are indicative of unconfined conditions. Well 6 was drilled to a depth of 175 ft (about 45 ft higher in the formation than the surrounding wells), and drillers' logs show no clay layers at or below the static water level. Significantly less drawdown in well 6 suggests anisotropic and heterogeneous aquifer conditions.

Well 7

Well 7 shows 20 ft of drawdown within the first 2 minutes of the test (13 ft due to aquifer loss and 7 ft due to well loss). A maximum of approximately 25 ft of drawdown occurred at the end of the pump test (18 ft corrected for well loss).

Logarithmic curve matching of drawdown data resulted in a value of 100 ft^2/day for transmissivity. Logarithmic recovery curve matching gave a transmissivity value of 500 ft^2/day. Cooper-Jacob analysis of recovery data resulted in a transmissivity value of 550 ft^2/day. Drawdown analysis for well 7 was conducted using corrected drawdown values (subtracting the well loss of 7 ft from each drawdown data point).

Summary of Test Analyses

Using logarithmic recovery results, transmissivity ranged from 500 to 9000 ft^2/day for wells 6 and 7. However, a best estimate of transmissivity probably came from well 2. The effects of vertical flow in well 2 were likely minimal due to the wells distance from the pump well. A larger volume of aquifer material was also being tested compared to other wells closer to the pump well. Using the transmissivity value from well 2, a representative value for hydraulic conductivity is approximately 32 ft/day. A summary of test analysis is provided in Table 3.

SINGLE-WELL TRACER TEST

The tracer test was performed in the single-well drift and pumpback mode described by Leap and Kaplan (1988). Using this method, a tracer slug is injected into a test well, is allowed to drift for a period of time, and is retrieved by pumping. The velocity of ground-water flow is calculated as a function of the amount of time required to recover the tracer slug at a given pumping rate. Data analysis also requires an estimate of effective porosity.

The method of Leap and Kaplan was derived for confined aquifers, that is, no dewatering is accounted for in their formula. However, the test at the VA site was conducted using a pumpback rate of only 60 gpm, with a maximum estimated drawdown of about 5 ft or about 10% of the aquifer thickness.

TABLE 3. Test Analyses Grouped by Method

Well	Transmissivity, ft^2/day	Storage Value
	Logarithmic Drawdown Curve Matching	
2	1200	1.5×10^{-4}
3	900	4×10^{-4}
4	600	5×10^{-4}
6	6000	3×10^{-2}
7	100	---
	Cooper-Jacob Semilog Recovery	
2	3700	---
3	2600	---
4	2000	---
6	9900	---
7	550	---
	Logarithmic Theis-Type Recovery Curve Matching	
2	2400	1.5×10^{-4}
3	1600	3.5×10^{-4}
4	1300	3×10^{-4}
6	9000	4.5×10^{-2}
7	500	---

The effect of this drawdown may be viewed as a small perturbation of effective porosity in the vicinity of the well bore during pumpback.

Leap and Kaplan describe a "velocity shadow" downgradient from the test well, the effect of which is an apparent reduction of flow velocity near the well. As drift time increases, the effect of the shadow decreases. The effect of the shadow is consistent with the fact that within the well bore the porosity is 100%, and horizontal flow rate through the well will be smaller than through the sediments. Although the tracer slug will require extra time to be flushed from the well, that additional time increment will become negligible as drift time increases. Leap and Kaplan offer no method to compensate for the effect of a velocity shadow except to perform a series of tests using progressively longer drift times.

Tracer Injection

Ground water collected during previously conducted pumping tests was stored in six 55-gallon drums and was available for the tracer test at the test site. On July 11, 1989, approximately 42 grams of LiBr was added to each of the six drums to prepare the tracer solution. The solution in each drum was mixed by air injection. Untreated ground water and each of the treated drums was sampled for analysis.

Beginning at 1104 hr on July 11, the tracer solution was injected into the test well at a net rate of 4.0 gpm. Injection of the tracer was completed by 1202 hr. Total slug volume was estimated to be 319 gallons, which is approximately one standing bore volume of the well. Injection of the tracer was accomplished using a 12-V battery-operated marine bilge pump (Mayfair Pro-line 600 Model 2260) connected to a 3/4-in. (ID) garden hose. Maximum flow rate of tracer into the well was 5.1 gpm.

Volume of the injected tracer was determined by measuring the drums and subtracting 2 in. from the drum height to allow for 1 in. of solution remaining at the bottom of each drum (the pump could not pick up less than about 1-in. depth) and 1 in. at the top of each drum (which was incompletely filled). Calculations show that approximately 53.2 gallons from each drum were injected into the well.

Field Measurements

A bromide-ion-selective electrode was available for monitoring the ground water during the pumpback phase of the test. The Corning bromide electrode (model no. 476128) was used in conjunction with an Orion double junction reference electrode (model no. 900200) and a portable Hach®[a] One pH Meter (model no. 43800-00). Outer filling solution for the reference electrode was 10% KNO_3. The Hach meter was used in the millivolt mode, and it was necessary to splice both electrodes to a single BNC connector.

No ionic strength adjuster was used for bromide measurements, and the electrode was calibrated by spiking samples of the ground water with a high and low concentration bromide solution. The resulting calibration was

$$C = 10^{[(119.5-E)/56.9]} \quad (2)$$

where C is bromide concentration in mg/L and E is measured potential in millivolts.

On July 15 (4 days later) at 0834 hr, the test well was pumped at a rate of 60 gpm, and field analysis for bromide was performed using the ion-selective electrode. All samples were collected unpreserved in 125-mL polyethylene bottles. Laboratory analyses of collected samples were intended to provide a check on the electrode readings; however, these analyses were inconclusive. Field data were therefore used for data analyses and interpretation.

Figure 4 shows the results of the field analysis. Field data showed that the center of mass of the slug was recovered after 34 minutes of pumping.

GROUND-WATER VELOCITY

The average ground-water velocity in the immediate vicinity of well 7 was calculated by analysis of the aquifer test results coupled with the

(a) Hach is a registered trademark of Hach Corporation, Loveland, Colorado.

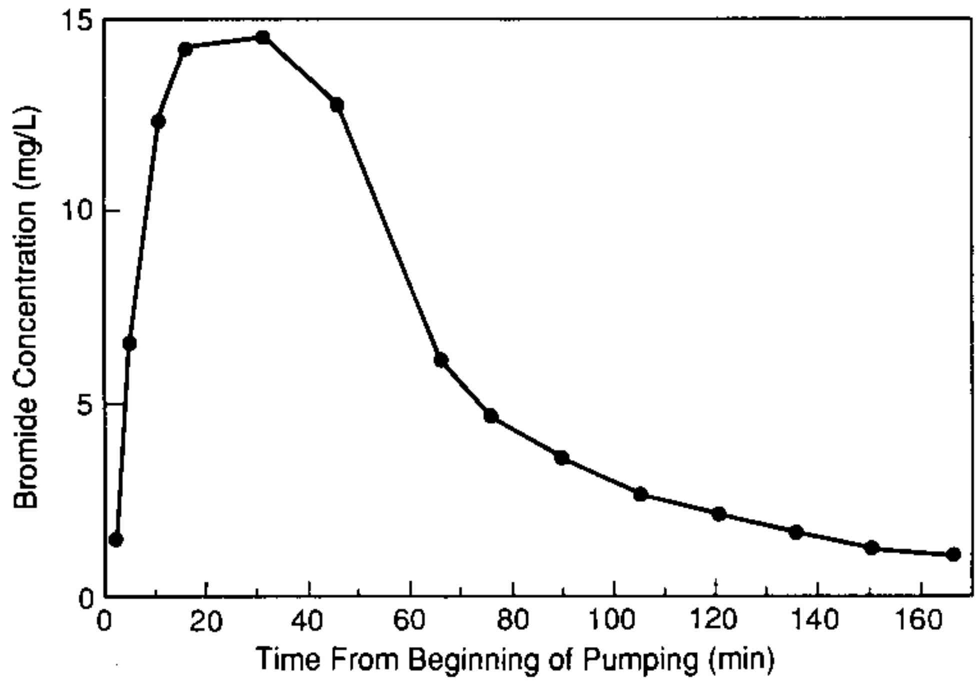


FIGURE 4. Concentration of Lithium Bromide Tracer Versus Time for the Pumpback Portion of the Tracer Test at the VA Site

hydraulic gradient and by analysis of the tracer test. Effective porosity was varied in both analyses to arrive at the velocity determinations. The calculated velocity based on hydraulic methods is proportional to the inverse of the effective porosity, while velocity calculated from the tracer test data is proportional to the square root of the effective porosity.

Darcy's Law

The results of velocity calculations from the aquifer test are based on Darcy's Law as follows:

$$V = (K \cdot I)/n \quad (3)$$

where V = average linear ground-water velocity
K = hydraulic conductivity
I = hydraulic gradient
n = effective porosity

Letting K = 32 ft/day and I = 0.003, velocities for a range of effective porosity, n, can be calculated. These are plotted in Figure 5.

Tracer Test

The following formula offered by Leap and Kaplan was used to calculate advective ground-water velocity from the results of the tracer test:

$$V = [1440 \cdot \sqrt{Qt/(n \cdot b \cdot \pi)}]/T \qquad (4)$$

where V = velocity in ft/day

Q = pump discharge in cubic feet per minute (cfm)

t = time in minutes from the start of pumping to recovery of the center of mass

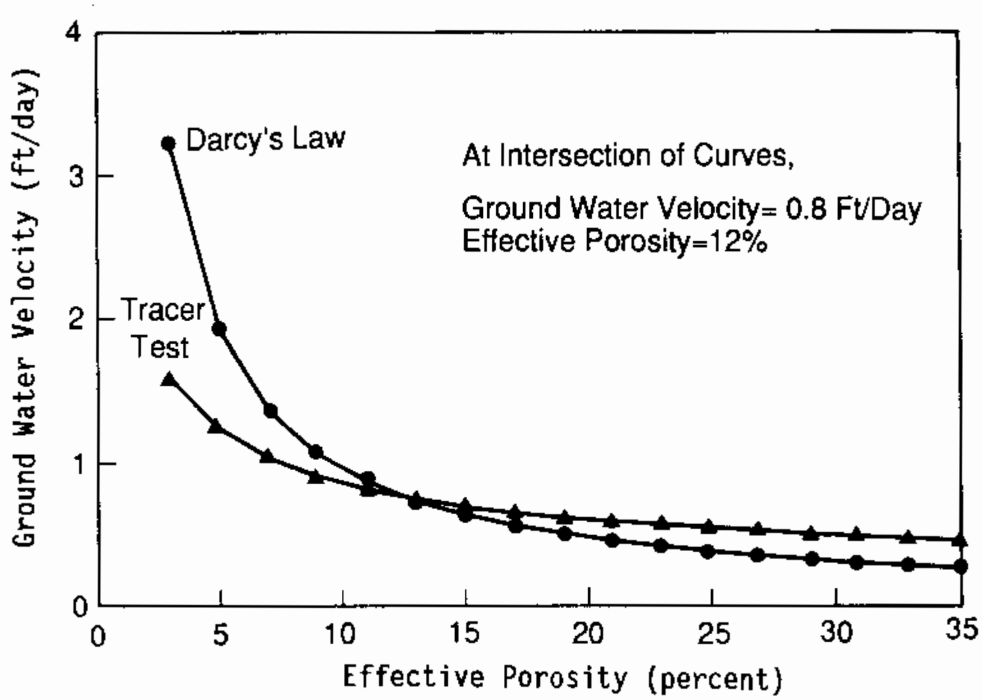


FIGURE 5. Plot of Velocity Versus Effective Porosity By Both the Tracer Test Method and Darcy's Law

n = effective porosity

b = aquifer thickness

T = time in minutes from injection of tracer to recovery of center of mass of tracer slug

With values for all variables, velocities for a range of effective porosity, n, can be calculated. These also are plotted on Figure 5.

Simultaneous Analysis

The values for velocity and effective porosity are taken from the point where the curves resulting from the above equations intersect. That is, the point of intersection of the curves represents the solution of two simultaneous equations in two unknowns. The intersection of these lines results in a ground-water velocity of approximately 0.8 ft/day and an effective porosity of approximately 12%.

CONCLUSIONS

Results obtained from the aquifer pumping and tracer tests at the VA site provide quantitative values of aquifer properties. The transmissivity in the vicinity of well 2 is approximately 2400 ft^2/day. The average hydraulic conductivity is assumed to be approximately 32 ft/day. Groundwater flow at the VA site is generally toward the southwest with a gradient of approximately 3×10^{-3} ft/ft. Results of the tracer and pump tests were used simultaneously to determine ground-water velocity to be approximately 0.8 ft/day. An estimate of effective porosity is about 12% using the same method. Limitations of the analyses result from the complex geologic setting. Differences in responses to pumping in wells 3 and 6 (approximately the same radial distance from the pump well) suggest aquifer anisotropy and heterogeneity. Aquifer heterogeneities may cause varying hydraulic conductivity values through the vertical profile, thus varying velocities. Clay lenses located in the lower saturated sediments of the aquifer may be acting locally as a semi-confining layer.

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APPENDIX A

DRILLERS' LOGS FOR WELLS DRILLED IN THE VICINITY OF THE VETERANS ADMINISTRATION FACILITY, TUSCALOOSA, ALABAMA

APPENDIX A

DRILLERS' LOGS FOR WELLS DRILLED IN THE VICINITY OF THE VETERANS ADMINISTRATION FACILITY, TUSCALOOSA, ALABAMA

TABLE A.1. Well 1

Depth Below Land Surface, ft	Lithology
0-18	red sandy clay
18-44	sand
44-55	clay
55-75	sand w/clay streaks
75-90	sand, coarse
90-93	sand
93-98	clay
98-115	sand
115-120	clay
120-138	sand
138-161	sticky clay
161-164	sand
164-168	clay
168-195	coarse sand
195-232	coarse sand and small gravel
232	to Pottsville

Rock at 44, 55, 63 and 161 feet
192 ft, 2 in. PVC; 40 ft, 2 in. PVC screen 0.032
Date: 5-16-89
Well at front of building

TABLE A.2. Well 2

Depth Below Land Surface, ft	Lithology
0-18	red sandy clay
18-45	sand with clay deposits
45-50	sand
50-53	clay
53-75	sand
75-90	sticky clay
90-96	clay
96-105	fine sand
105-123	sand
123-132	clay
132-150	sand
150-175	coarse sand and small gravel
175-178	clay
178-180	sand
180-192	sand and pea gravel
192-194	clay
195-210	sand and pea gravel
210	Pottsville

Rock at 70 and 74 feet
170 ft, 2 in. PVC; 40 ft, 2 in. screen 0.032
Date: 5-15-89
60 ft from production well

TABLE A.3. Well 3

Depth Below Land Surface, ft	Lithology
0-20	red sandy clay
20-45	sand
45-60	sand with clay streaks
60-80	sand
80-88	clay
88-125	sand
125-133	clay
133-140	sand
140-143	clay
143-157	sand
157-158	clay
158-161	sand
161-162	clay
162-195	sand
195-215	sand and pea gravel

215 ft bottom of sand, top of Pottsville
Rock at 27, 69, 88, 134 and 215 feet
175 ft, 2 in. PVC; 40 ft, 2 in. PVC 0.032 screen

TABLE A.4. Well 4

Depth Below Land Surface, ft	Lithology
0-16	red sandy clay
16-24	sand with clay deposits
24-30	sand
30-35	coarse sand
35-36	gumbo
36-45	coarse sand
45-55	sand
55-60	sand with clay deposits
60-70	sand
70-75	sand with clay deposits
75-79	fine sand
79-89	clay
89-94	sand
94-105	clay
105-125	fine sand
125-135	sticky clay
135-136	clay
136-150	fine sand
150-160	coarse sand
160-162	clay
162-185	coarse sand
185-189	clay
189-195	coarse sand with small gravel
195-210	coarse sand and gravel
210-220	coarse sand and fine gravel
220	Pottsville

Lost circulation at 200 ft
Rock at 20, 24, and 55 feet
180 ft, 2 in. PVC; 40 ft, 2 in. PVC screen 0.032
Date: 5-12-89
20 ft from production well

TABLE A.5. Well 5

Depth Below Land Surface, ft	Lithology
0-17	red sandy clay
17-30	sand
30-40	sand and gravel
40-58	clay
58-73	fine sand
73-87	sand with clay streaks
87-104	sand
104-115	sticky clay
115-117	sand
117-164	sticky clay
164-168	sand
168-172	clay
172-188	sand
188-191	clay
191-195	sand
195-219	sand and small gravel
219-223	clay
223-248	sand and gravel
248	Pottsville

Rock at 40, 73, 87, 92, and 164 ft
208 ft, 2 in. PVC; 40 ft, 2 in. PVC screen 0.032
Date 5-17-89
Well at back of building

TABLE A.6. Well 6

Depth Below Land Surface, ft	Lithology
0-18	sandy red clay
18-35	sand
35-62	sand with clay streaks
62-79	sand
79-85	clay
85-124	sand with clay streaks
124-130	clay
130-142	sand with clay streaks
142-175	sand

135 ft, 2 in. PVC pipe; 40 ft, 2 in. 0.032
PVC screen;
Date: 6-14-89
50 ft from production well

TABLE A.7. Well 7

Depth Below Land Surface, ft	Lithology
0-20	sand red clay
20-37	sand
37-63	sand with clay streaks
73-78	sand
78-89	clay
89-95	sand
95-102	clay
102-127	sand with clay streaks
127-134	clay
134-161	sand
161-162	clay
162-223	sand

143 ft, 10 in. PVC casing; 80 ft, 20 in. PVC
screen 0.032
Date: 6-7-89

APPENDIX B

STEP DRAWDOWN ANALYSIS

APPENDIX B

STEP DRAWDOWN ANALYSIS

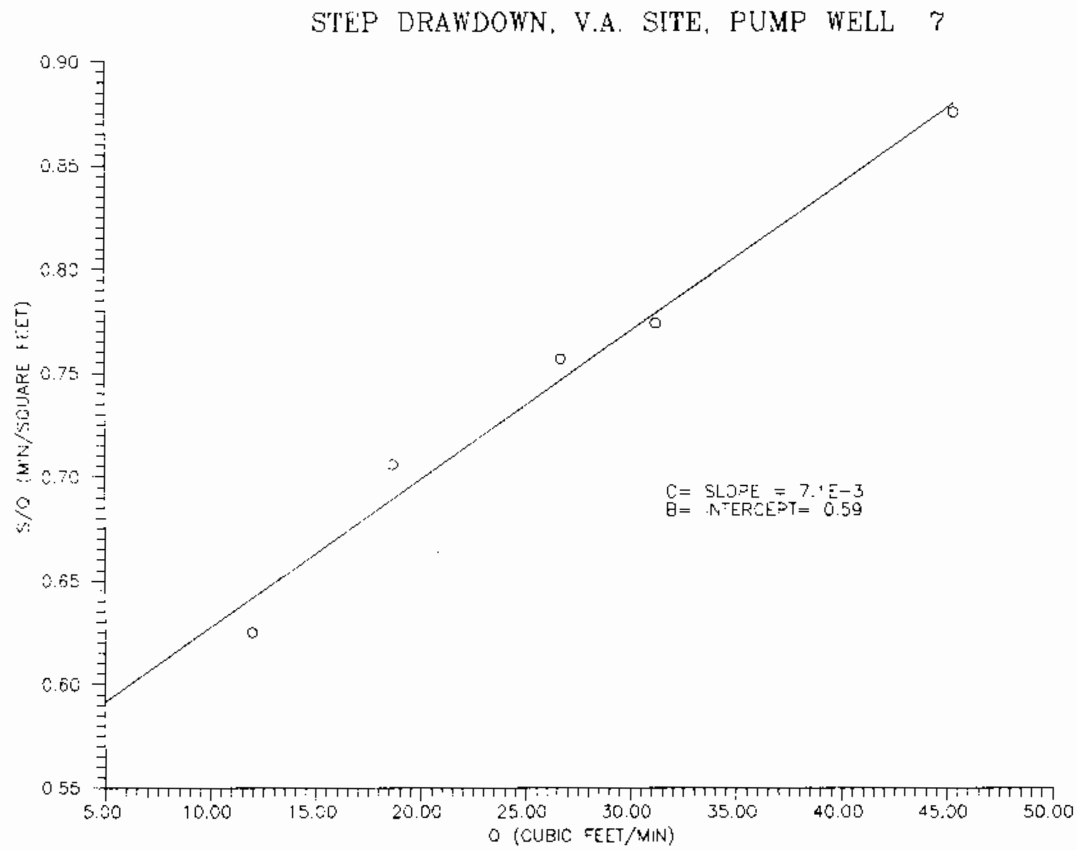

FIGURE B.1. Step Drawdown Analysis for Well 7

STEP DRAWDOWN, V.A. SITE, WELLS 3, 6, AND 7

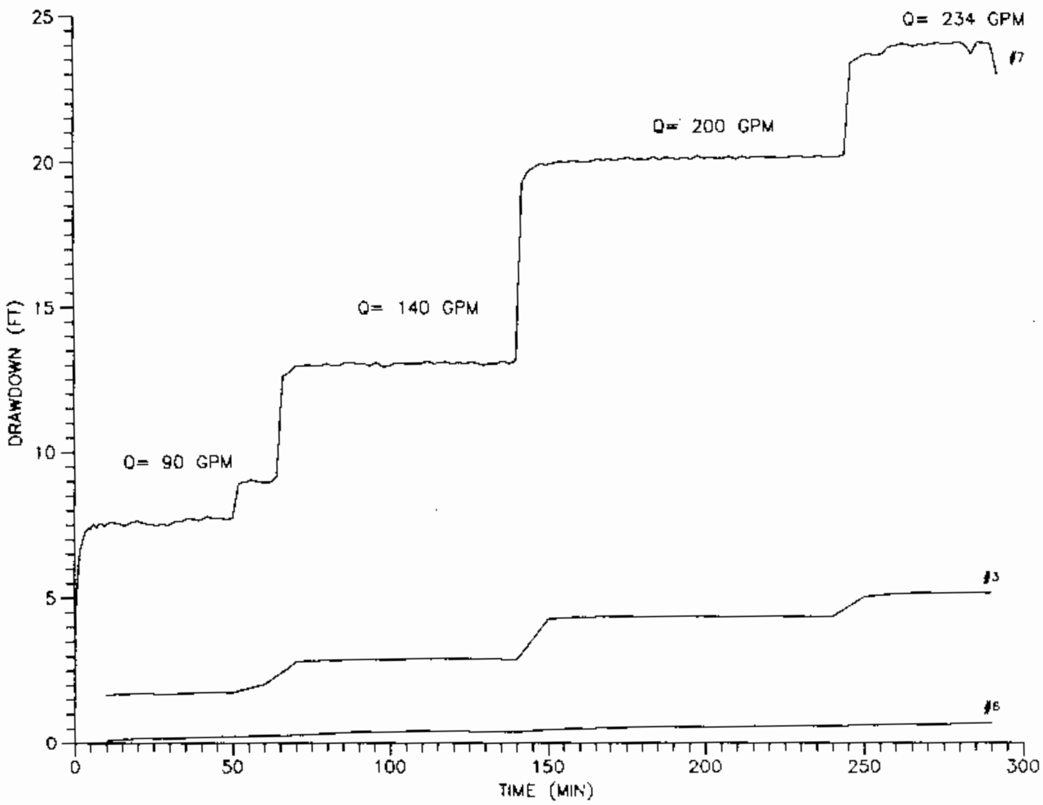

FIGURE B.2. Responses to Pumping Rates in Wells 3, 6, and 7 During Step Drawdown Test

APPENDIX C

PUMP TEST DATA

APPENDIX C

PUMP TEST DATA

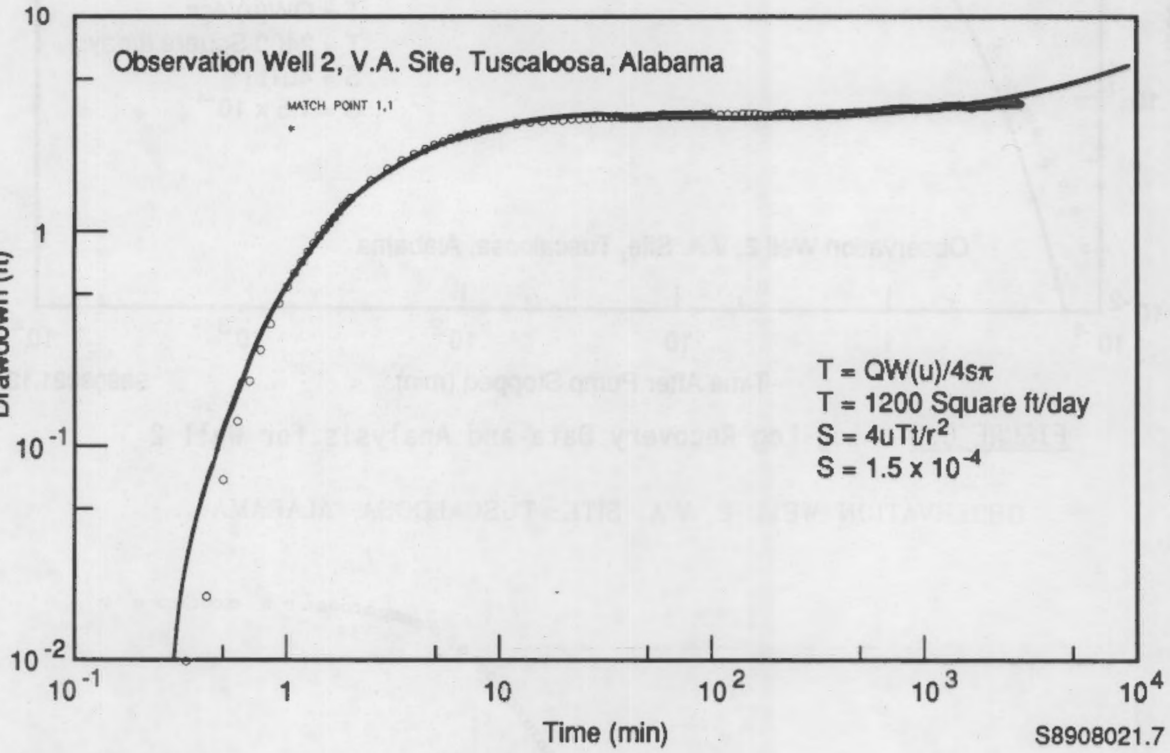

FIGURE C.1. Drawdown Data and Analysis for Well 2

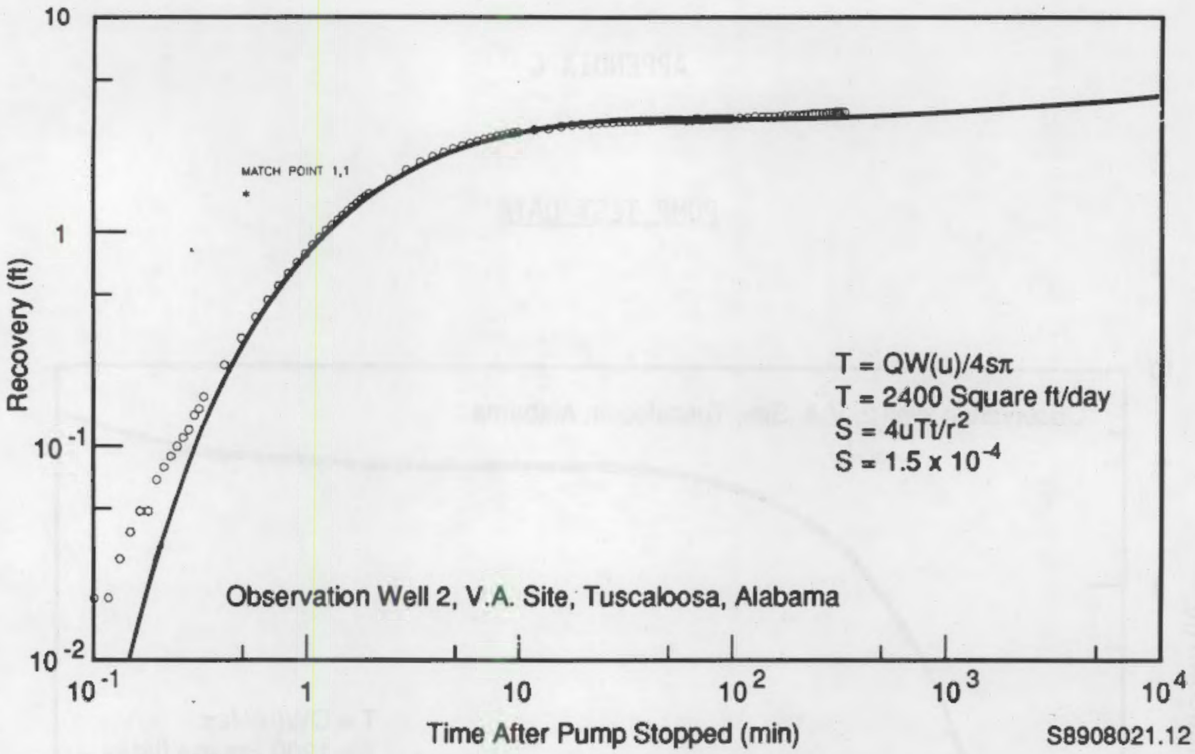

FIGURE C.2. Log-Log Recovery Data and Analysis for Well 2

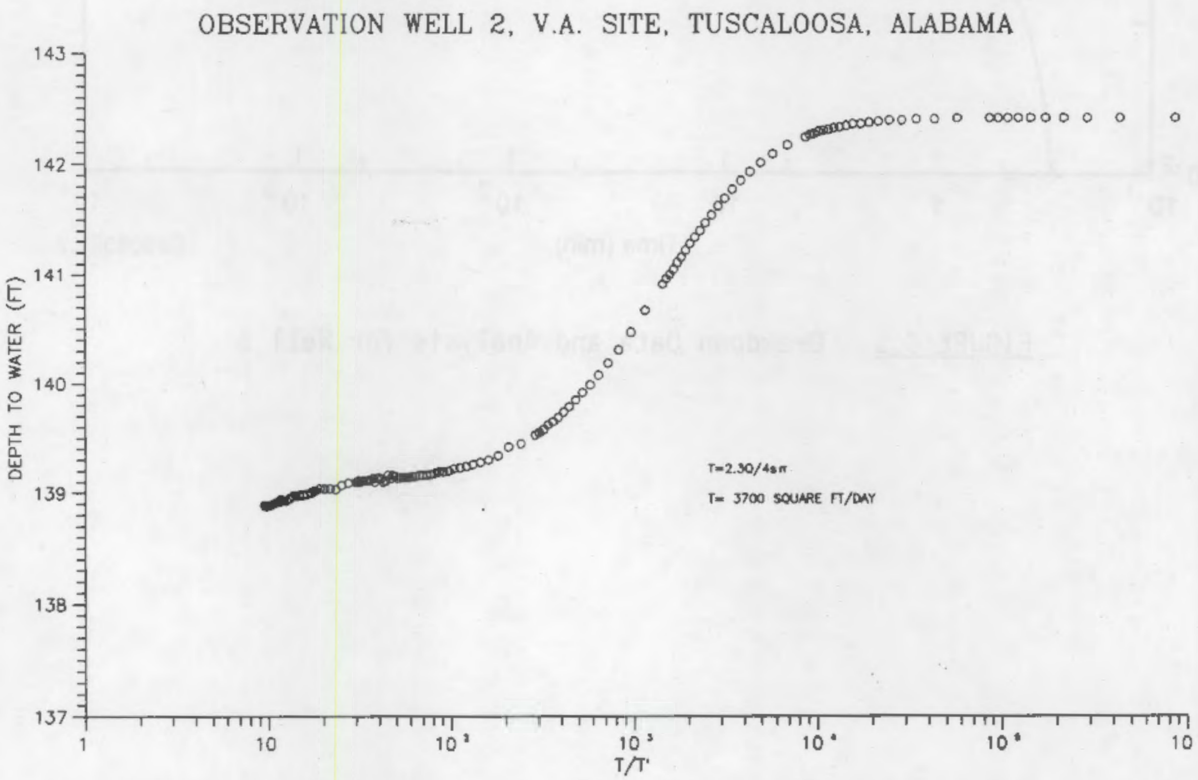

FIGURE C.3. Cooper-Jacob Semilog Recovery Data and Analysis for Well 2

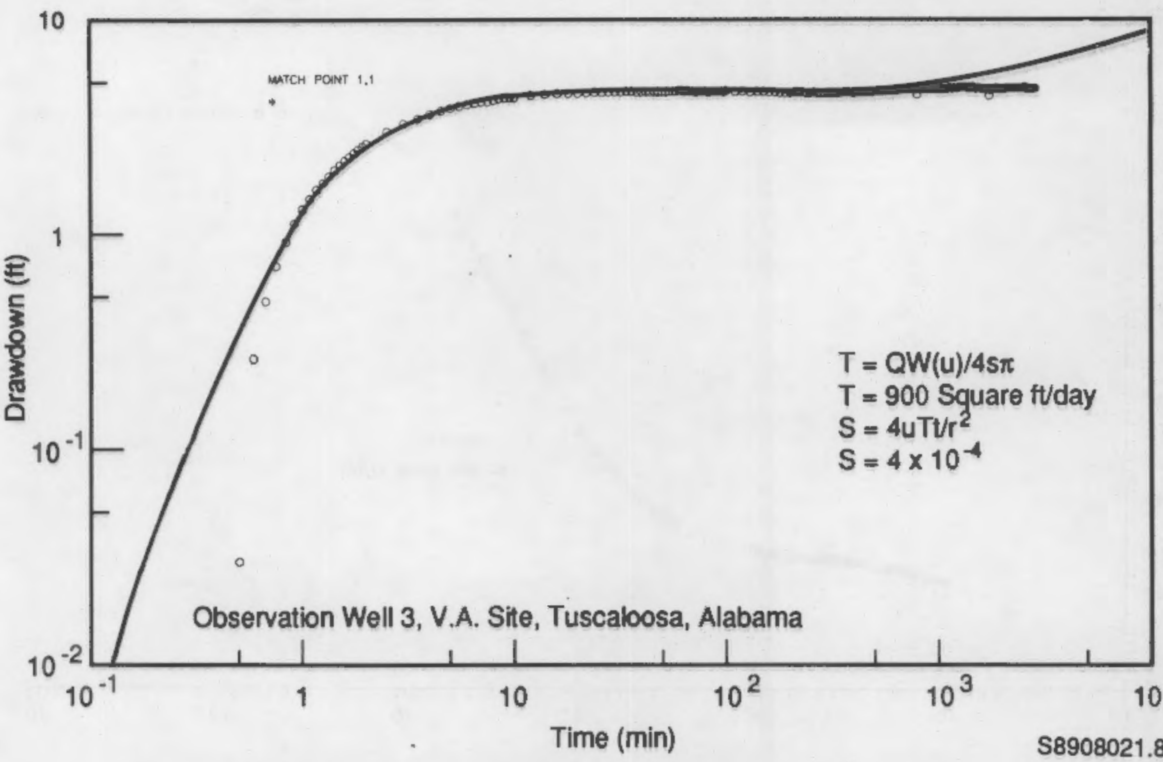

FIGURE C.4. Drawdown Data and Analysis for Well 3

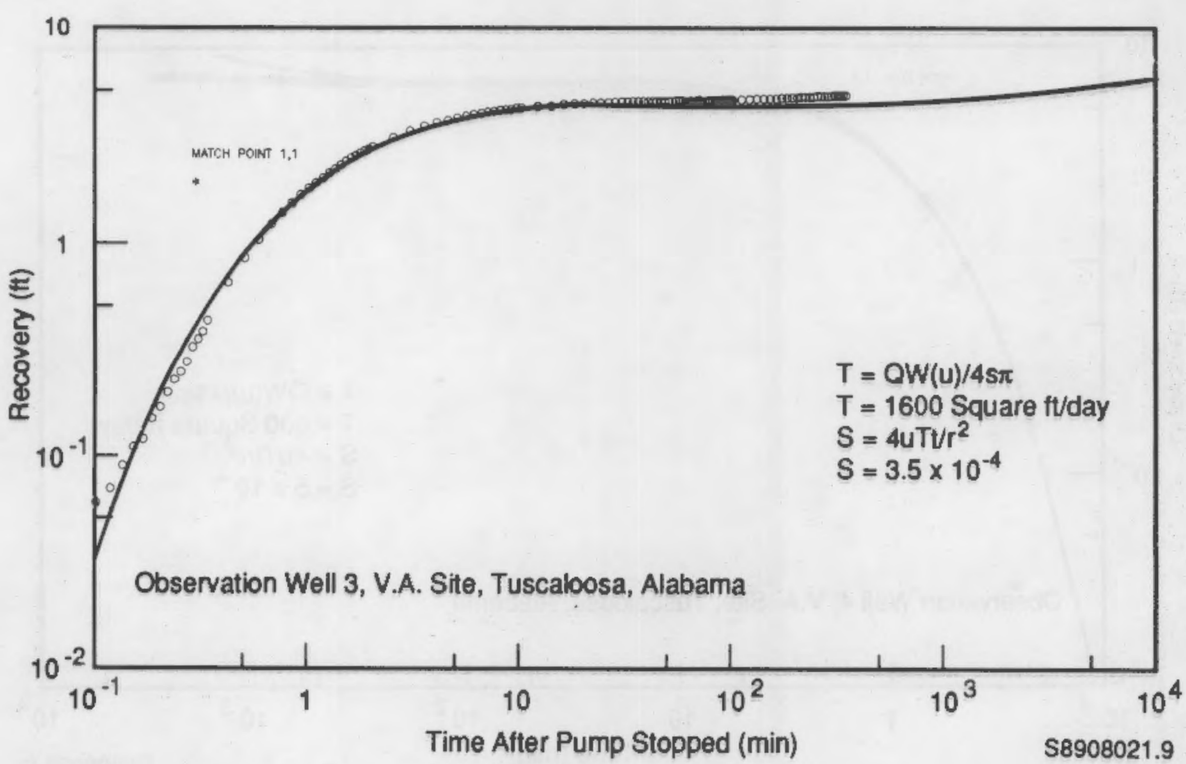

FIGURE C.5. Log-Log Recovery Data and Analysis for Well 3

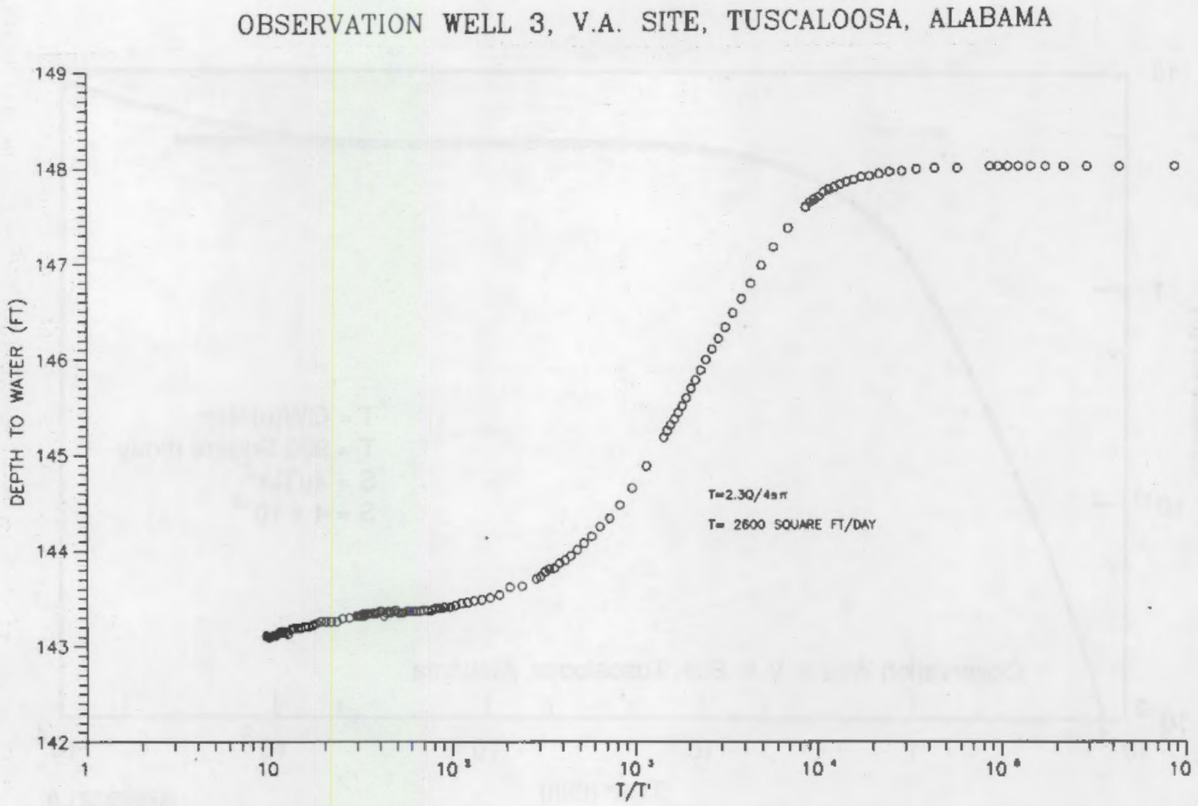

FIGURE C.6. Cooper-Jacob Semilog Recovery Data and Analysis for Well 3

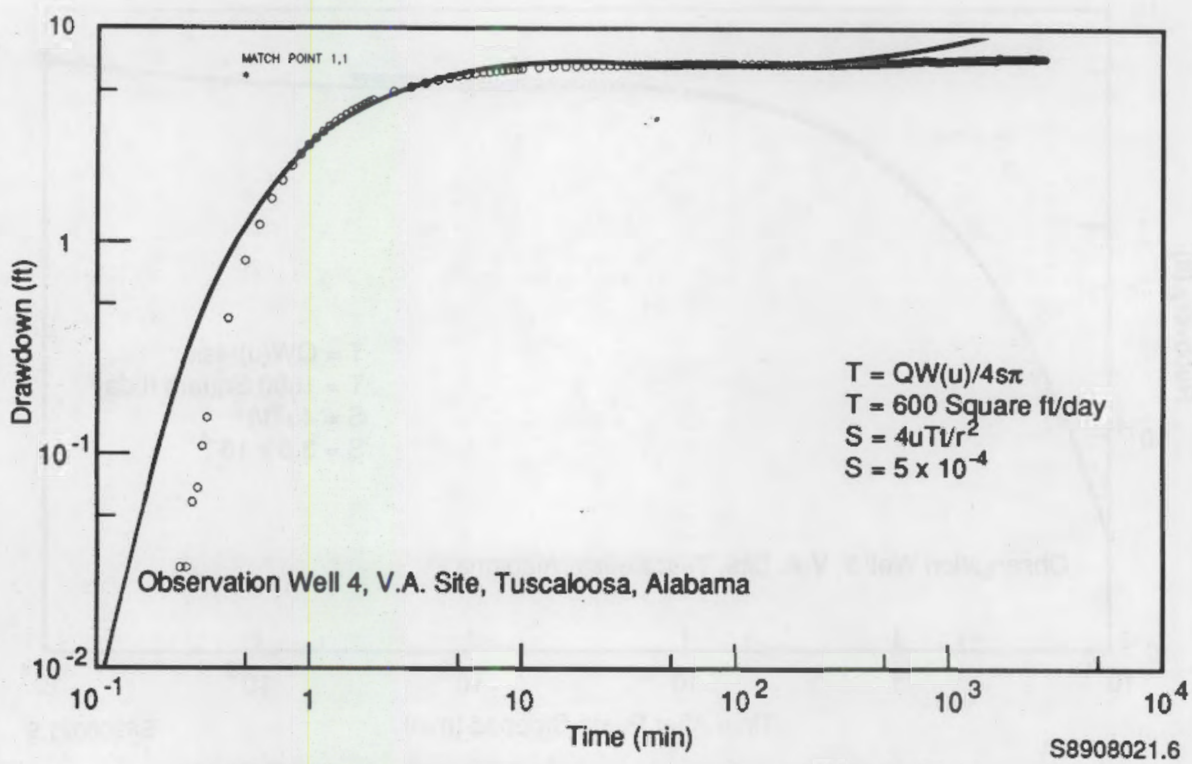

FIGURE C.7. Drawdown Data and Analysis for Well 4

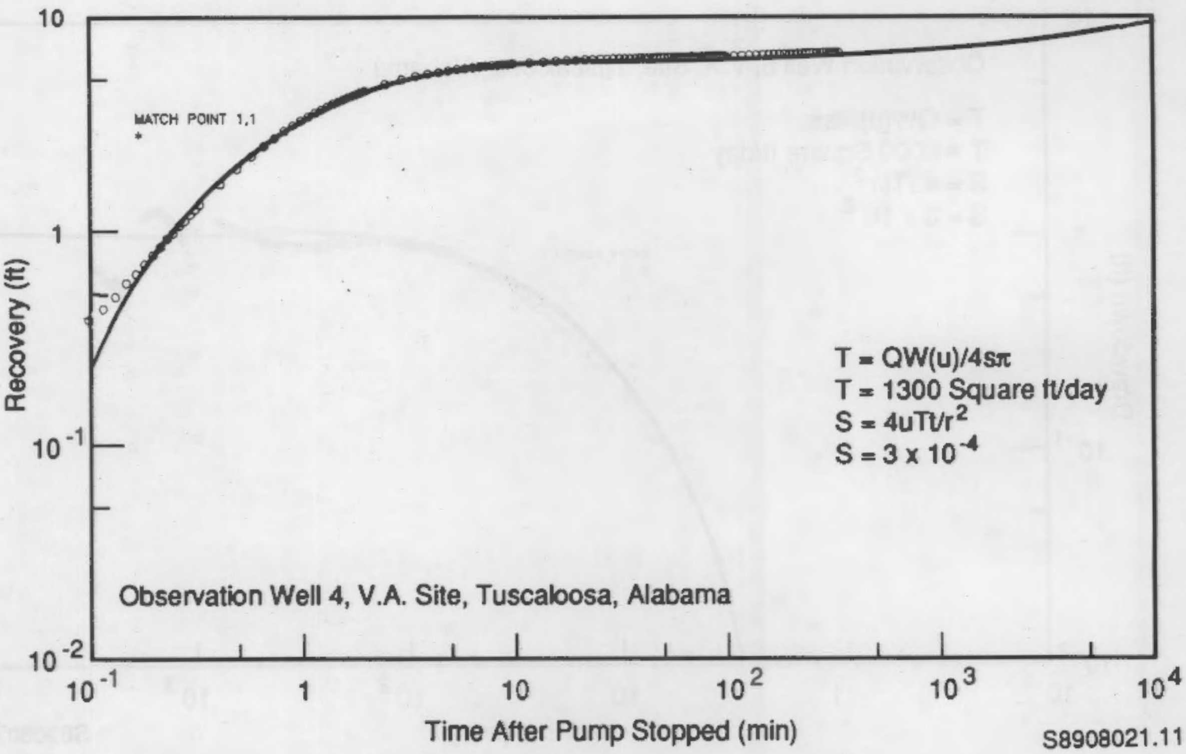

FIGURE C.8. Log-Log Recovery Data and Analysis for Well 4

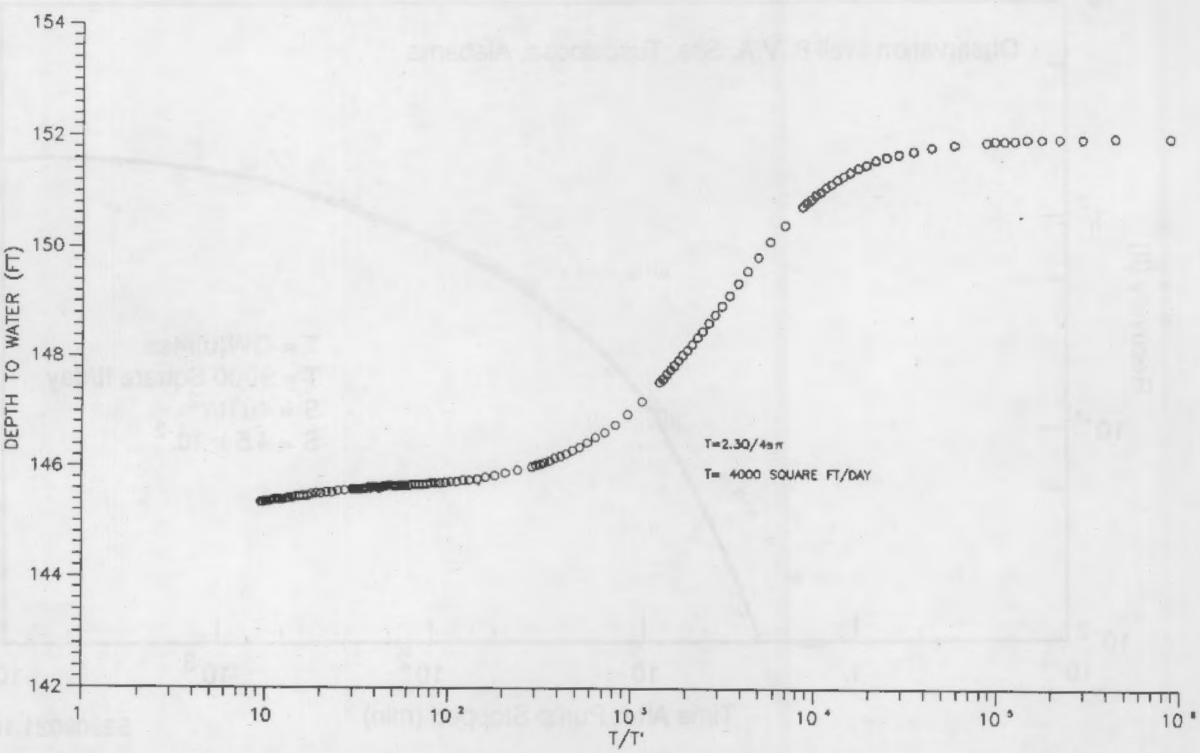

FIGURE C.9. Cooper-Jacob Semilog Recovery Data and Analysis for Well 4

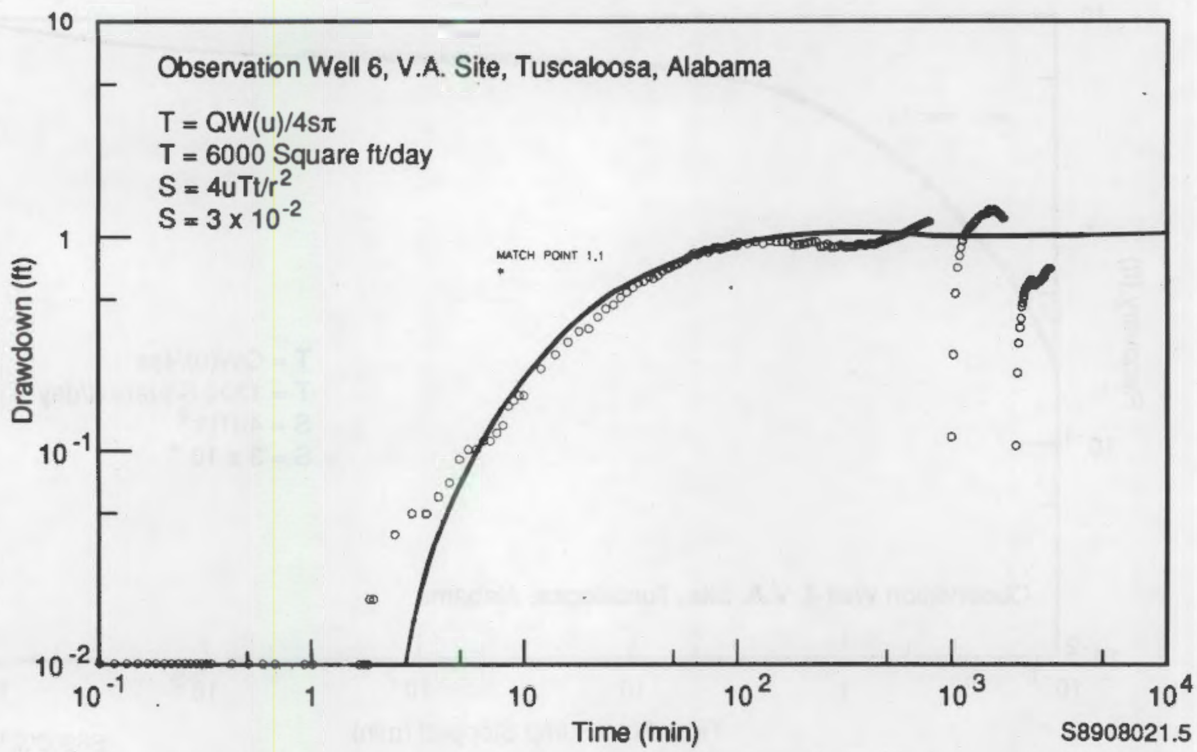

FIGURE C.10. Drawdown Data and Analysis for Well 6

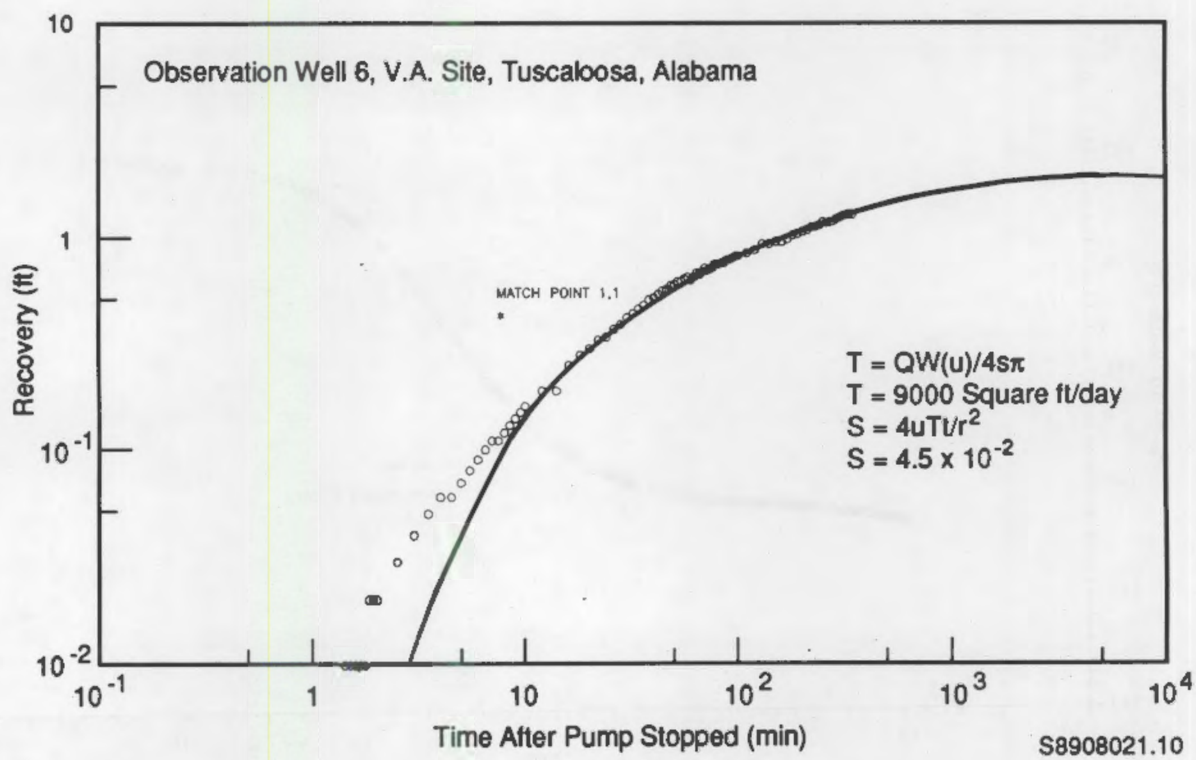

FIGURE C.11. Log-Log Recovery Data and Analysis for Well 6

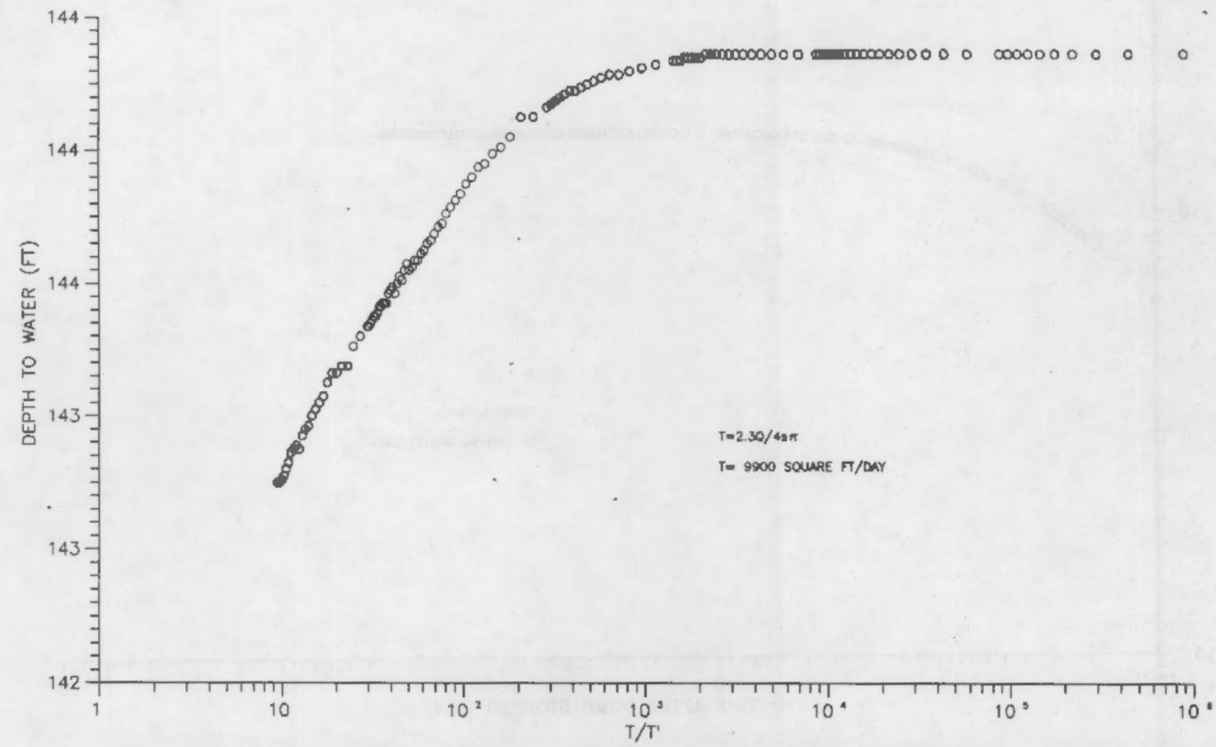

FIGURE C.12. Cooper-Jacob Semilog Recovery Data and Analysis for Well 6

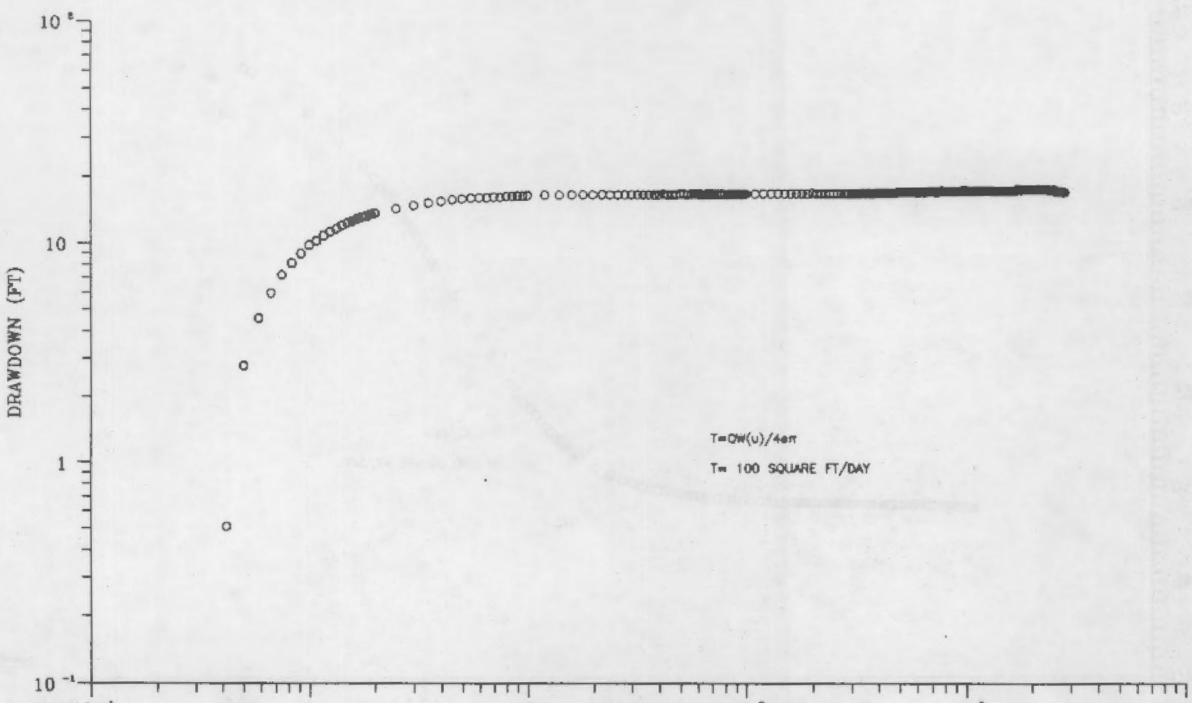

FIGURE C.13. Drawdown Data and Analysis for Well 7

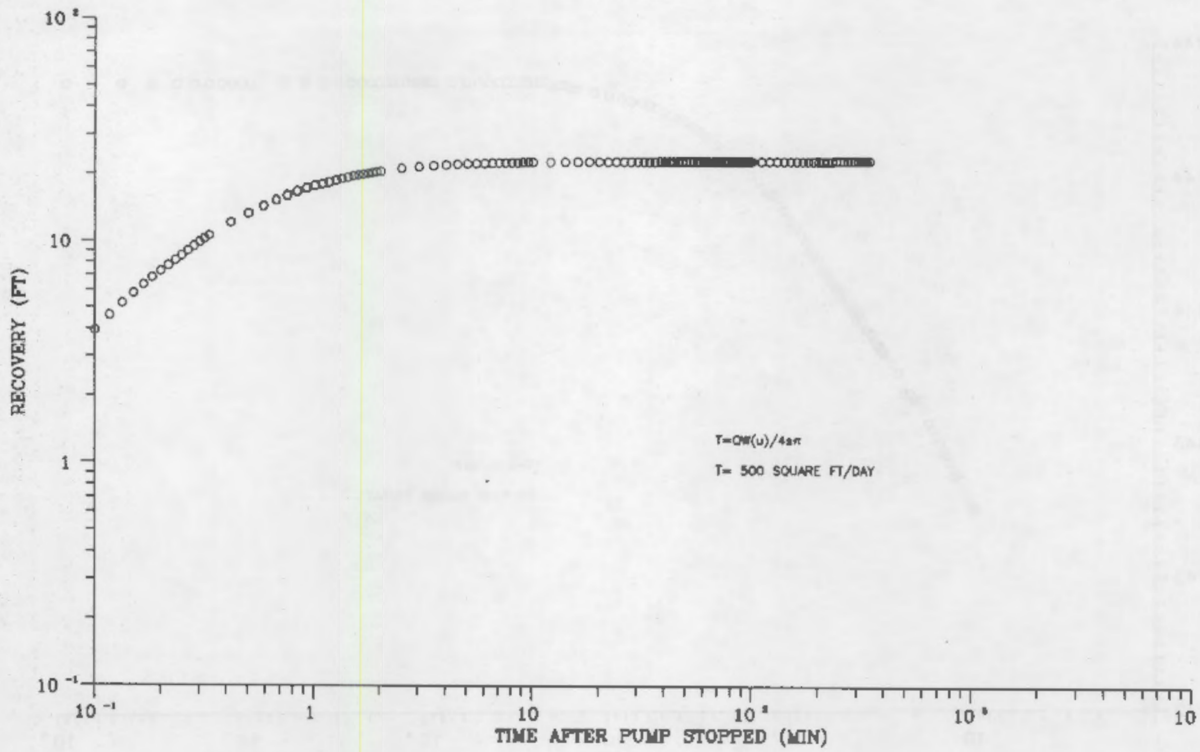

FIGURE C.14. Log-Log Recovery Data and Analysis for Well 7

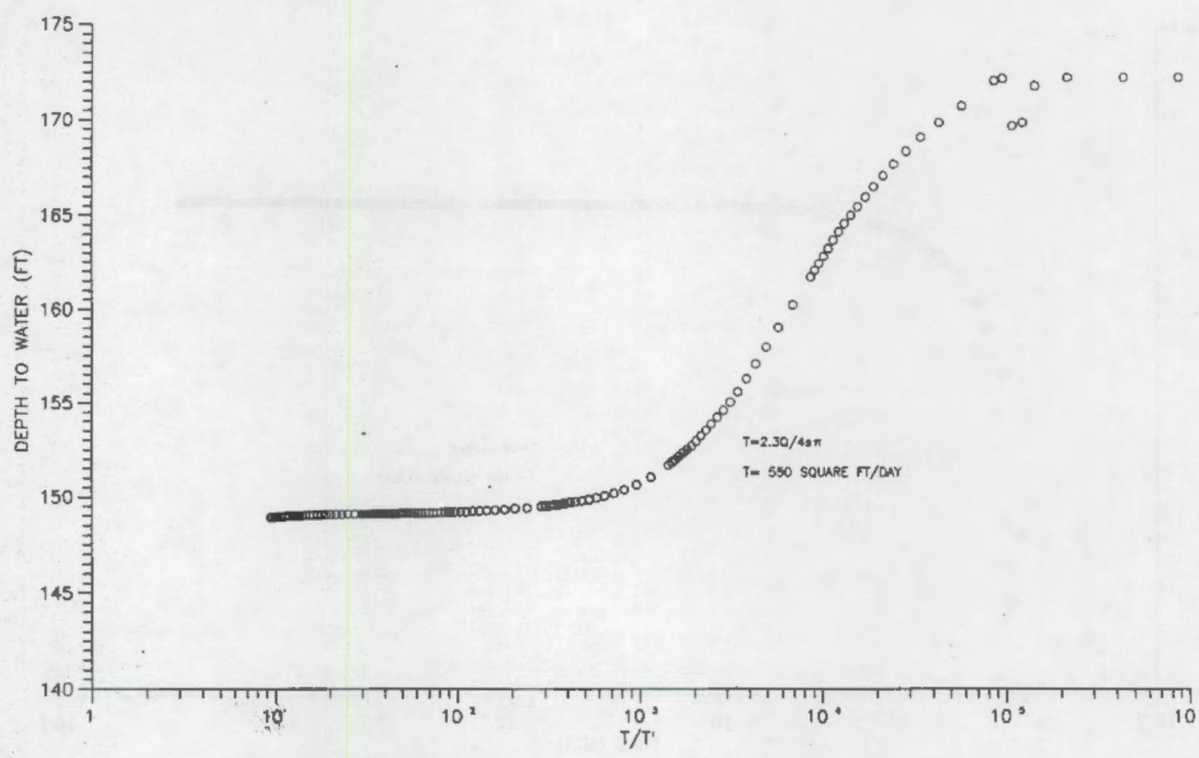

FIGURE C.15. Cooper-Jacob Semilog Recovery Data and Analysis for Well 7

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