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A Study on the Causes of Variations in Transmissivity and Storativity During Pump Tests at Asylum Lake

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A STUDY ON THE CAUSES OF VARIATIONS IN TRANSMISSIVITY AND STORATIVITY DURING PUMP TESTS AT ASYLUM LAKE

by

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A STUDY ON THE CAUSES OF VARIATIONS IN TRANSMISSIVITY AND STORATIVITY DURING PUMP TESTS AT ASYLUM LAKE

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Over a two year period, Western Michigan University ran a number of pump tests in the Asylum Lake Area in Kalamazoo, Michigan. The transmissivities and storativities calculated from these tests differed significantly from well to well in any particular test, and from pump test to pump test. Utilizing the computer programs AQTESOLV 3.0 and Aquifer Parameter Estimator, a number of T and S values were calculated. After analysis of the results, the following conclusion was drawn. The main reason for the deviations in the T and S values arose from the mixing of the results of numerous methods (some of which were confined aquifer methods). The aquifer that was affected by the pump test is an unconfined aquifer, which required an unconfined analysis method in order to get results within reasonable limits.

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CHAPTER I

INTRODUCTION

Thesis Statement

The objective of this study is to determine the reasons for the seemingly wide variance in the transmissivities and the storativities which have been observed in four different pump tests conducted over two years at the Asylum Lake study area during the Western Michigan University hydrogeological field camps.

Overview

The following study deals with the analysis and interpretation of four pump tests from the Lee Baker Farm (near Asylum Lake) Western Michigan University Hydrogeological study station in Kalamzaoo located off Drake Road between its intersections with Parkview and Stadium Drive. These pump tests were run in Spring 1993 (July 13-16), Summer 1993 (August 24-27) , Spring 1994 (June 21-24), and Summer 1994 (August 1-6). The initial purpose of these pump tests was to serve as field exercises for the WMU Hydrogeological field courses. Pump tests are used as a tool to determine the characteristics of an aquifer; specifically, how readily water flows through aquifers. This knowledge can be used in a variety of ways, such as determining water availability for a municipal well, the parameters used in designing a remediation effort, etc. In this case, the pump test was being used as an exercise to define the characteristics of the area in a systematic way. Having data for multiple pump tests in this area is an additional advantage, because it allows a degree of reproducibility, along with determining any temporal changes that may have occurred.

Short History of Hydrogeology and Pump Tests

The first person to integrate pump time and drawdown data into a single analysis method was Charles Theis (Theis, 1935). This allowed analysis of transient drawdown data to determine aquifer parameters. Previously, a pump test had to be continued until the aquifer reached steady-state conditions conditions (where recharge = discharge) in order to determine aquifer parameters. The Theis solution method includes a number of equations and a type-curve. A type-curve is a theoretical curve which is fit to measured data points in order to determine necessary information to plug into the Theis equations. This method does require a number of assumptions (called the Theis assumptions) in order for its results to be as accurate as possible:

1. Discharge from the pumping well is instantaneous with decline in pressure.

2. The well fully penetrates and is open through the entire extent of the aquifer.

3. The well's radius is very small so that in the well storage is negligible.

4. Flow to the well screen is radial, horizontal and laminar.

5. The aquifer is homogeneous and isotropic.

6. Aquifer thickness is uniform.

7. The aquifer is horizontal and bounded above and below by impermeable beds (aquifer is confined).

8. The aquifer remains saturated during the entire

pumping test.

9. The aquifer is infinite (in areal extent, no areal boundaries and thus, no recharge).

10. All water released from storage within the aquifer comes from the cone of depression (the aquifer is isolated from the overlying or underlying leaky aquifers, local recharge, precipitation, irrigation, rivers, lakes, and wetlands) (Kasenow, 1995).

Two difficulties with the Theis method are: the Theis method's curve matching technique has a strong subjective component to it and the curve matching is time/labor intensive. In 1946, Jacob and Cooper created an alternative method to the Theis curve. While it still must meet the assumptions discussed above, its results are obtained from fitting a straight-line through the test data (usually the late-time data). The need for using late-time data (or nearby observation wells) arises from the fact that there is an additional assumption in the Jacob-Cooper method. The benefits of using this method include: (a) the straight-line analysis is less subjective, (b) the time/labor is greatly reduced, and

(c) this method can be applied to different wells simultaneously, to one well over time, or both.

The disadvantages to obtaining aquifer parameters using graphs are numerous, the largest being that it is time consuming to create and there is a certain subjectivity in the actual construction and interpretation. Therefore, Sheahan (Sheahan, 1967) created a method for calculation of T and S without a Theis graph (but using the Theis equations), therefore making the technique more efficient. Using a list called the Z(u) list, Sheahan developed a method to obtain u and W(u), needed for the Theis equations. The difficulty involved was that it was time consuming to do this method by hand, and it was not until computers became more readily avaiable this method was incorporated into a computer program. An adaption of Sheahan's method was used in Aquifer Parameter Estimator.

The above discussion of pump test data analysis considered only confined aquifer solutions. Although these equations can be modified to simulate an unconfined solution, they are not true unconfined aquifer solutions. This makes the results suspect. One such solution was used this study, based on the work of Neuman (1974, 1975). He created a solution which would analyze delayed yield behavior in an aquifer. The delayed yield effect is caused by the aquifer pores dewatering during the test (Bouwer, 1978). This causes the graph to become flat in the middle, thereby deviating from the Theis curve. Neuman essentially created a solution to match both parts of the S-shaped curve produced by the pump test data on log-log axes. The transmissivity and storativity can then be obtained from curve matching and using the matched points in his equations.

Both Theis (Theis, 1935) and Jacob (Jacob, 1963) created equations and graphs that allowed transmissivity to be calculated using the data obtained as the wells recover after the pump has been turned off. Both these methods use the water level measurements as the wells recover, called residual drawdowns (or drawup), and these points are plotted on graphs (both Theis and Jacob recovery techniques are straight line methods). In more recent times, Kasenow (1995) created a method allowing the Theis equations to be implemented using a non-graphical technique. Kasenow's method allows the storage coefficient to be obtained. While Kasenow was not the first person to come up with such a method, he was the first to implement it in a fashion which could be used quickly in a non-graphical fashion.

Location

The pump tests were run on the Lee Baker Farm (near Asylum Lake) Western Michigan University Hydrogeological study station in Kalamazoo located off Drake Road between its intersections with Parkview and Stadium Drive. The aquifer pumped is an unconfined aquifer.

Lithology

In the study area, the soils at depths between 1 to 3 feet are a mixture of fine/medium sand, loamy soil, and organics. From 3 feet down to a clay layer at 180 feet, the aquifer consists of sand ranging from fine to medium grained. From a number of wells installed in the area, both lenses of very fine material (very fine sand to almost silt) and coarse material (pebbles) have been observed. These lenses appear random and non-uniform throughout the area.

Well Design/Configuration

The site is during this study was configured with a pumping well and four observation wells (Figure 47, Appendix G). The pumping well is designated as AL-4; it is a 5.25 inch diameter steel cased well installed by cable tool rig. It is screened from 74 to 89 feet below the surface, using a 10 slot stainless steel screen from 74 to 84 feet and a 15 slot stainless steel screen from 84 to 89 feet. The pump is a 5 horsepower Flint and Walling submersible pump. The observation well AL-18 is 45.67 feet east of AL-4, and is screened from 55 to 70 feet (Figure 45, Appendix G). There are two observation wells on the west side of AL-4. AL-1 is 23.75 feet from AL-4 and is screened from 80 to 95 feet. AL-27 is 64.67 feet from AL-4 and is screened from 63 to 78. AL-28 is 52.75 feet north of AL-4 and is screened from 63 to 78 feet (Figure 46, Appendix G). All observation wells are 2 inch PVC wells, with 10 slot PVC screens.

CHAPTER II

METHODOLOGY

Test Specifications

Four data sets were used in the analysis. The first data set was collected in the Spring 1993 Hydrogeology field camp. AL-1, AL-4, and AL-18 were used in the analysis of the pump test. The pumping rate was 73.7 gallons per minute (gpm) over a 48 hour period. The Summer 1993 Hydrogeology field camp used AL-1, AL-4, and AL-18 in the analysis. The pumping rate was 77.3 gpm for 50 hours and 45 minutes. AL-1, AL-4, and AL-18 were used for the Spring 1994 analysis; the test ran for 51 hours and 30 minutes at a rate of 71 gpm. Finally, the Summer 1994 test analysis used AL-1, AL-4, AL-18, AL-27, and AL-28. The pumping rate was 67.5 gpm for 97 hours.

Computer Programs Used in Analysis

The four sets of data were analyzed using both pump test equations and recovery equations. Two computer programs were used in the analysis of the data: Aquifer Parameter Estimator 1.0-3.0 (APE) and AQTESOLV 2.0. AQTESOLV 2.0 is published by Geraghty & Miller Modeling Group and APE is published by Water Resources Publications. The analysis with APE included: Jacob-Cooper Regression Analysis, Theis Sensitivity Analysis, Theis Time-Drawdown Analysis, and Theis Recovery Analysis. In the AQTESOLV program, the following analyses were used: Jacob-Cooper time-drawdown analysis using visual curve matching or statistical curve matching, Theis method using visual curve matching and statistical curve matching, Neuman method (both visual and statistical curve matching), and Theis recovery using both the curve matching and statistical options. The graphical results are presented in Appendices A-E.

Equations

The following equations are the basic equations used in the analysis of pump test data. The other equations (presented later) are derivatives of these equations.

Theis

$Z(u) = s(1/2t)/s(t)$

$T = 144.6*Q*W(u)/s$

$S = uTt/1.8r^2$ (Kasenow, 1995)

s = drawdown at time t = ft

T = transmissivity = gpd/ft

S = storage coefficient or specific yield = unitless

Q = pump rate = gpm

W(u) = Theis parameter

u = Theis parameter = r^2*S/(4*T*t)

r = observation well distance = ft

Jacob-Cooper

$T = (264*Q)/\Delta s$

$S = (0.3*T*t(o))/r^2$

Δs = slope of straight line data fite over one log cycle = ft

t(o) = time of zero drawdown on straight line = min

Recovery

$T = 264*Q/(\Delta s') = 114.6*Q/s'*\ln(t/t')$ (Kasenow, 1995)

$\Delta s'$= slope (rise over one log cycle) of residual drawdown = ft

t = time duration of pumptest + residual time = min

t'= residual time = time since pumping ceased = min

s' = residual drawdown

Aquifer Parameter Estimator

The program APE, Aquifer Parameter Estimator, is a groundwater analysis program based on the work of prior hydrogeologists, with further developments by Michael Kasenow (Kasenow, 1995). The version published in 1993 and further embellished versions were used throughout this study. It has modules that can handle anything from steady-state data to pumping well data to observation well data, using a variety of methods and techniques. The main solutions used were: a Theis-z(u) time-drawdown method, a regression analysis time-drawdown method, a sensitivity analysis method, and a Theis-Z(u) recovery and regression analysis method for observation well data. Pumping well data sets were analyzed using a Theis-Z(u) recovery and regression analysis solution.

Theis-z(u) Time-drawdown Solution

This method uses time-drawdown data, calculating a transmissivity and a storativity for each point. This is accomplished using the equation

$$Z(u) = s(1/2t)/s(t)$$ (Kasenow, 1995)

The power of this equation lies in the fact that this value has been calculated, it is related to the list of u and W(u) values which are part of Theis' equations. This list is searched and an interpolated matched u and W(u) are found. T and S are then calculated for this particular data point. These individual T and S values are then averaged for a range of data points. The information output to the user includes a the list of these T and S values, along with the slope at each point. One can use the slope, T, and S values to look for trends, and thereby take only a select interval of points to calculate one's final T and S values.

Regression Analysis Time-drawdown Solution

This takes time-drawdown data and uses a least-squares statistical approach to determine the T and S values. The following equations are used obtain the needed information to calculate T and S.

$$m = [n(\Sigma XY) - (\Sigma X)(\Sigma Y)] / [n(\Sigma X^2) - (\Sigma X)^2]$$

$$b = [(\Sigma Y)(\Sigma X^2) - (\Sigma X)(\Sigma XY)] / [n(\Sigma X^2) - (\Sigma X)^2]$$

m = slope of least-squares line fit through the data = ft

n = # of data points

b = y-intercept = ln(t(o))

ΣX = summation of the natural log of the times

ΣY = summation of the drawdowns = ft

ΣX^2 = summation of the square of the natural log of the times

$\Sigma XY = \Sigma X * \Sigma Y$

With these variables, T and S can be calculated using the equations

$$T = Q / (4)(P)(m)$$

$$S = [2.25(T) / r^2][\mathrm{Exp}[(-4)(P)(T)(b) / Q]]$$
(Khan,1982)

Q = discharge = gpm

r = observation well distance = ft

It is also possible to calculate the correlation coefficient, R. R is a guage of the adequacy of the line fit. The value of R approaches 1.0 as the line fit approaches perfection. The equation for R is:

$$R = [n(\Sigma XY) - (\Sigma X)(\Sigma Y)] / \{[n(\Sigma X^2) - (\Sigma X)^2][n(\Sigma Y^2) - (\Sigma Y)^2]\}^{1/2}$$

ΣY^2 = summation of the drawdowns squared = ft^2

Sensitivity Analysis

In this approach, a preliminary T and S are calculated and then these values are slowly changed by minor increments, until both of them (simultaneously) fit within certain tolerance limits.

Recovery Analysis

This method uses residual drawdown data and a number of unique equations to calculate T and S. The following equations are used in order to calculate T and S.

$$T = (114.6 * Q) * s' * \ln(t/t')$$

$$m = (264)(Q) / T$$

$$t(o)' = -[s(off) + \{(m)(\log(t/t'))\} - s'] / m$$

$$S = (0.3)(T)(t(o)') / r^2$$ (Ulrick and Associates, 1989)

Q = pumping rate = gpm

t' = time since pump was turned off = min

t = total time of pump test + t' = min

s' = residual drawdown = ft

m = slope of straight-line fit = ft

t(o)' = time of zero recovery = min

s(off) = drawdown when pump was turned off = ft

r = observation well distance = ft

Just as in the Theis Z(u) method, T and S are calculated for each residual time-drawdown point. An average of these T and S values is then calculated. It is possible to take an interval of residual time-drawdown points, and obtain the average T and S values from this. The interval is based on looking at a consistency in the slopes calculated and upon the T and S values determined. This solution method appears best because this data set does not have the inherent error present in time-drawdown data from the pumping phase; that is, data from the pumping phase has fluctuations caused by turbulence in the well, oscillations in the well, and a plethora of other mechanical type variations.

CHAPTER III

RESULTS

Previous Methods

Prior to this study, a consistent analysis of the data from these pump tests had never been carried out. During the field camps, the data was split among groups who did the analysis in their own manner. Differences in method occured, such as: entering the data differently (for example, taking the drawdown when it first appears versus when it appears last), using different computer programs for different methods, using slightly different numbers of observation well distances, using slightly different numbers for pump rates, etc. None of these differences, however, can account for the variance seen from test to test, or from well to well. The most probable reason for the differences is because methods used were inapplicable to this situation. The analyses done by the groups were mainly Theis methods, while this unconfined aquifer requires delayed-yield solutions. In order to correct this problem, the Neuman method in AQTESOLV 2.0 was used; both the analytical and the graphical aspects were utilized. The results (as shown in Tables 9 and 10) showed better consistency from well to well and from year to year than the Theis and/or Jacob-Cooper derived solutions.

Theis Methods

Variations in T and S were wide (Tables 1 through 8). At times the transmissivity or storativity are fairly close to one another from two different wells (or pump tests), but the other parameter (T or S) is a great deal different. The Theis (statistical) method for AL-18 for Spring 93 and Summer 93, is one example. The T is of similar magnitudes for the two, but the storativities differ by a whole order of magnitude. The limitations of the confined methods is apparent in the actual graphical matches (Appendices A, B, C, D, and E). The most apparent ones occur is in the Theis curve matches. Most of the matches only approximate half of the curve, indicating a different solution was needed.

Table 1

Transmissivity (gpd/ft) and Storativity Results
From AL-1 for 1993

	Spring		Summer	
	T	S	T	S
APE				
Regression	79986	.0076	85014	.0042
Sensitivity	84162	.0029	85333	.0026
Theis-Zu	62775	.0348	89022	.0072
Recovery-> Theis	67444	.0264	82046	.0040
Regression	67368	.0254	86242	.0030
AQTESOLV 2.0				
Theis (g)	68354	.0205	61600	.0300
J-C (g)	65090	.0243	57895	.0386
Recovery-> Theis (g)	52035	-----	57722	-----
Neuman (g)	61966	.0306	62936	.0249
Neuman (n)	61967	.0306	62904	.0249

g = graphical
n = numerical

Neuman Methods

The matches of the Neuman curve (Appendices A through E) are moderately close, and the results for wells are within a similar range. The major exception is Summer 1993 data, which shows highly suspect T and S values.

Table 2

Transmissivity (gpd/ft) and Storativity Results From AL-1 for 1994

	Spring		Summer	
	T	S	T	S
APE				
Regression	95969	.0044	75285	.0011
Sensitivity	99779	.0014	75953	.0088
Theis-Zu	-----	-----	-----	-----
Recovery-> Theis	86148	.0069	78744	.0073
Regression	88525	.0058	76401	.0081
AQTESOLV 2.0				
Theis (g)	58484	.0814	65036	.0263
J-C (g)	59058	.0753	59133	.0384
Recovery-> Theis (g)	77757	-----	50904	-----
Neuman (g)	55606	.1039	65919	.0244
Neuman (n)	55471	.1039	65918	.0243

g = graphical
n = numerical

One indirect piece of support for using the Neuman method for this aquifer is that T and S from data set to data set vary much less. That is, a similar T shows a similar S in many more cases using this method. The Neuman method results are much closer to one another than with the confined Theis-type solutions.

Table 3

Transmissivity (gpd/ft) and Storativity Results
From AL-4 for 1993

		Spring		Summer	
		T	S	T	S
APE					
Recovery->	Theis	72203	-----	72686	-----
	Regression	69466	-----	74896	-----
AQTESOLV 2.0					
Recovery->	Theis (g)	46574	-----	48739	-----

g = graphical

Table 4

Transmissivity (gpd/ft) and Storativity Results
From AL-4 for 1994

		Spring		Summer	
		T	S	T	S
APE					
Recovery->	Theis	81753	-----	65764	-----
	Regression	87492	-----	68218	-----
AQTESOLV 2.0					
Recovery->	Theis (g)	51508	-----	46327	-----

g = graphical

Table 5

Transmissivity (gpd/ft) and Storativity Results
From AL-18 for 1993

	Spring		Summer	
	T	S	T	S
APE				
Regression	85069	.0102	84737	.0211
Sensitivity	64829	.0400	69064	.0455
Theis-Zu	57619	.0712	68005	.0668
Recovery-> Theis	78916	.0216	77747	.0333
Regression	84771	.0185	79052	.0322
AQTESOLV 2.0				
Theis (g)	62591	.0500	55428	.0902
J-C (g)	57324	.0642	83754	.0576
Recovery-> Theis (g)	54297	-----	46887	-----
Neuman (g)	58379	.0635	56839	.0770
Neuman (n)	58377	.0616	56837	.0770

g = graphical
n = numerical

Table 6

Transmissivity (gpd/ft) and Storativity Results
From AL-18 for 1994

	Spring		Summer	
	T	S	T	S
APE				
Regression	83343	.0301	56151	.0763
Sensitivity	54622	.1626	52065	.1066
Theis-Zu	-----	-----	-----	-----
Recovery-> Theis	94373	.0226	72393	.0316
Regression	99247	.0208	74224	.0301
AQTESOLV 2.0				
Theis (g)	72253	.0589	59704	.0703
J-C (g)	50032	.1650	54254	.0883
Recovery-> Theis (g)	54157	-----	53522	-----
Neuman (g)	40930	.2500	51121	.0790
Neuman (n)	45055	.2275	51055	.0799

g = graphical
n = numerical

Table 7

Transmissivity (gpd/ft) and Storativity Results
From AL-27 for 1994

	Spring		Summer	
	T	S	T	S
APE				
Regression	-----	-----	95210	.0201
Sensitivity	-----	-----	70123	.0753
Theis-Zu	-----	-----	-----	-----
Recovery-> Theis	-----	-----	69196	.0946
Regression	-----	-----	76083	.0828
AQTESOLV 2.0				
Theis (g)	-----	-----	64853	.0861
J-C (g)	-----	-----	65111	.0762
Recovery-> Theis (g)	-----	-----	53672	-----
Neuman (g)	-----	-----	59241	.1000
Neuman (n)	-----	-----	62439	.0936

g = graphical
n = numerical

Table 8

Transmissivity (gpd/ft) and Storativity Results
From AL-28 for 1994

	Spring		Summer	
	T	S	T	S
APE				
Regression	-----	-----	79157	.0207
Sensitivity	-----	-----	72678	.0372
Theis-Zu	-----	-----	-----	-----
Recovery-> Theis	-----	-----	74393	.0356
Regression	-----	-----	78147	.0320
AQTESOLV 2.0				
Theis (g)	-----	-----	71542	.0349
J-C (g)	-----	-----	67363	.0391
Recovery-> Theis (g)	-----	-----	52466	-----
Neuman (g)	-----	-----	64732	.0500
Neuman (n)	-----	-----	62472	.0476

g = graphical
n = numerical

Table 9

Neuman Solution Transmissivity(gpd/ft) and Storativity Results From 1993 (Compilation)

	Spring		Summer	
	T	S	T	S
AL-1				
Neuman (g)	61966	.0306	62936	.0249
Neuman (n)	61967	.0306	62904	.0249
AL-18				
Neuman (g)	58379	.0635	56839	.0770
Neuman (n)	58377	.0616	56837	.0770

g = graphical
n = numerical

Table 10

Neuman Solution Transmissivity (gpd/ft) and Storativity Results From 1994 (Compilation)

	Spring		Summer	
	T	S	T	S
AL-1				
Neuman (g)	55471	.1039	65919	.0244
Neuman (n)	55606	.1039	65918	.0243
AL-18				
Neuman (g)	40930	.2500	51121	.0790
Neuman (n)	45055	.2275	51055	.0799
AL-27				
Neuman (g)	-----	-----	59241	.1000
Neuman (n)	-----	-----	62439	.0936
AL-28				
Neuman (g)	-----	-----	64732	.0500
Neuman (n)	-----	-----	62472	.0476

g = graphical
n = numerical

CHAPTER IV

DISCUSSION

The variances in transmissivity and storativity had a number of different causes. These causes included: previous methods of analysis were insufficient, oscillation of the pump, the flow meter worked improperly, lack of development of the pumping and observation wells, and minor changes in lithology in the subsurface.

Difficulties Involved in Each Pump Test

July 1993

There were a number of difficulties encountered during this field session. During this time period it rained intermittently for both pumping and recovery phases. This could lead to errors in two ways. First, there could have been some recharge present from the rain and second, the rain makes measuring water levels difficult. The pumping rate also fluctuated from 69 gpm to 74 gpm, which could lead to errors in the results.

August 1993

During this session, the pumping rate varied from 74 gpm to 78 gpm. Normal human errors were involved, such as different people reading the water levels slightly differently, darkness makes taking water level measurements at night difficult, and a variety of other difficulties.

June 1994

During this pump test the pump oscillated by an increasing amount (in comparison to previous years), ranging from 65 gpm to 72 gpm. There were large quantities of rain during the recovery period, which leads to both human errors and possibly aquifer recharge errors. In addition, no data were obtained from AL-27 since it required developing in the middle of the pump test.

August 1994

It rained during the pump test, but to a lesser degree than in previous years. The pump again oscillated during this pump test, to approximately the same degree as in the previous pump test, ranging from 64 gpm to 70 gpm. In addition, the students were running two pump tests. This required the water level measurements needed to be taken in a quicker succession and the measurements were taken with different water level meters. In past pump tests dedicated meters were used to avoid mechanical error associated with using different meters.

Difficulties With the Flow

One difficulty involved in any pump test is trying to keep the pump running as steady as possible, in order to assure a consistent pump rate. In order to use the solutions used in this study one must have a constant pumping rate (Kasenow, 1995). Unfortunately, the pump rate varied during all the pump tests. While this is not the largest factor involved in the variances of T and S, the pump rate is very important in their determination. As such, variances in the pump rate could cause inconsistences in the data obtained. Combined with the factors already discussed, this could explain the variances from test to test. This however, does not explain the variances seen from well to well in a single test.

Development Concerns

The pumping well was installed with a cable tool rig, observation well AL-1 was installed using hollow stem auger, and the other observation wells were installed with mud rotary. All disturb the formation as they are installed, but most dramatically mud rotary. Mud rotary clogs the formation around the bore hole, leading to a alteration in the true lithology of the formation. The pumping well and the observation well may also have been developed differently from each other and/or insufficiently. Any of these factors could lead to differences in the T and S values within the same pump test or different tests.

Changes in Lithology

Overall at the site, the lithology stays fairly constant. Observation well AL-1 was drilled using the hollow stem auger technique, with a large number of split spoon samples being taken (Figure 48, Appendix H). These samples (along with others taken from wells drilled at the site) indicate the lithology is mainly a fine-grained sand, with lenses of gravel or very fine sand or silt. Therefore, while the material varies to a minor extent, the actual lateral variation in the area is fairly small. One cavet should be made to the above statements. Three of the observation wells were drilled with mud rotary techniques, and the non split spoon samples seem to have sluff (material falling from above the drill bit) mixed in. The split-spoon samples are few and far between (because taking split spoon samples with a mud rotary rig is difficult); therefore the characterization of these wells is rather uncertain. Gamma-ray logs are available from the Department of Geology, which could give further detailed information about the lithology of these particular wells.

Miscellaneous Factors

During the pump tests discused it did indeed rain (sometimes quite heavily). This is probably not a major factor since the water table is approximately 60 feet below the surface and this soil would not have allowed such quick recharge (the pump tests did not last long). One piece of additional proof is the control well (AL-11) did not show any rapid fluctuation during or after these rains (therefore this indicates our test should not have been affected by the rain). One possible recharge point could be our discharge hose. An attempt was made to keep the hose as far from the pumping well as possible, but resources are finite. If this was a factor in our variances, it was a very minor one (since AL-18, the well closest to the discharge hose, did not show extreme changes in water level measurements). Finally, these data were collected by a class containing inexperienced people. Therefore, human error is always a distinct possibility in such circumstances.

CHAPTER V

CONCLUSIONS

The conclusion of this study is: by using the Neuman method discussed in the study, the variations seen in the past can be lessened from several orders of magnitude to within one order of magnitude. Methods which assume an unconfined aquifer do not give correct T and S values. The graphs (Appendices A thru E) pictorally show the solutions failures, particulary Theis curves presented. There were other minor difficulties. The pumping rate was not constant during the pump tests, which is a requirement of the methods employed in this study. The lithology does vary, therefore this can cause deviations to be present in the T and S results. Finally, weather and human error could have contributed to errors in the water level measurements. With more careful field work, a consistent pump rate, and the use of the Neuman (or equivalent unconfined solution), the results could become even more consistent.

Appendix A

T and S Results From AL-1

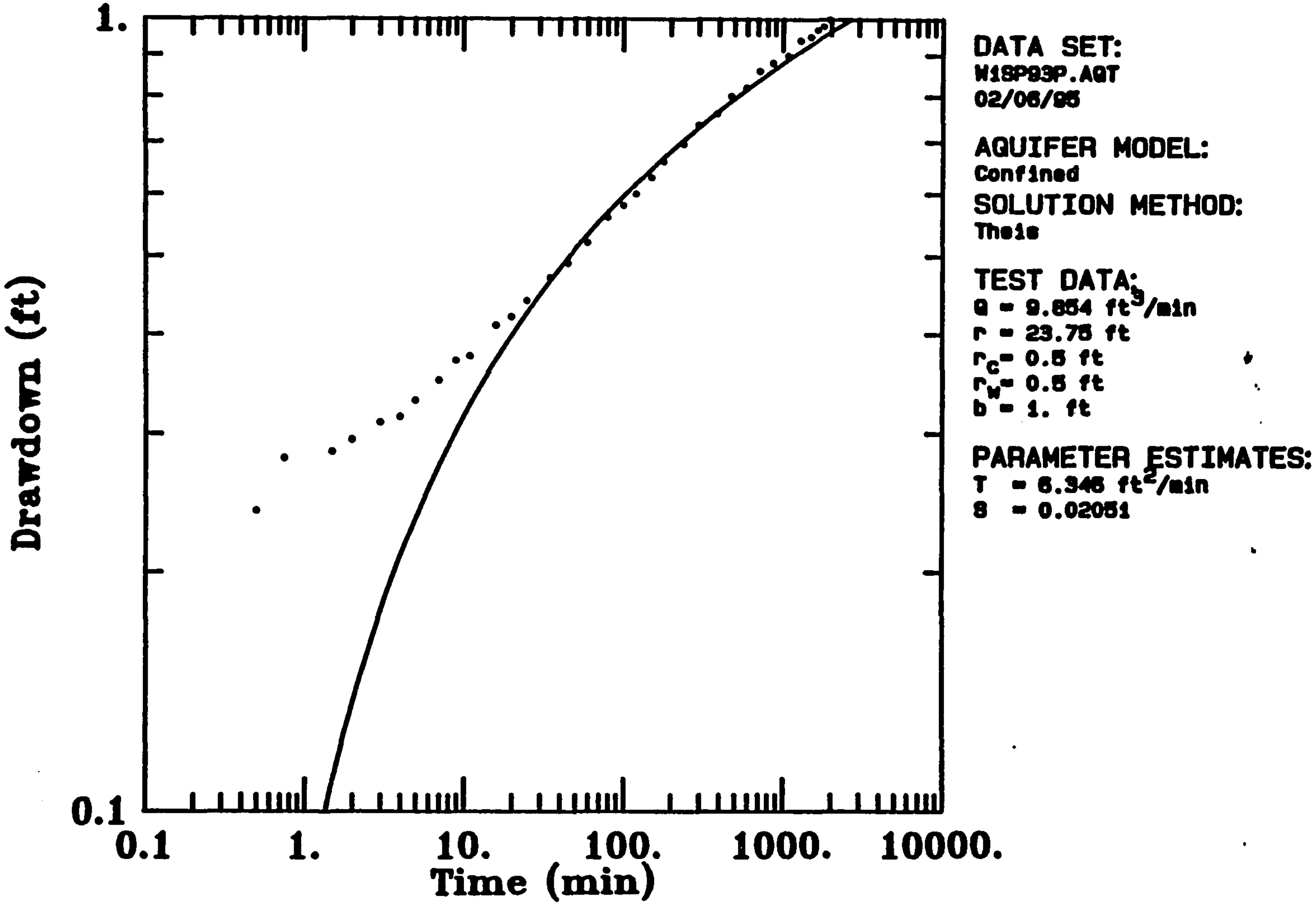

Figure 1. Theis Curve for Well AL-1 for July 1993.

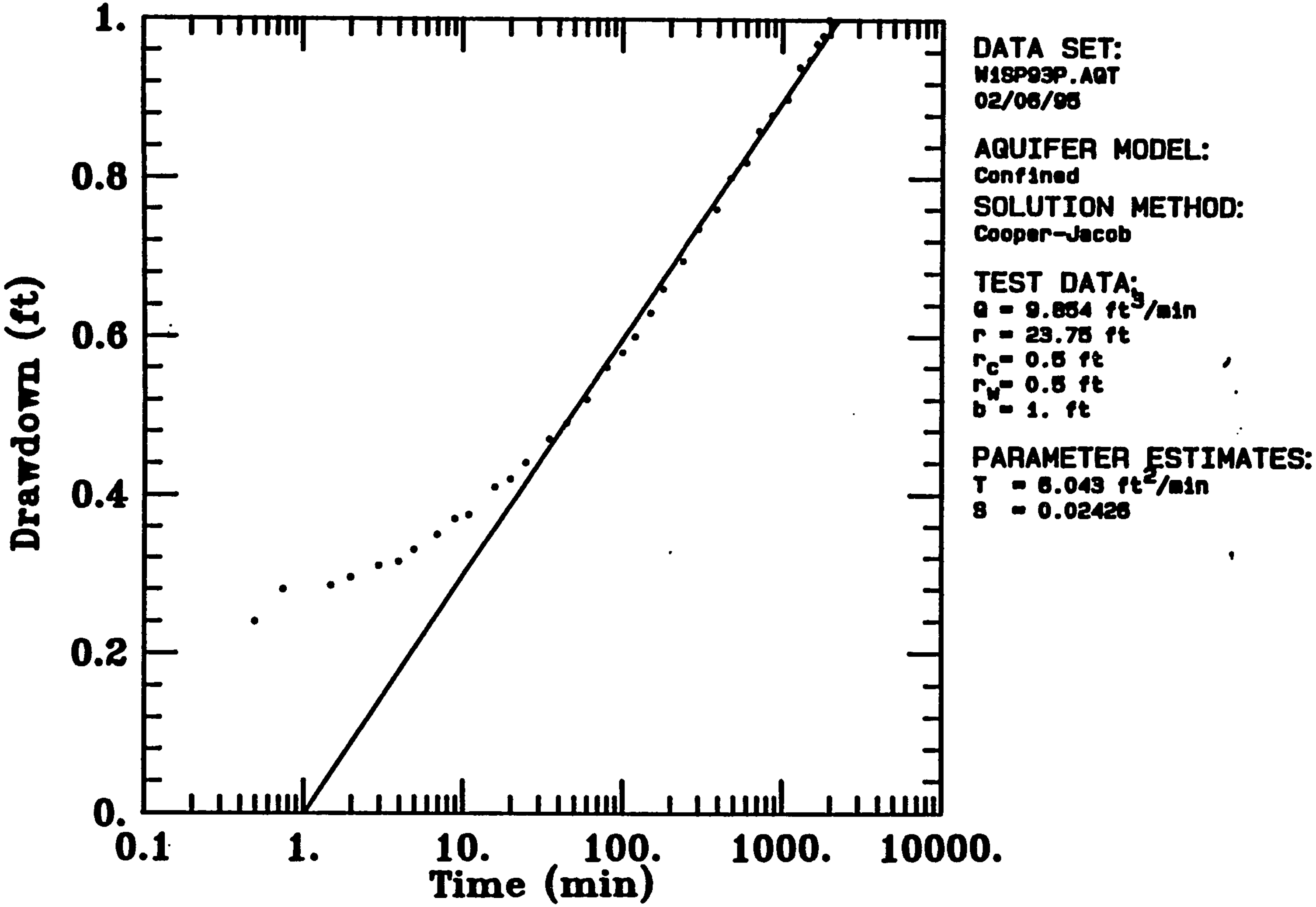

Figure 2. Jacob-Cooper Curve for Well AL-1 for July 1993.

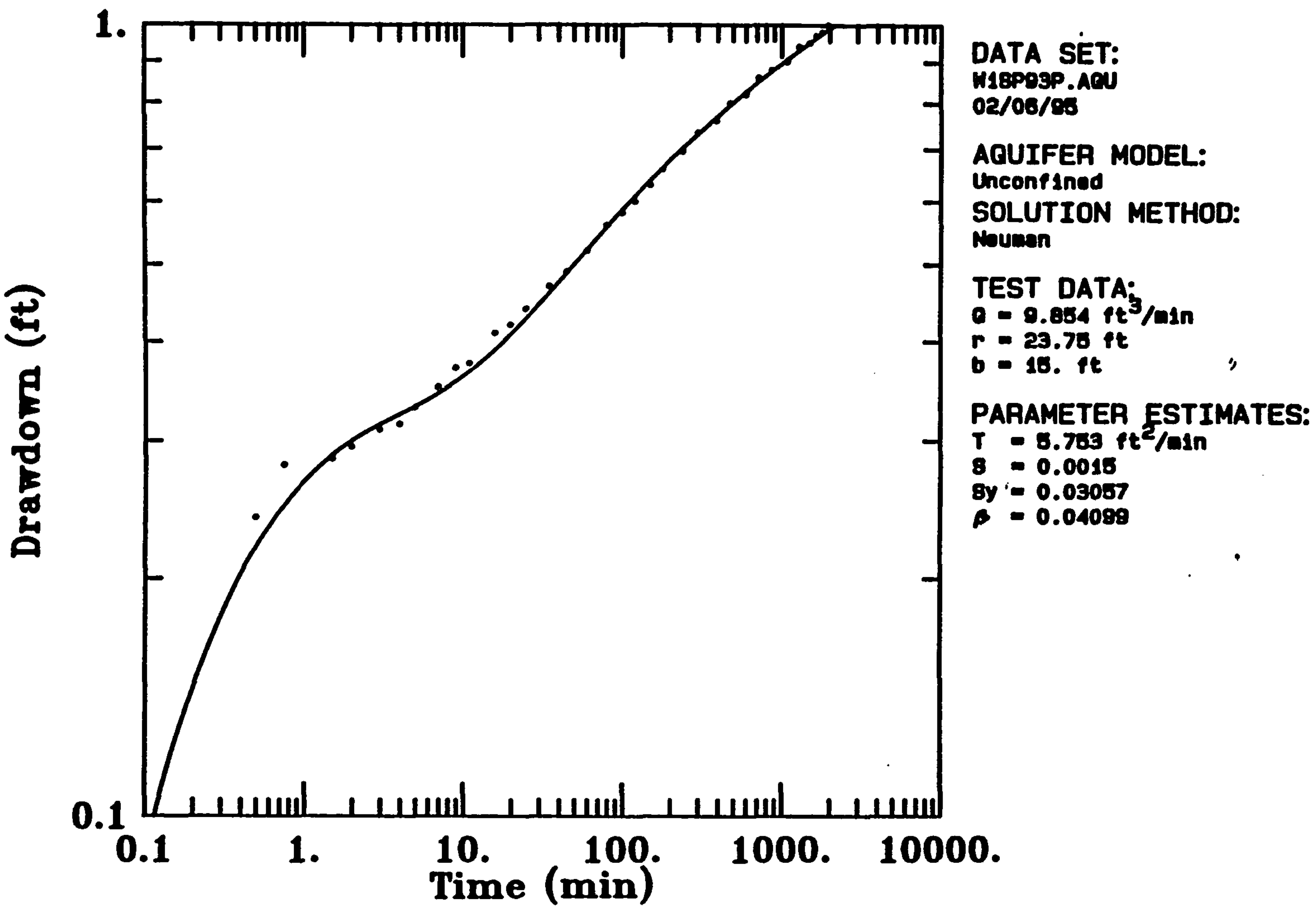

Figure 3. Neuman Method Curve for Well AL-1 for July 1993.

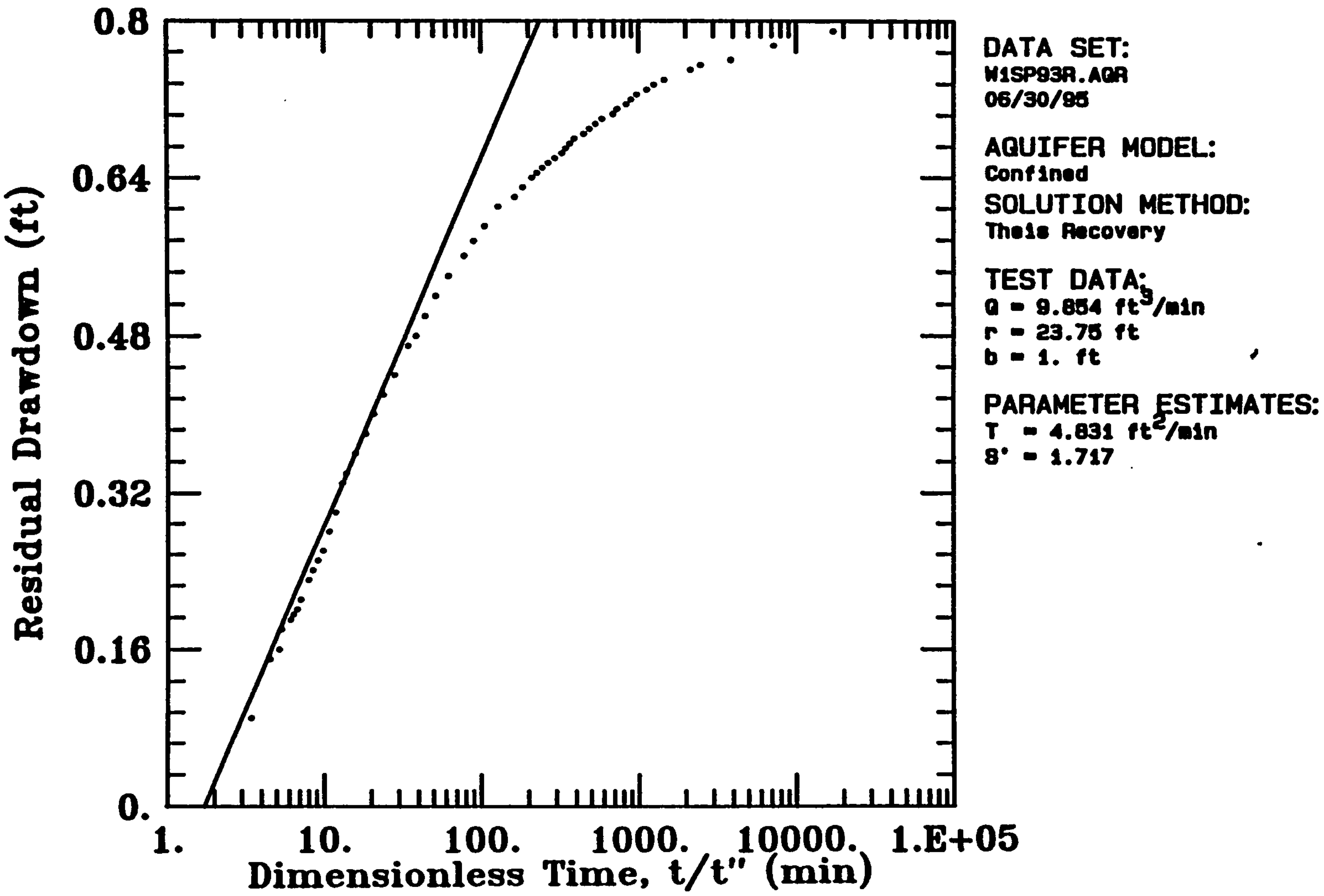

Figure 4. Theis Recovery Curve for Well AL-1 for July 1993.

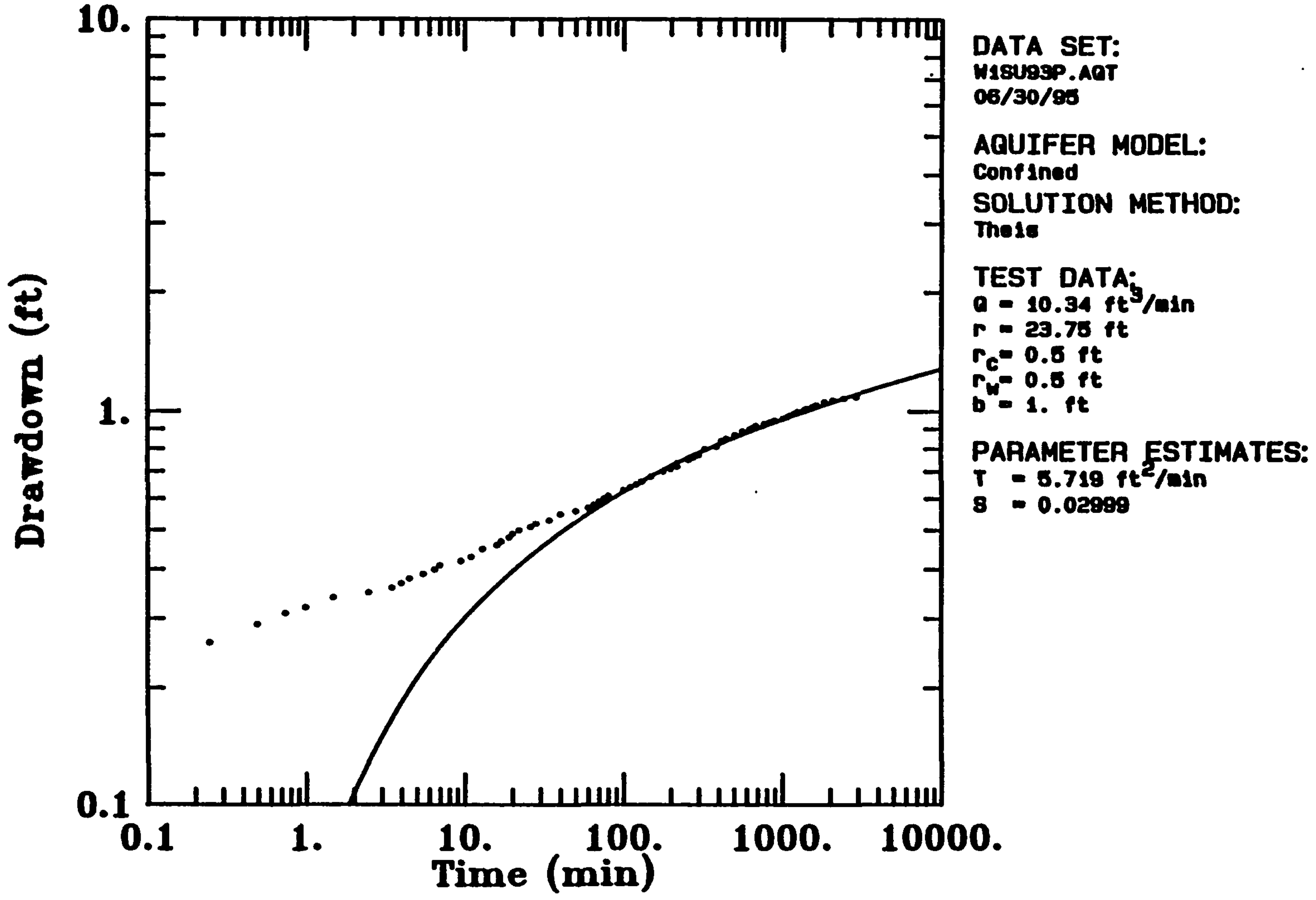

Figure 5. Theis Curve for Well AL-1 for August 1993.

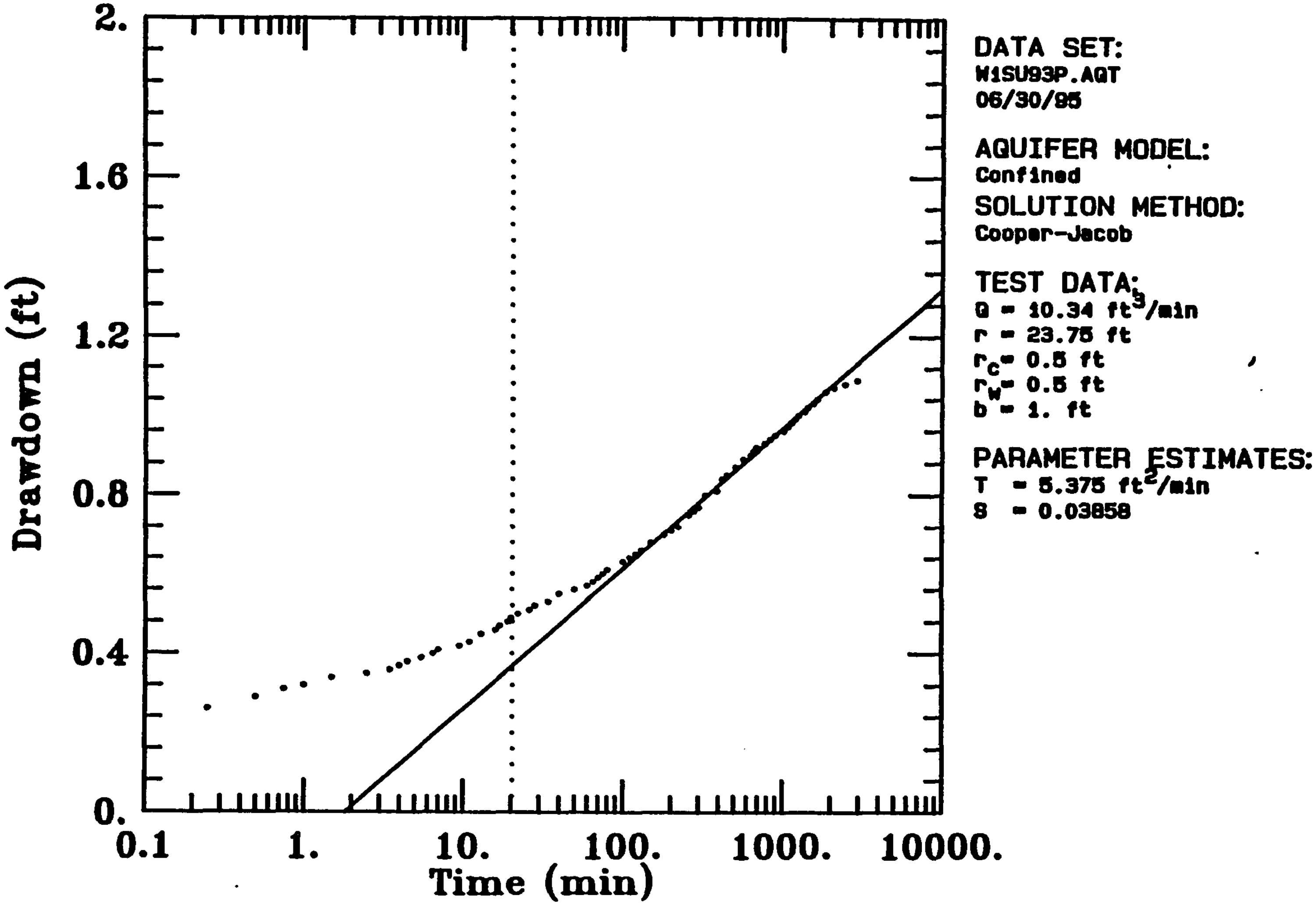

Figure 6. Jacob-Cooper Curve for Well AL-1 for August 1993.

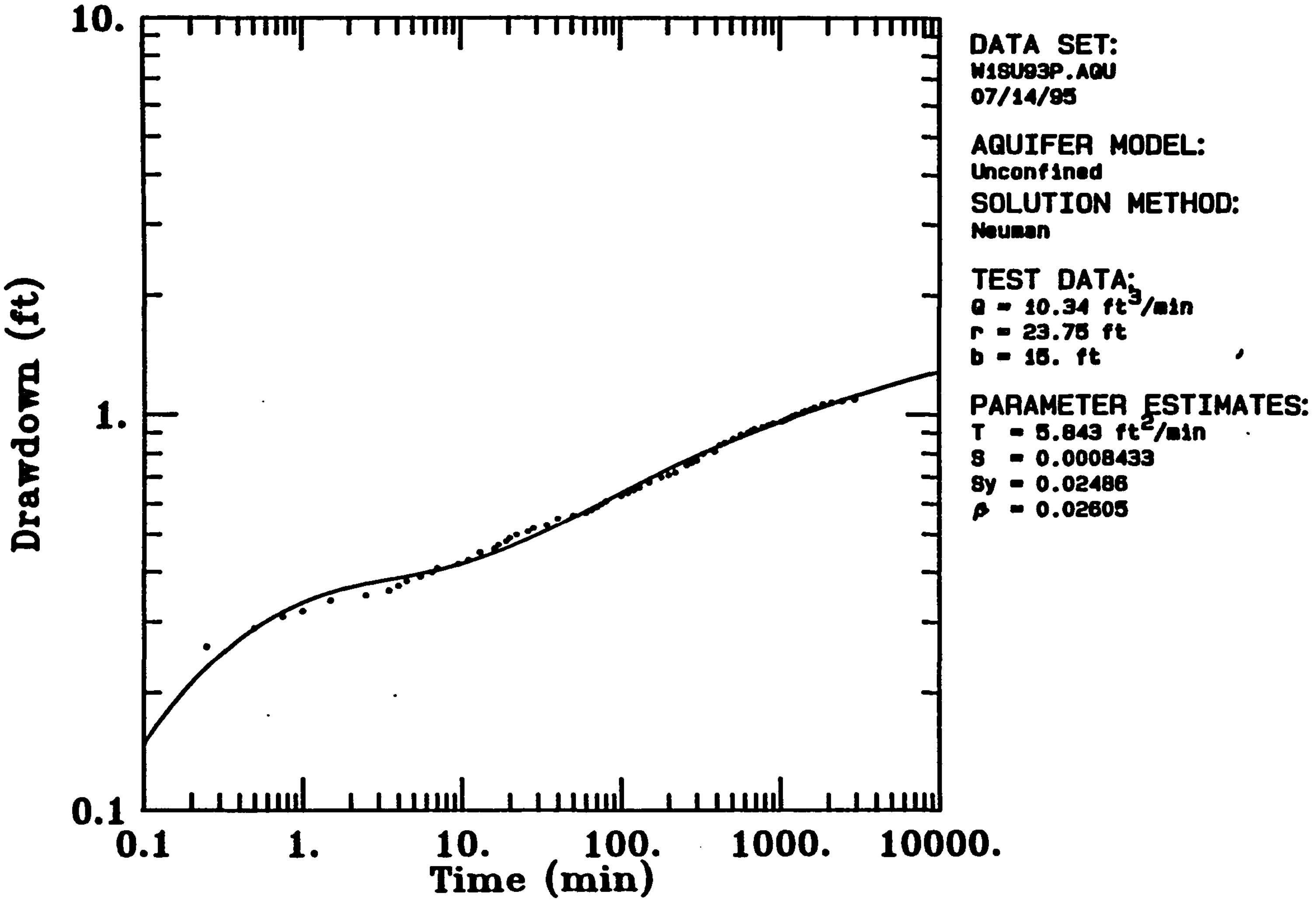

Figure 7. Neuman Method Curve for Well AL-1 for August 1993.

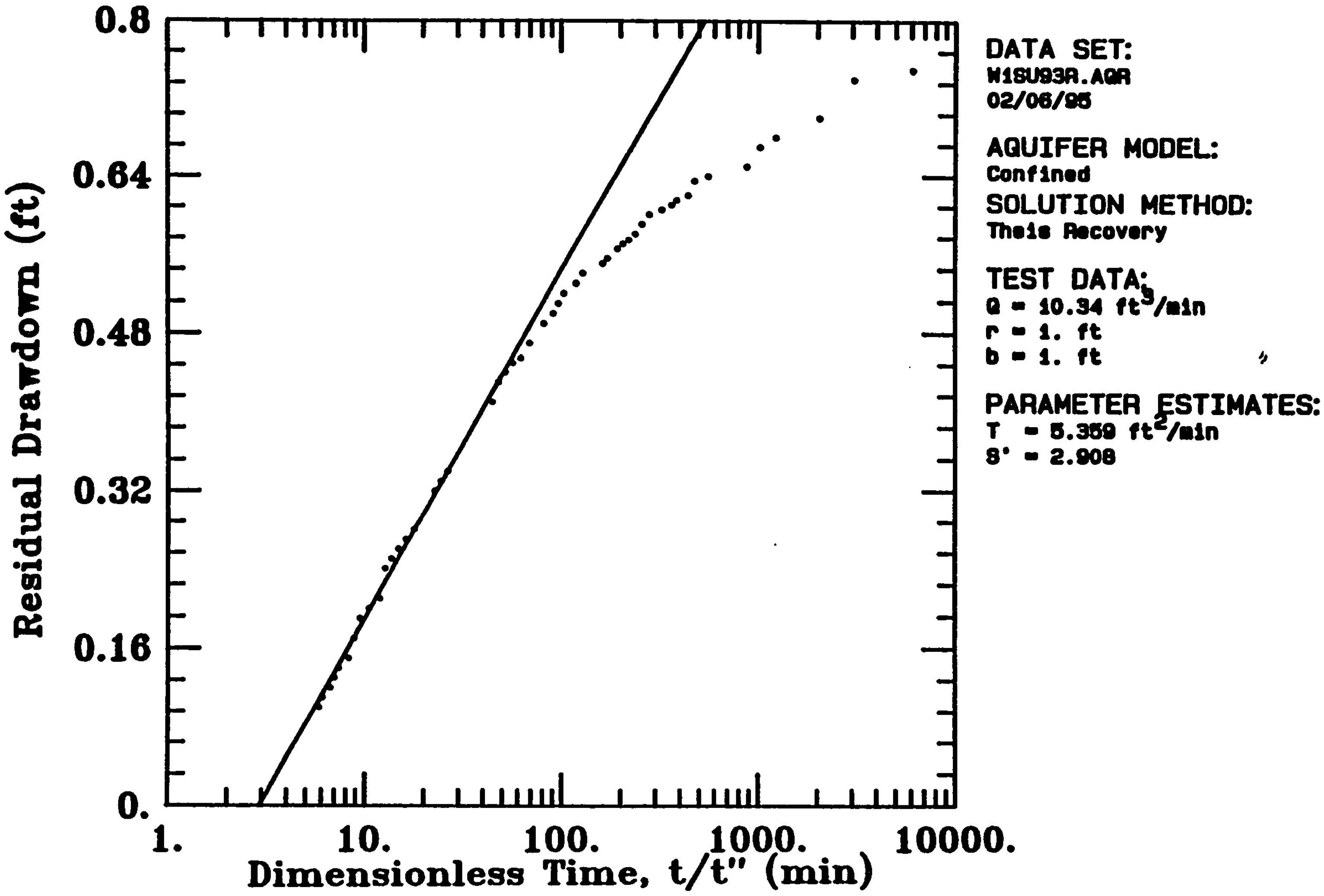

Figure 8. Theis Recovery Curve for Well AL-1 for August 1993.

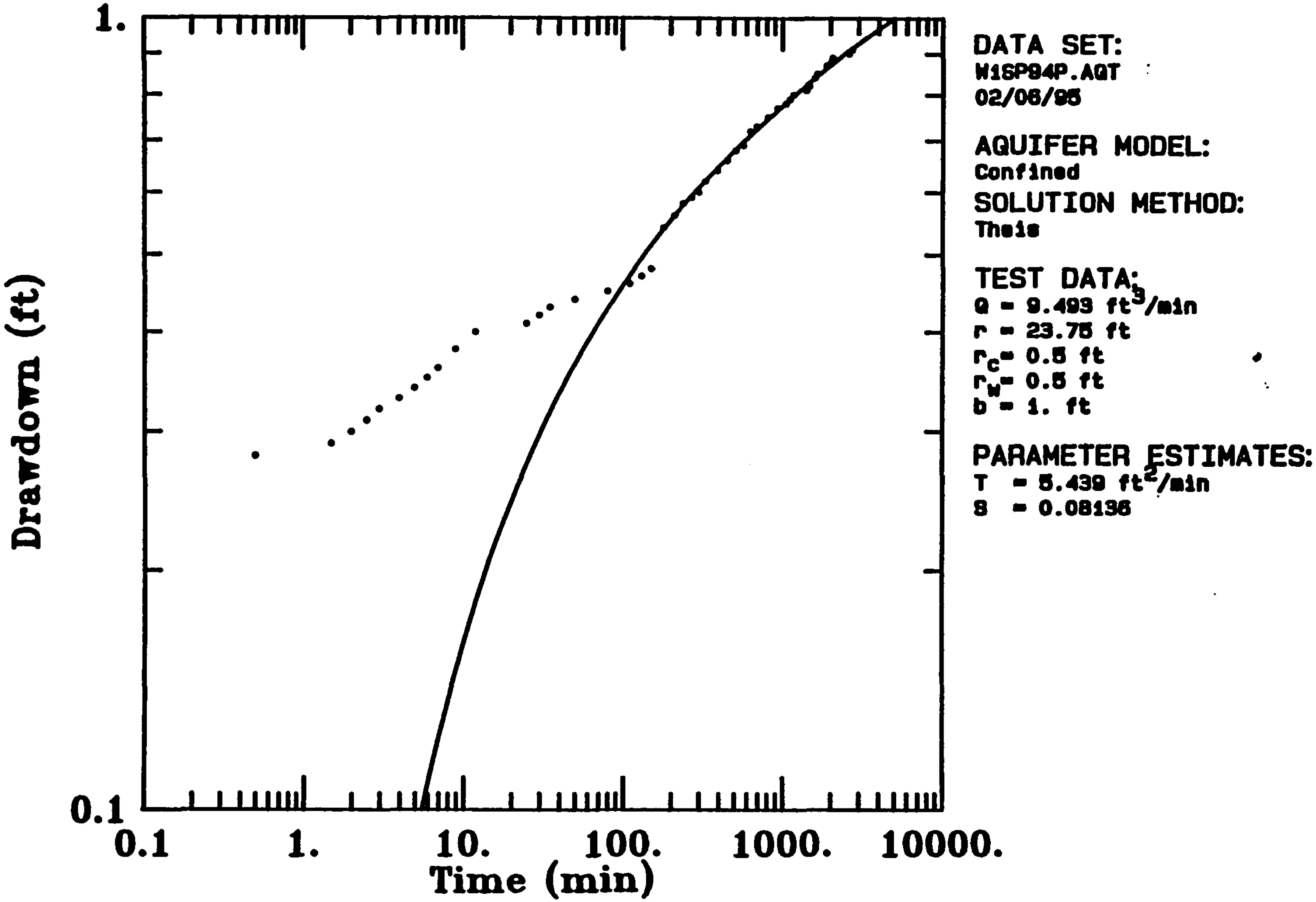

Figure 9. Theis Curve for Well AL-1 for June 1994.

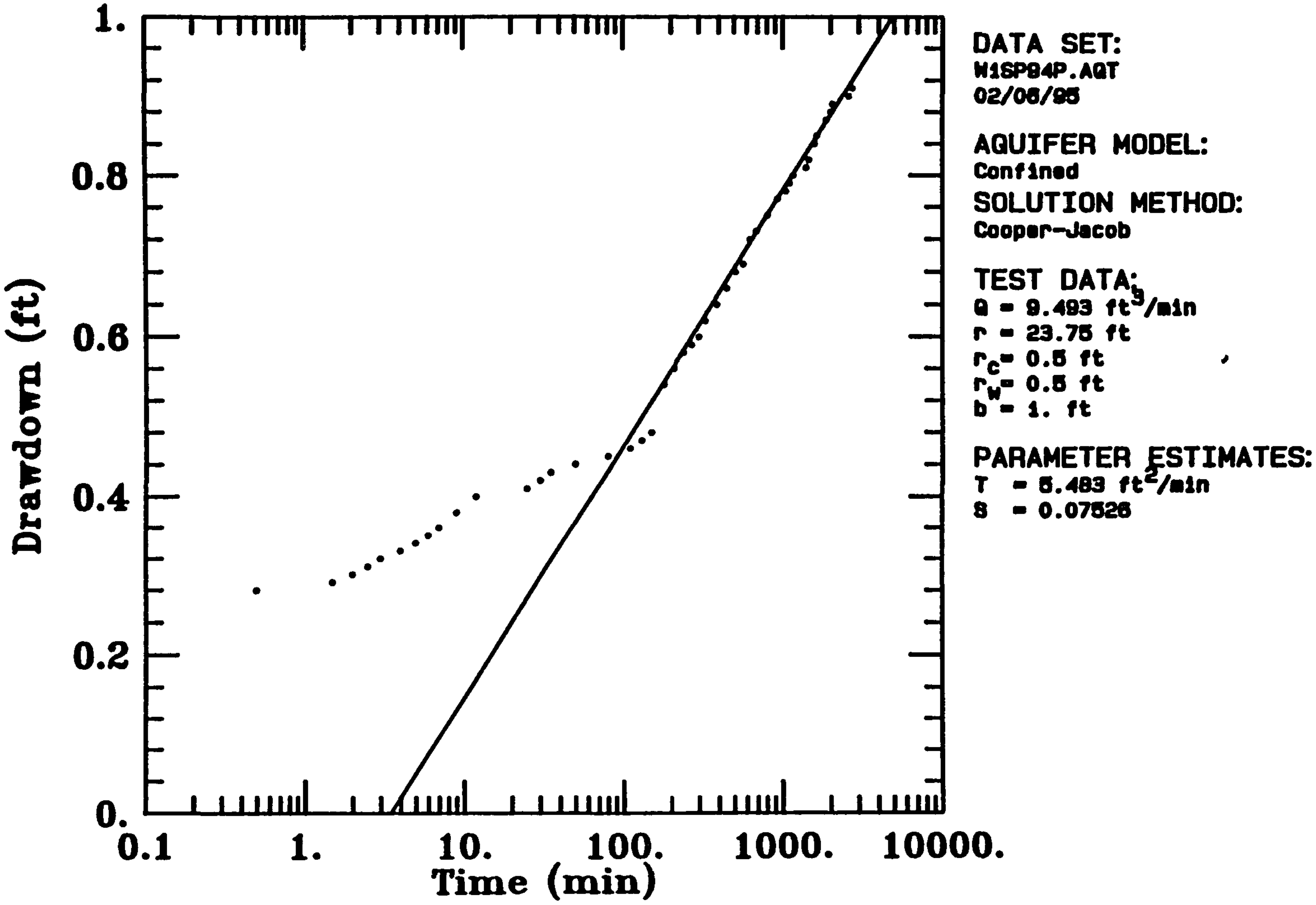

Figure 10. Jacob-Cooper Curve for Well AL-1 for June 1994.

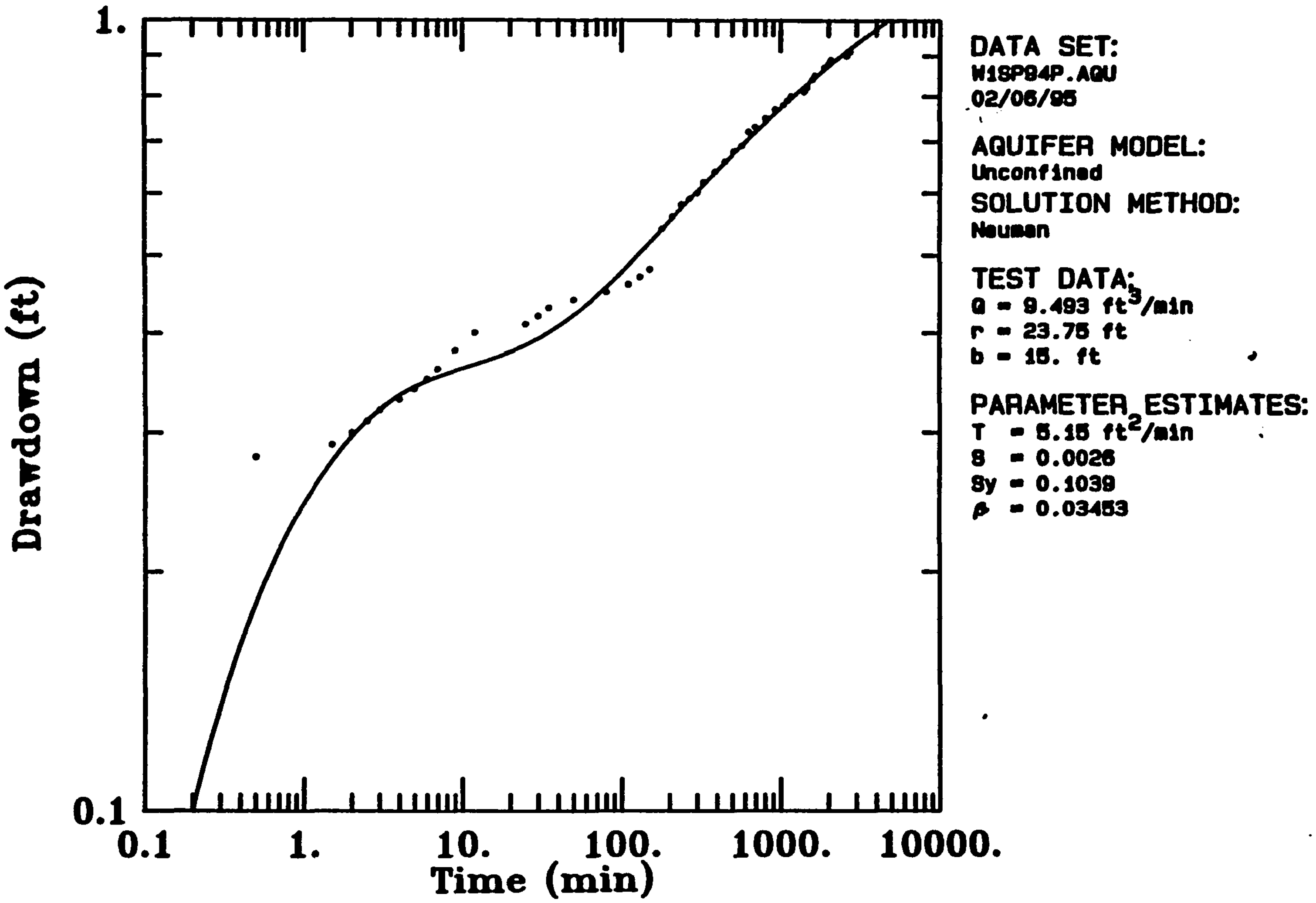

Figure 11. Neuman Method Curve for Well AL-1 for June 1994.

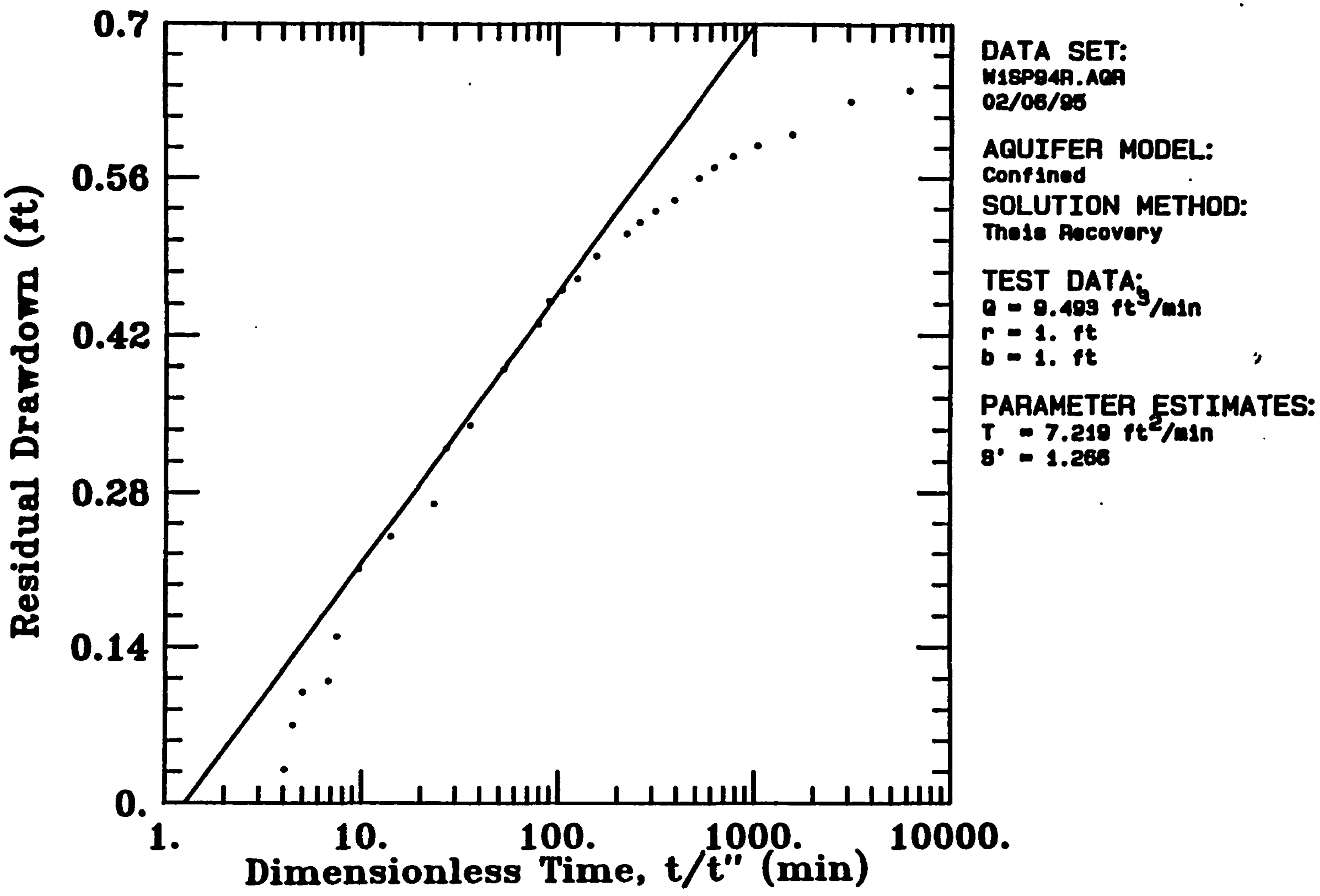

Figure 12. Theis Recovery Curve for Well AL-1 for June 1994.

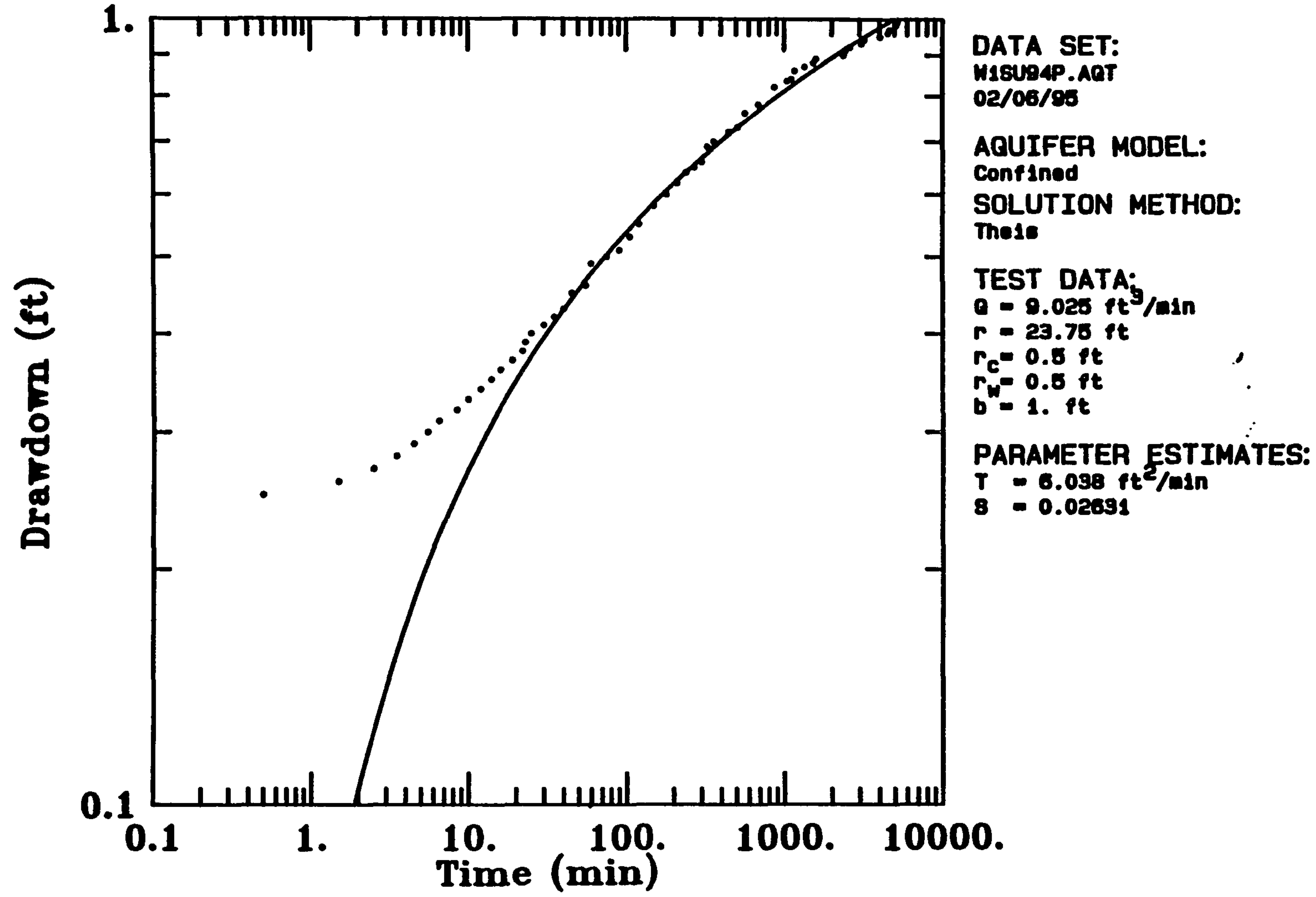

Figure 13. Theis Curve for Well AL-1 for August 1994.

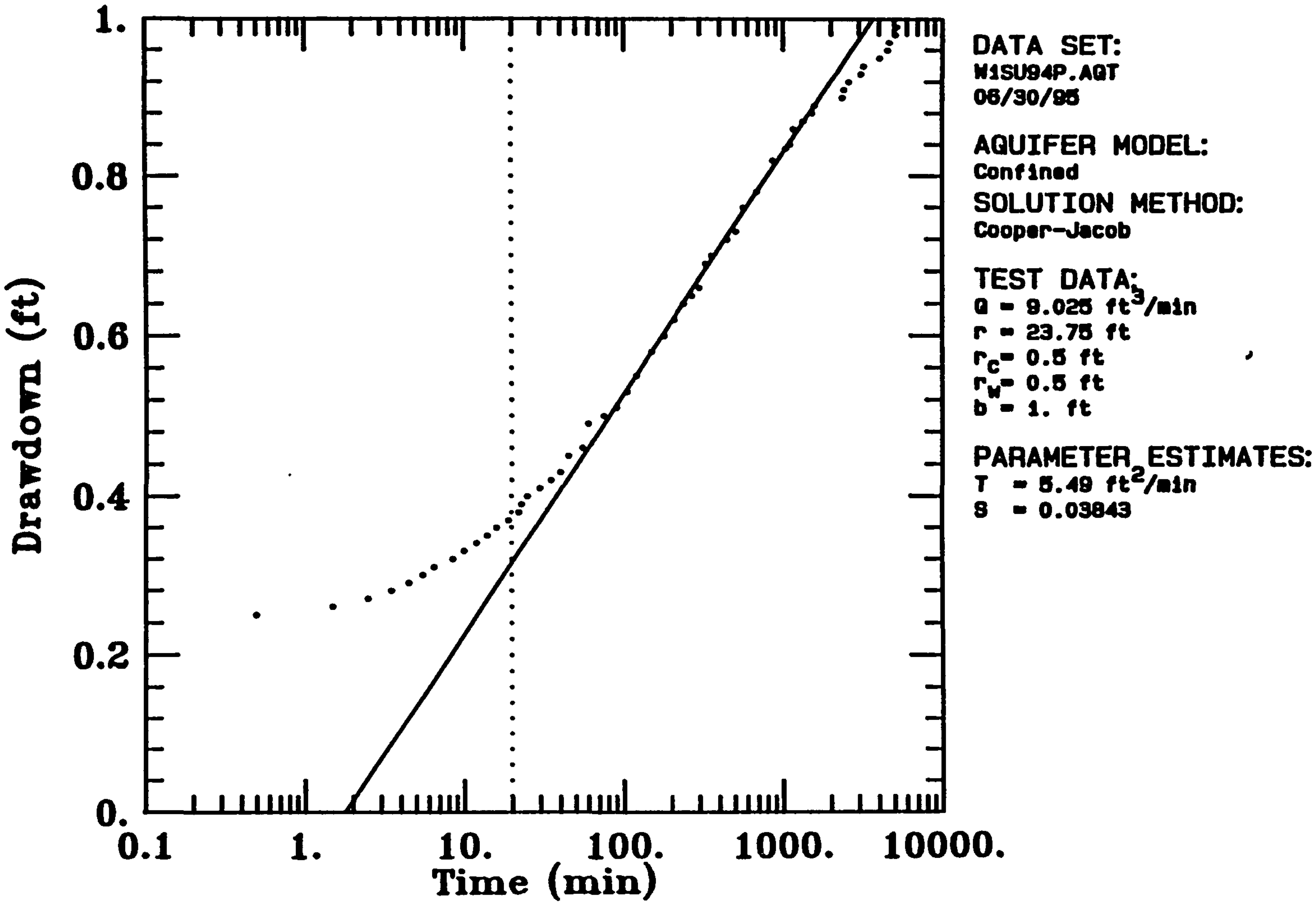

Figure 14. Jacob-Cooper Curve for Well AL-1 for August 1994.

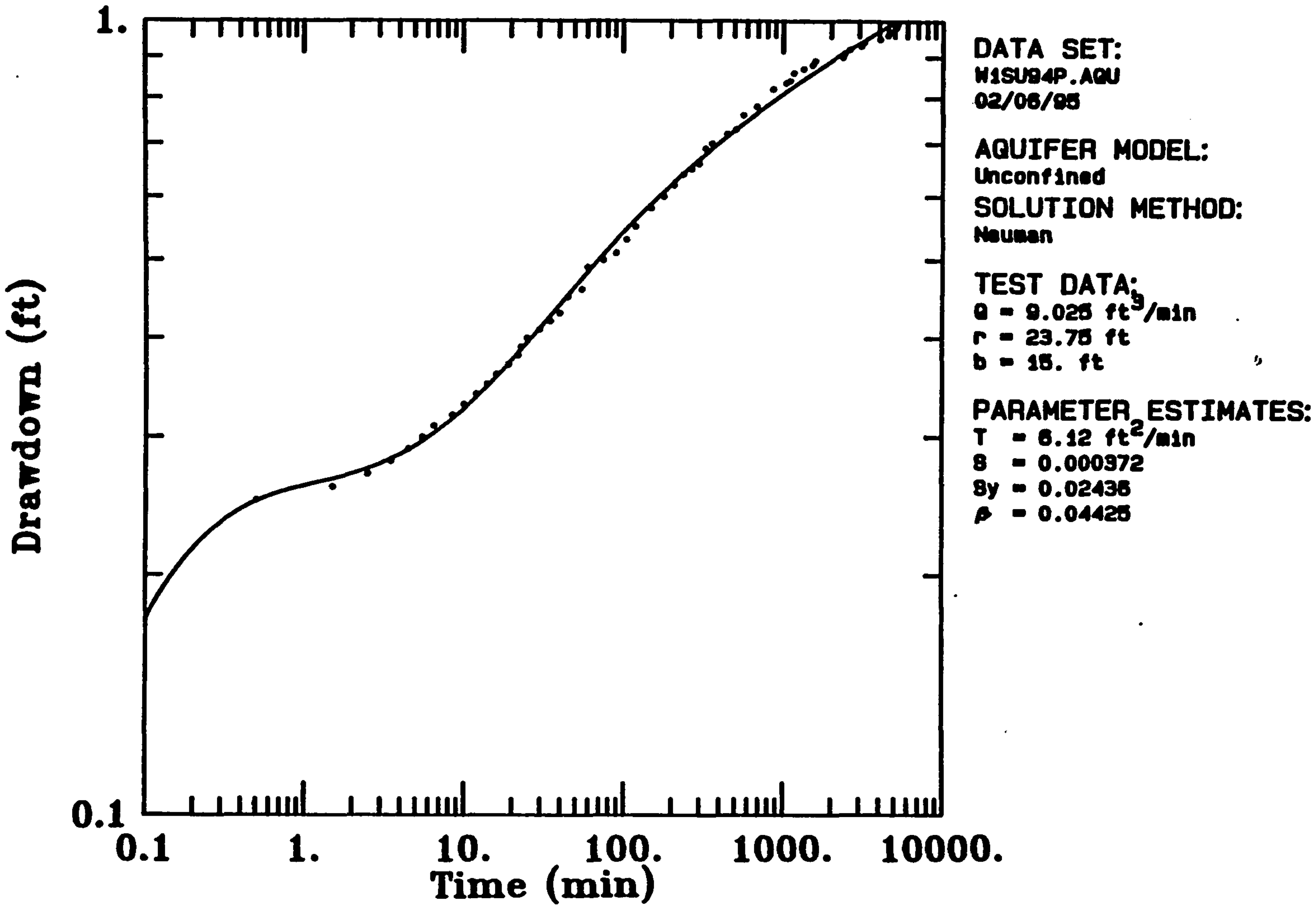

Figure 15. Neuman Method Curve for Well AL-1 for August 1994.

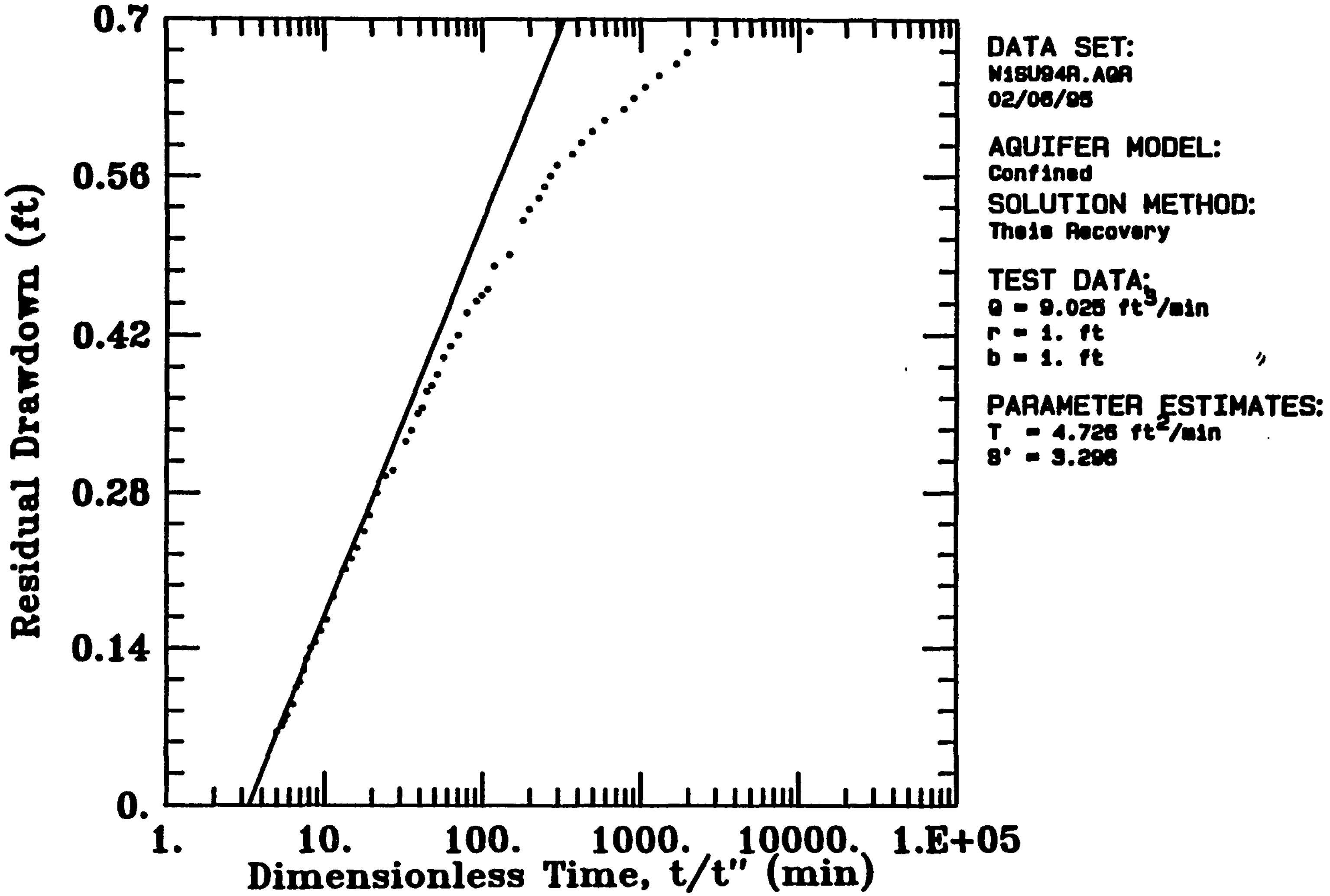

Figure 16. Theis Recovery Curve for Well AL-1 for August 1994.

Appendix B

T and S Results From AL-4

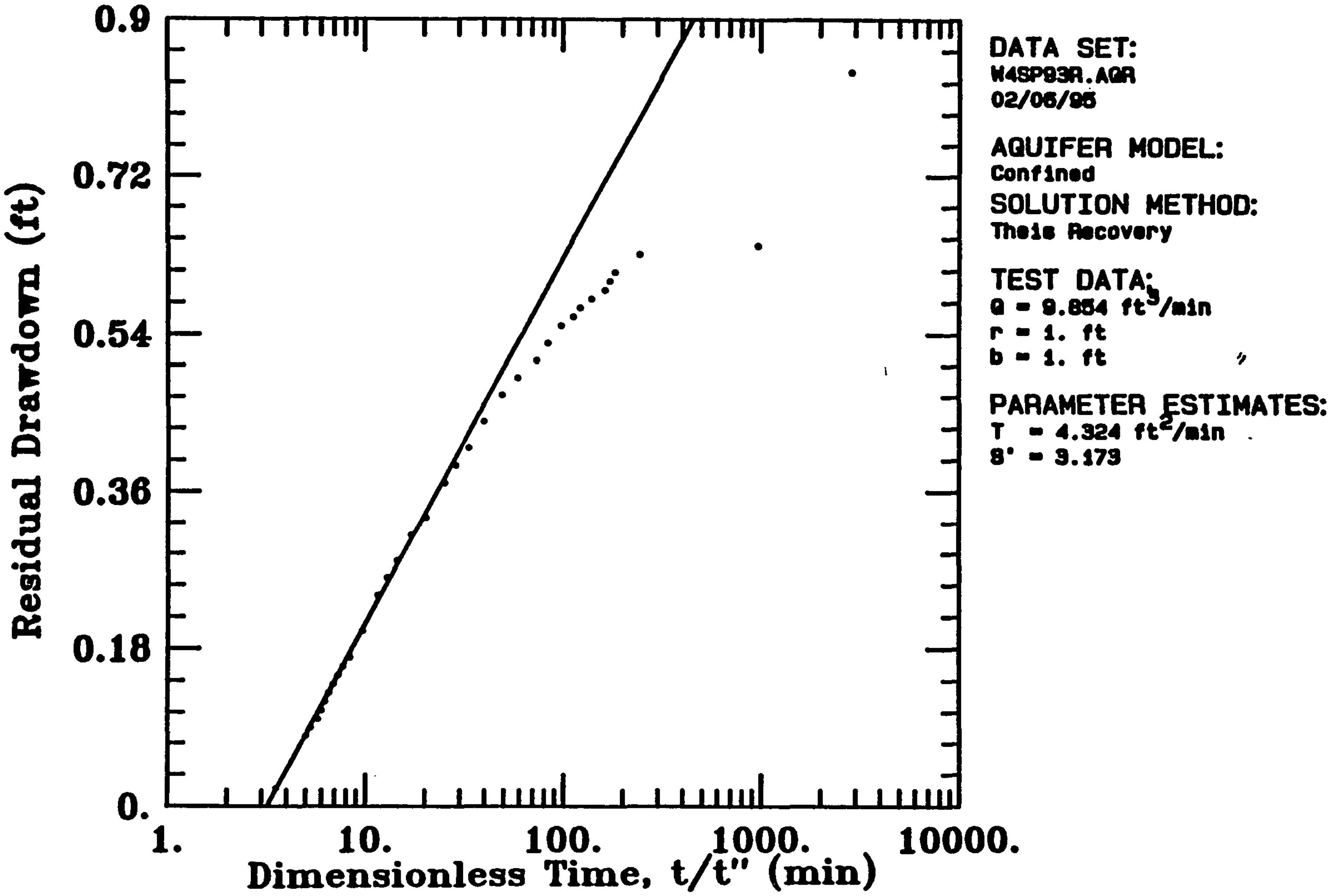

Figure 17. Theis Recovery Curve for Well AL-4 for July 1993.

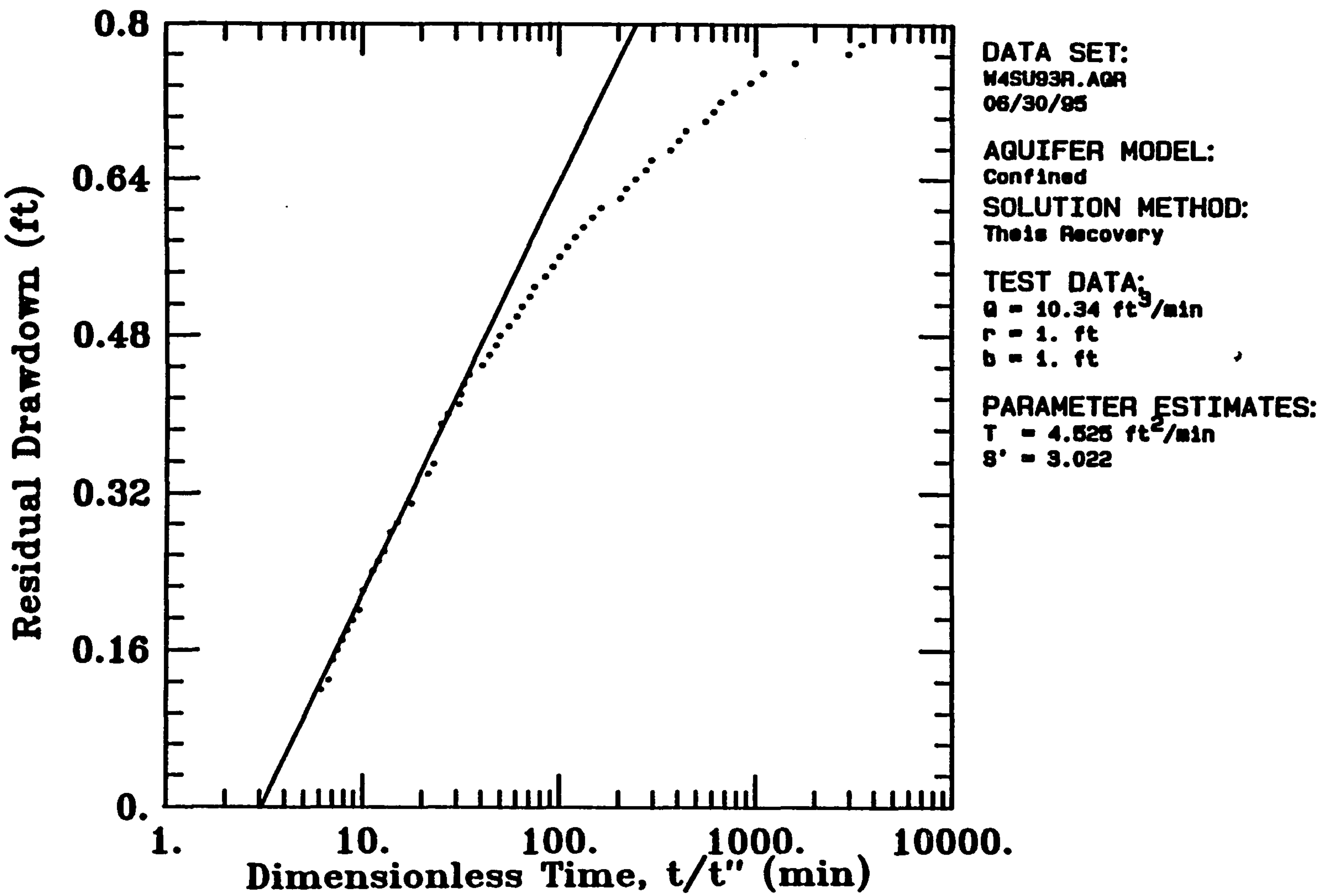

Figure 18. Theis Recovery Curve for Well AL-4 for August 1993.

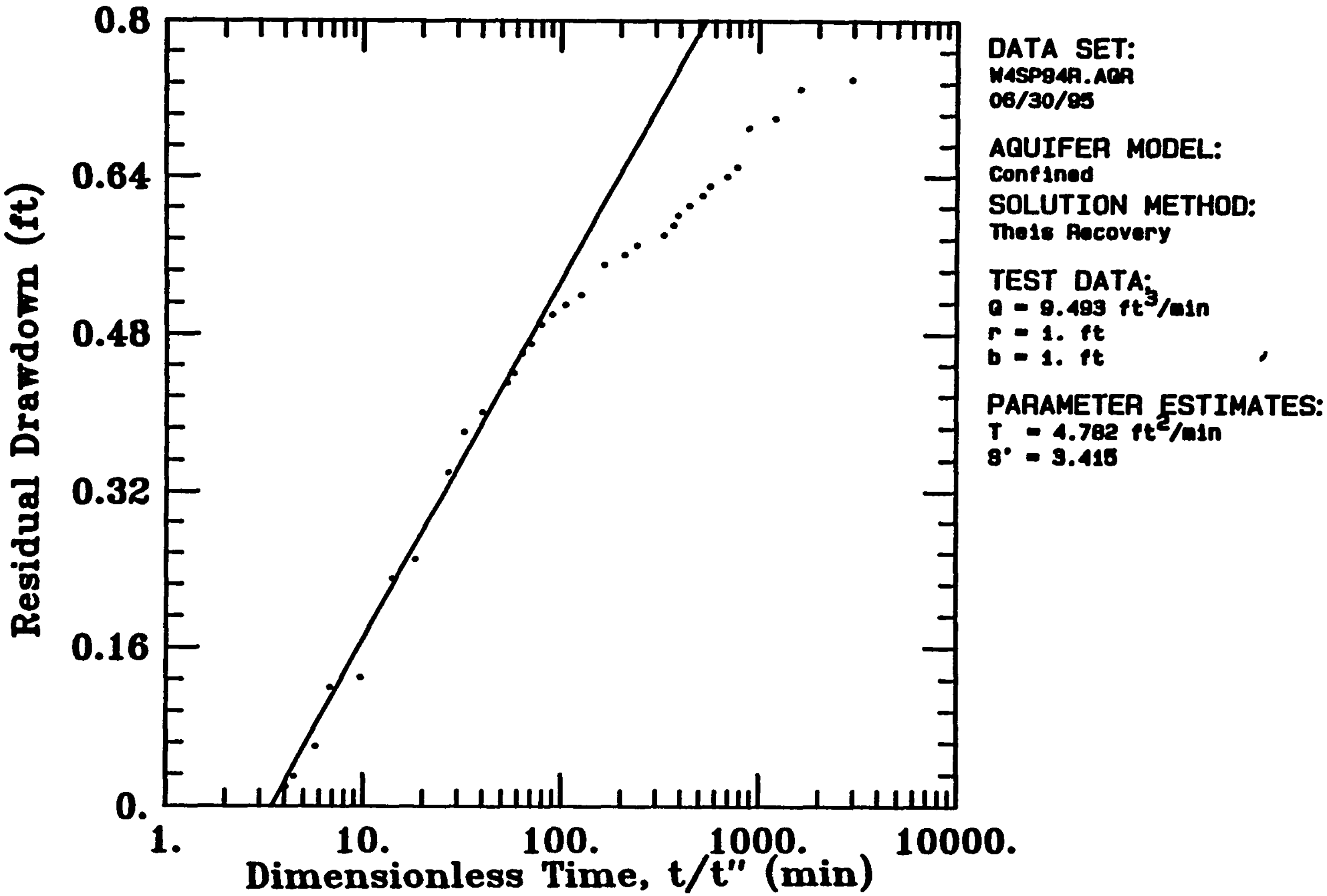

Figure 19. Theis Recovery Curve for Well AL-4 for June 1994.

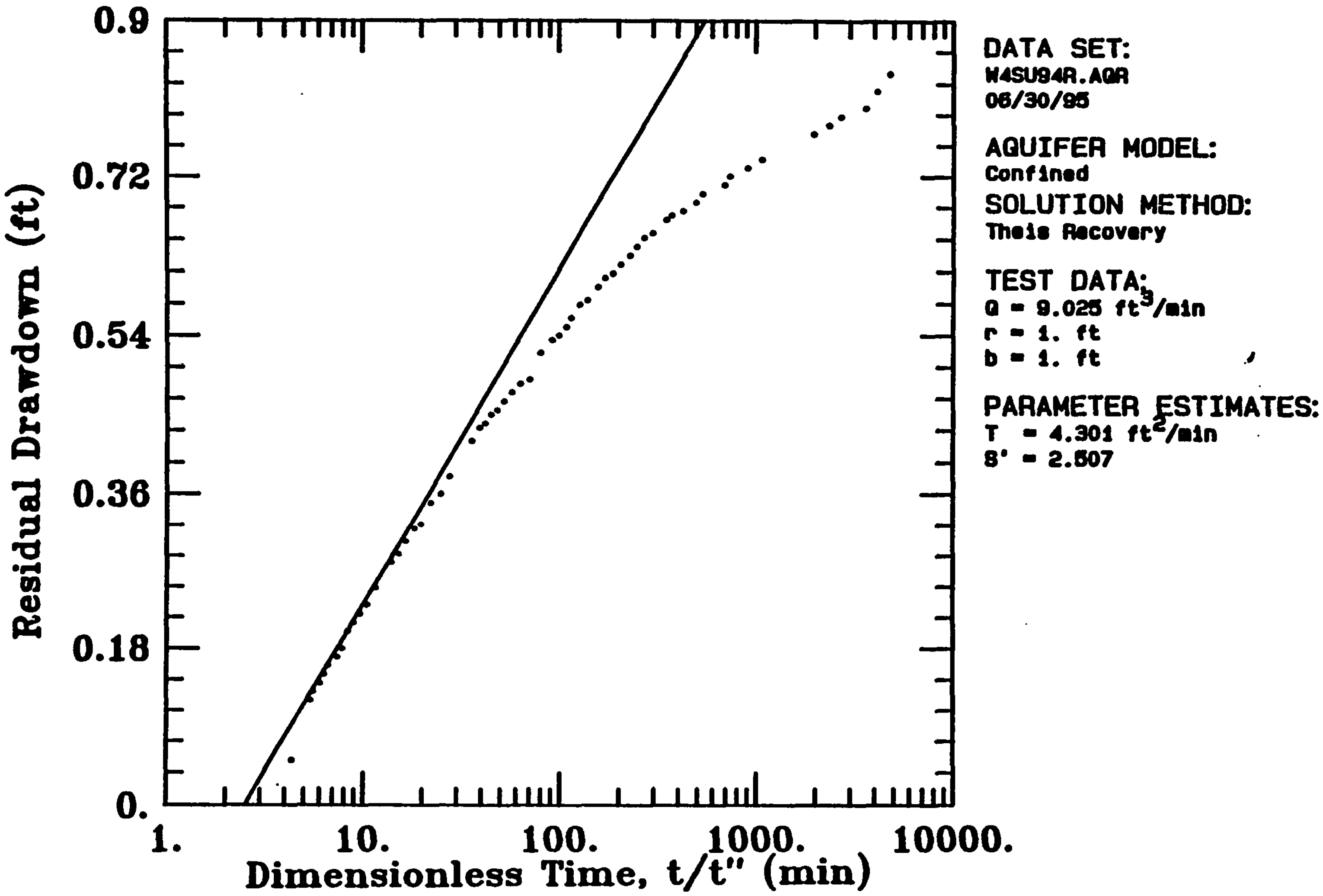

Figure 20. Theis Recovery Curve for Well AL-4 for August 1994.

Appendix C

T and S Results From AL-18

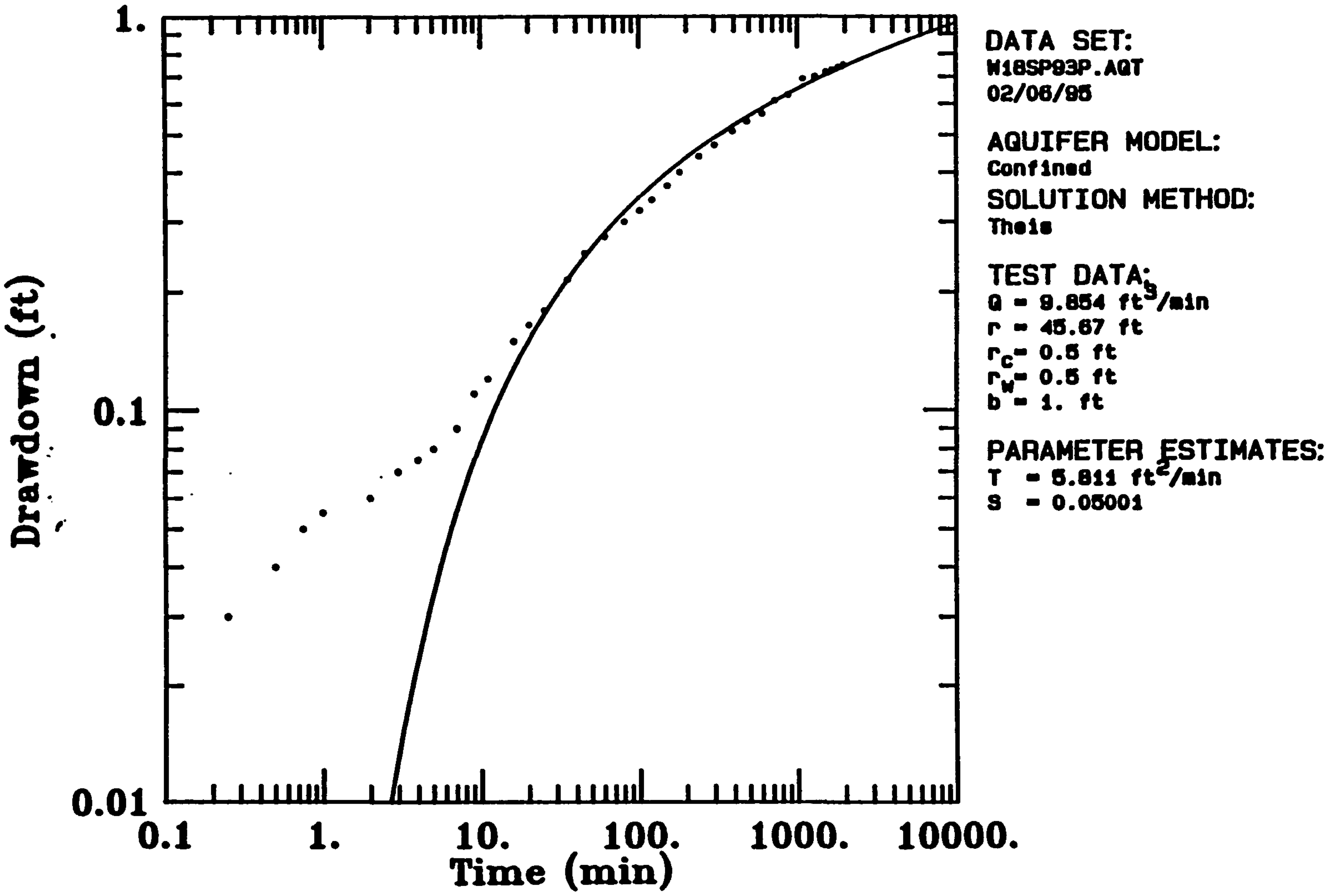

Figure 21. Theis Curve for Well AL-18 for July 1993.

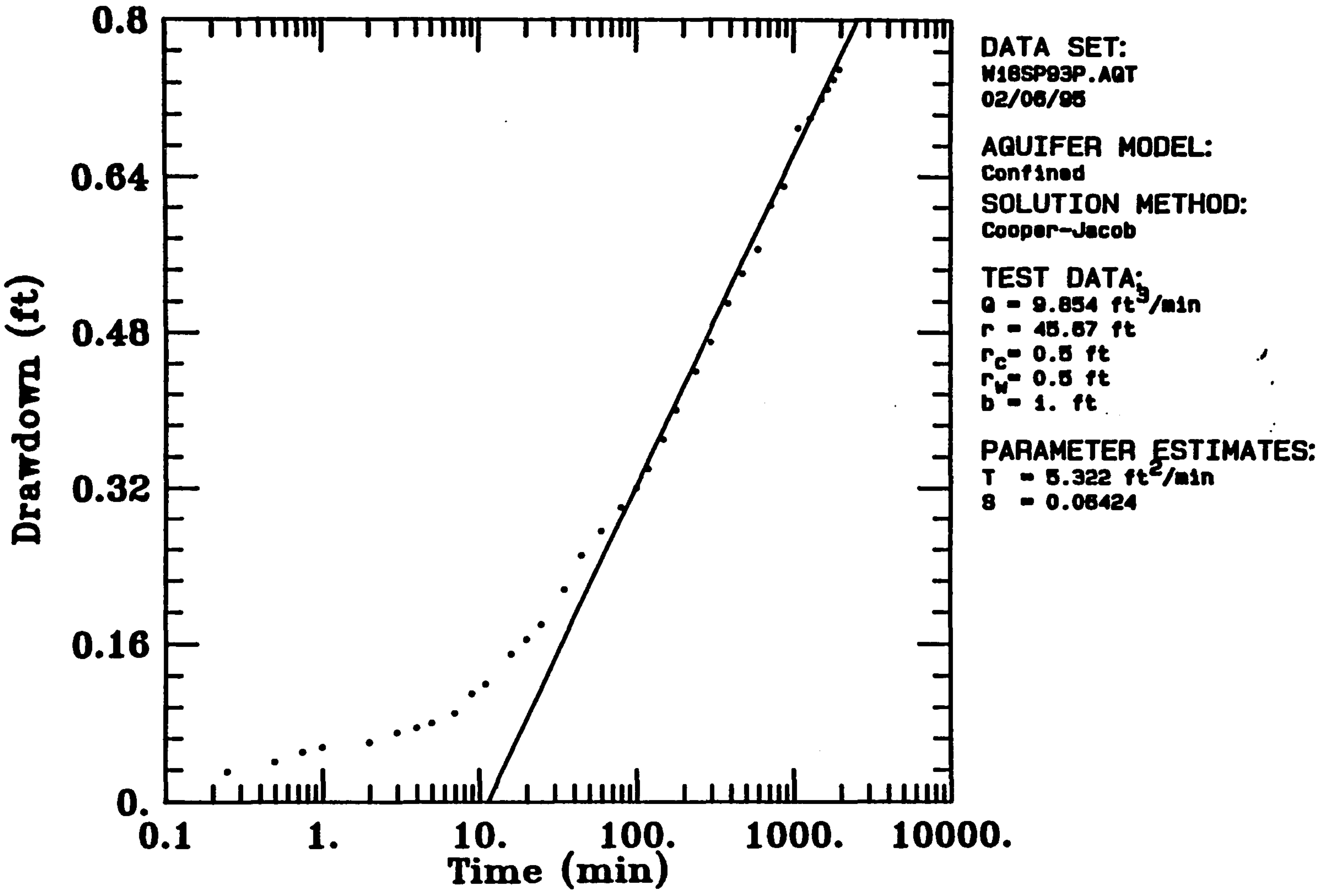

Figure 22. Jacob-Cooper Curve for Well AL-18 for July 1993.

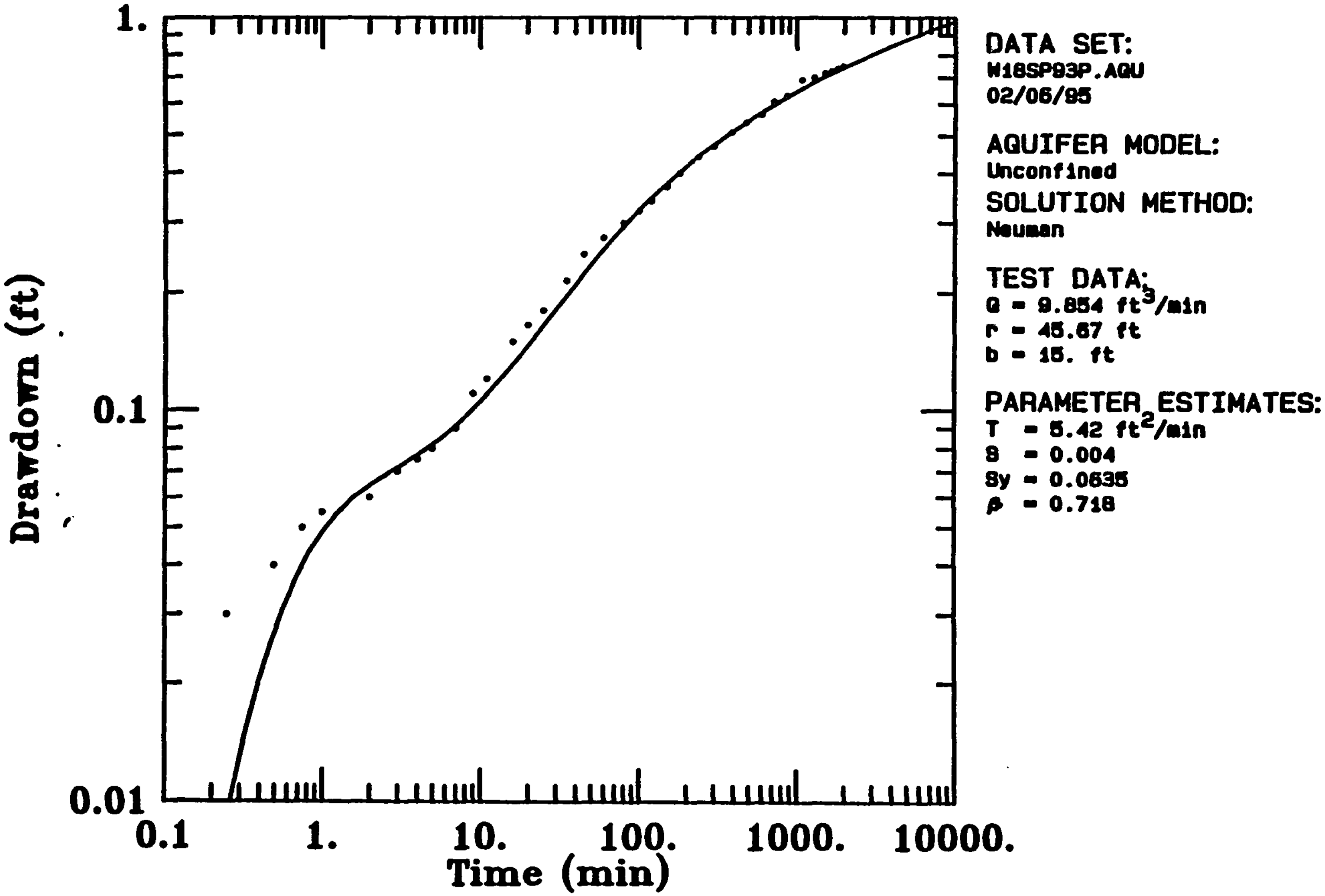

Figure 23. Neuman Method Curve for Well AL-18 for July 1993.

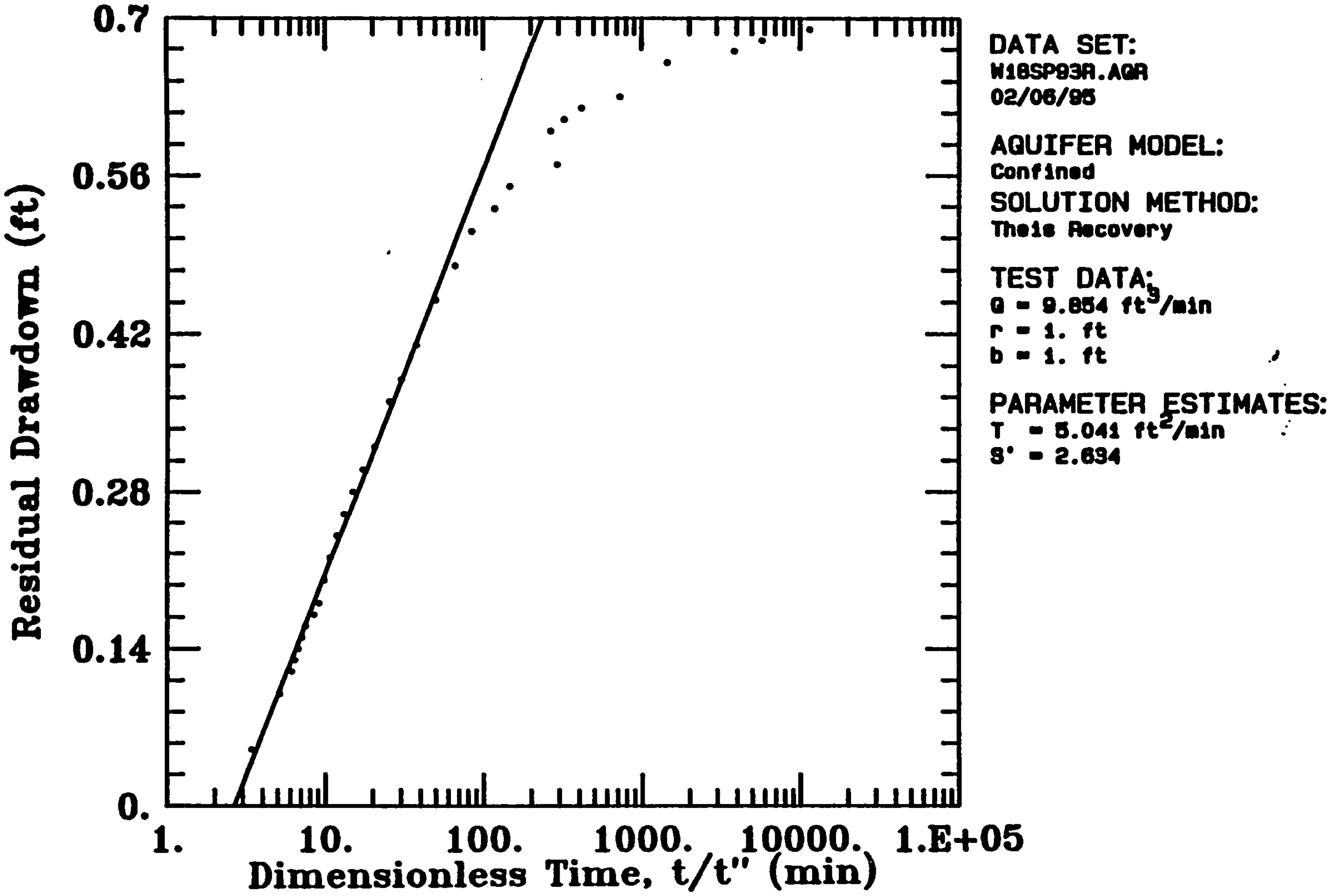

Figure 24. Theis Recovery Curve for Well AL-18 for July 1993.

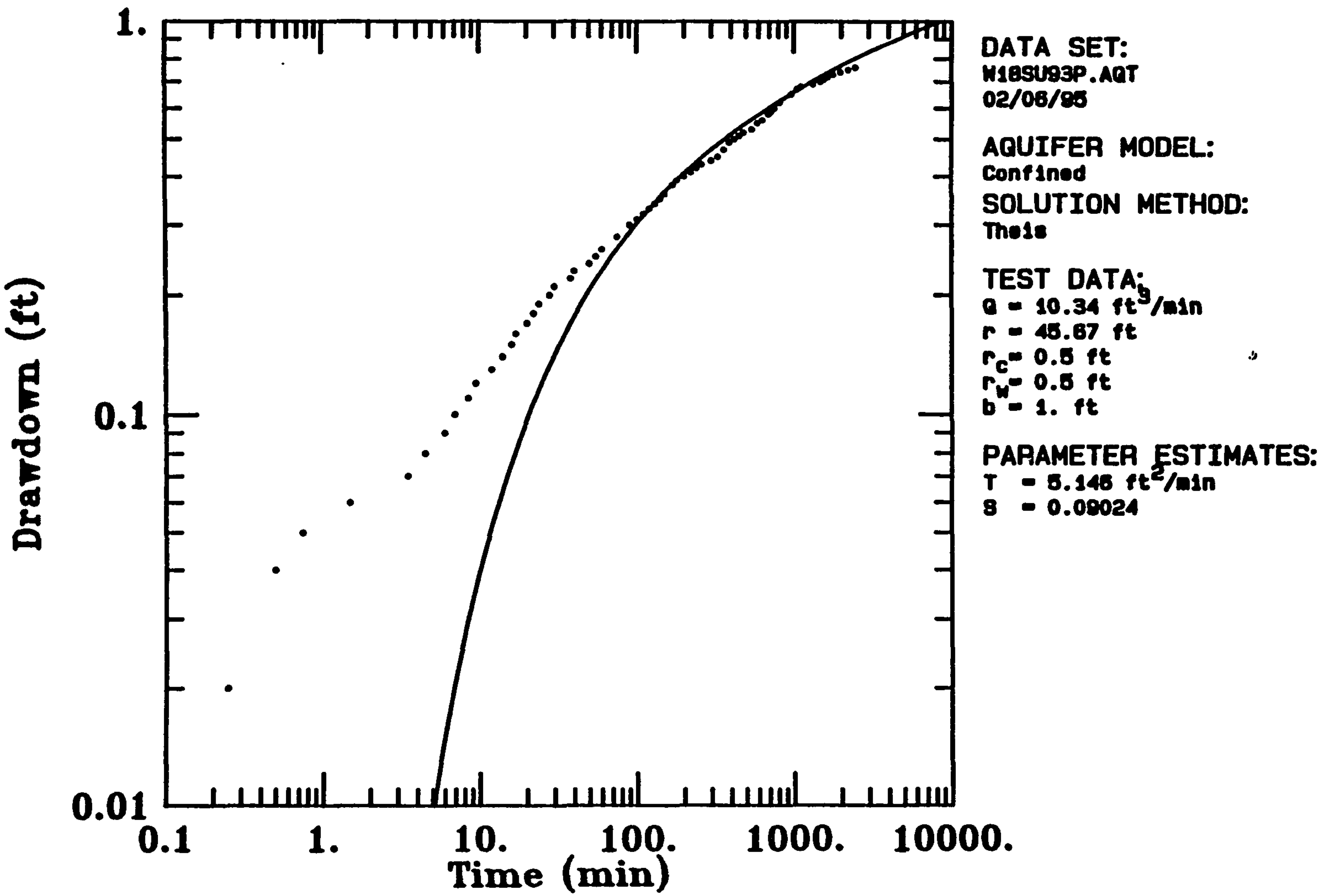

Figure 25. Theis Curve for Well AL-18 for August 1993.

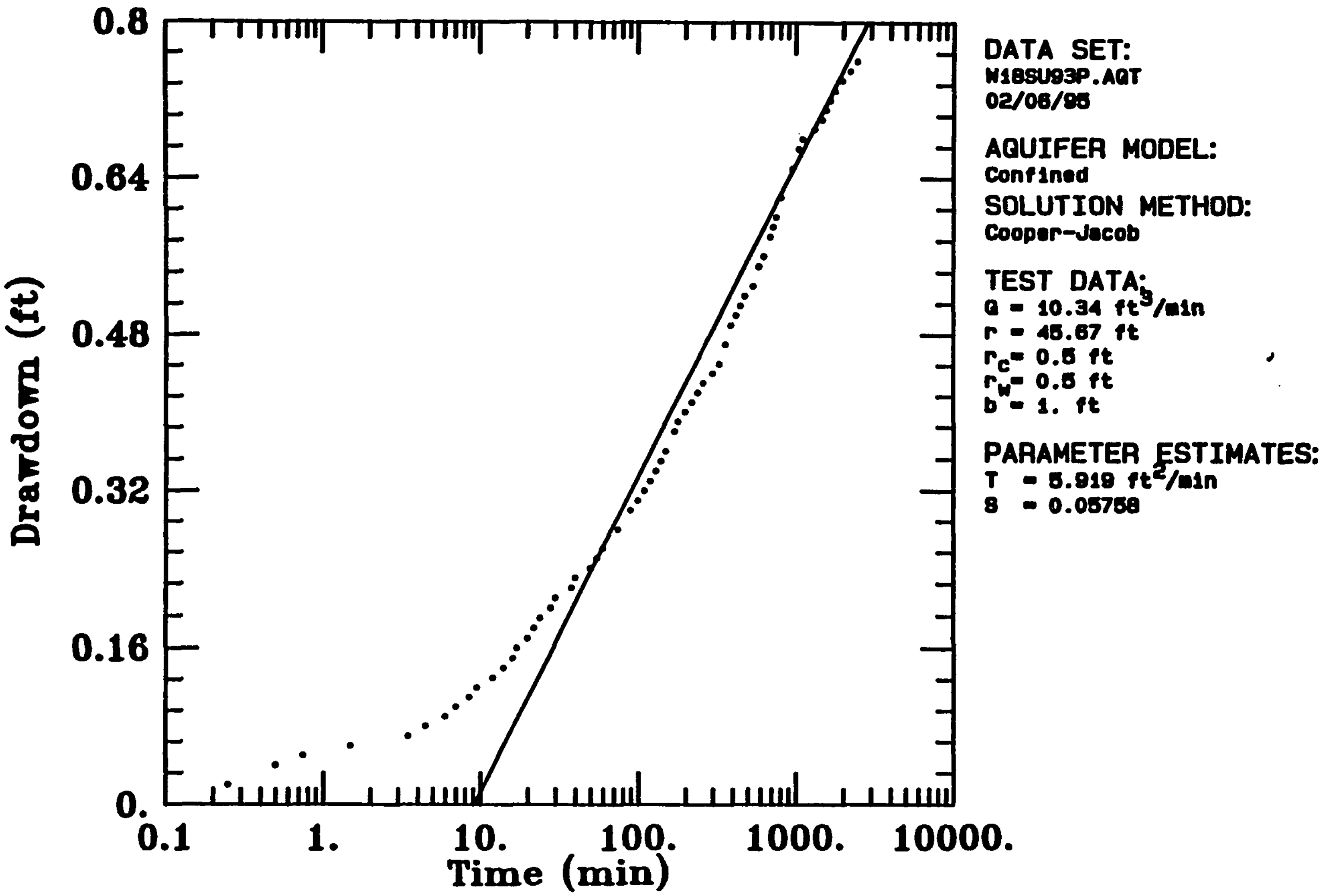

Figure 26. Jacob-Cooper Curve for Well AL-18 for August 1993.

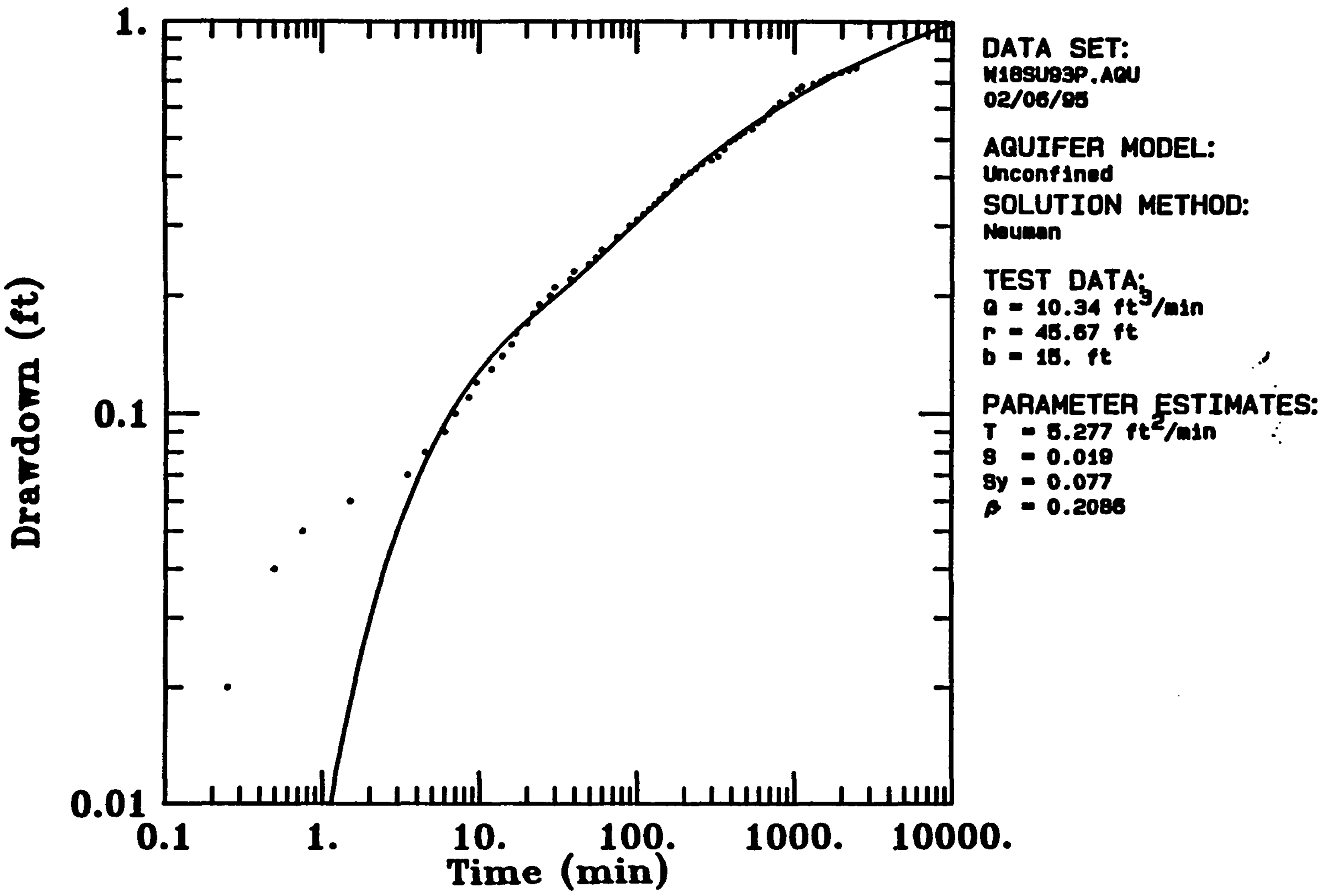

Figure 27: Neuman Method Curve for Well AL-18 for August 1993.

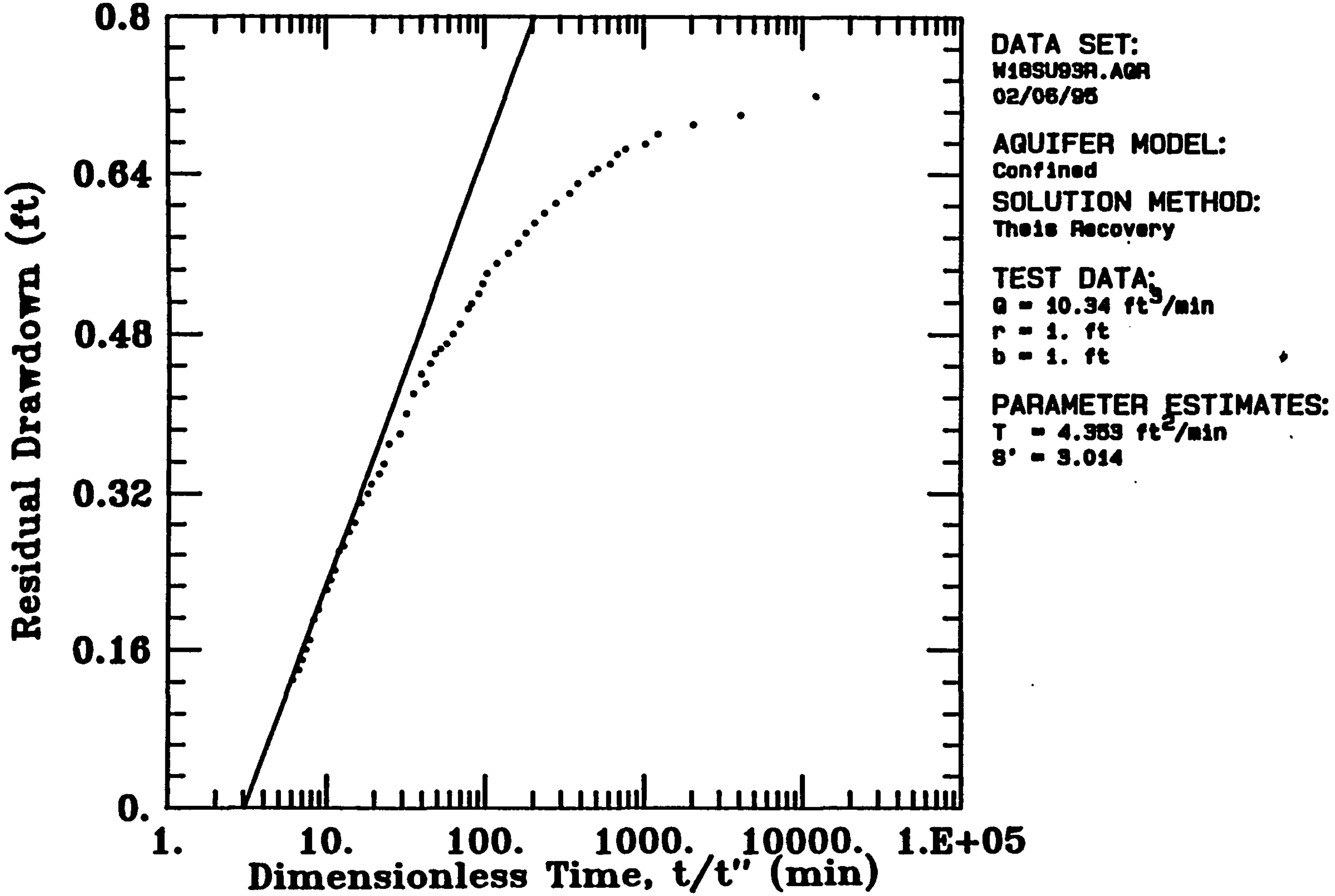

Figure 28. Theis Recovery Curve for Well AL-18 for August 1993.

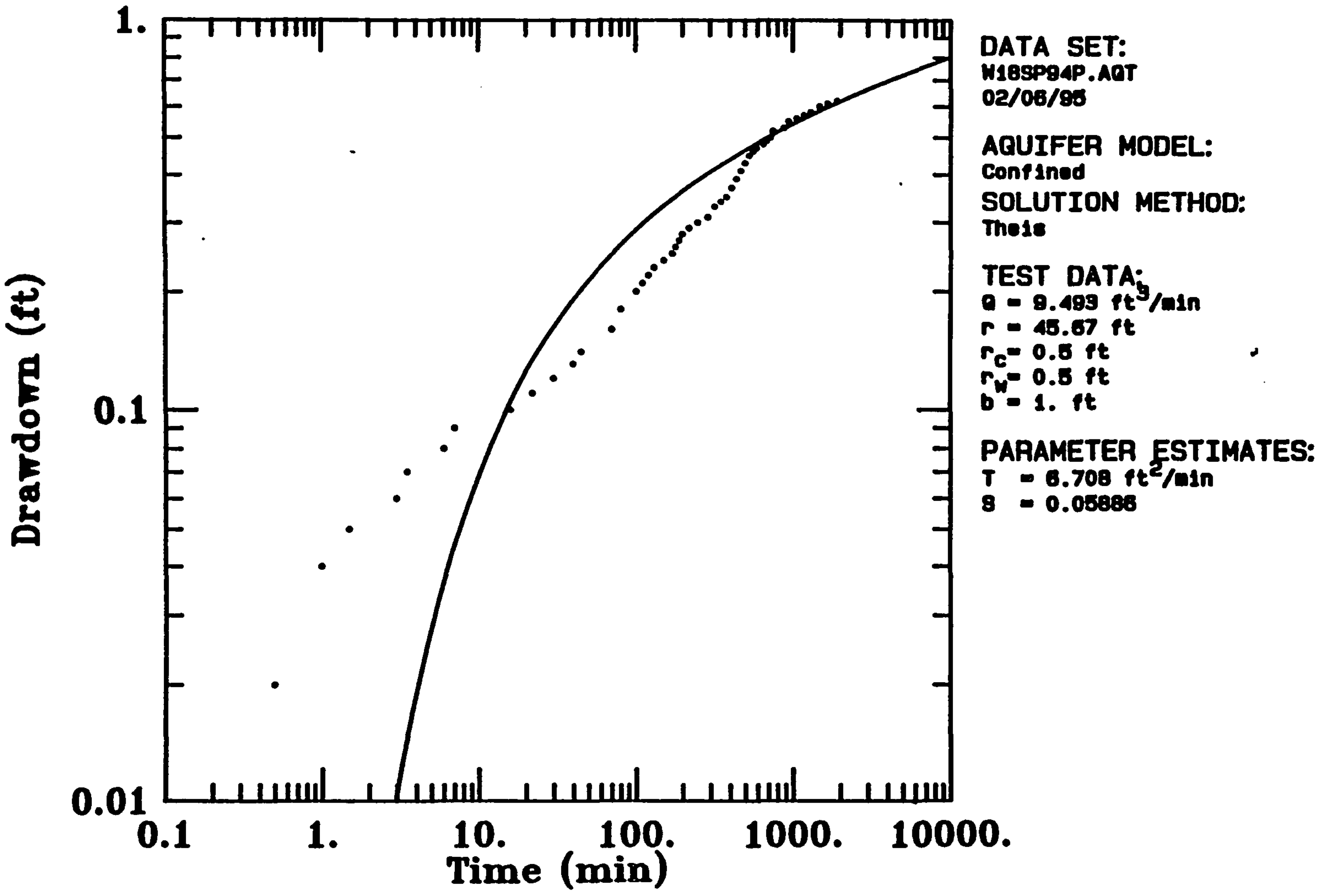

Figure 29. Theis Curve for Well AL-18 for June 1994.

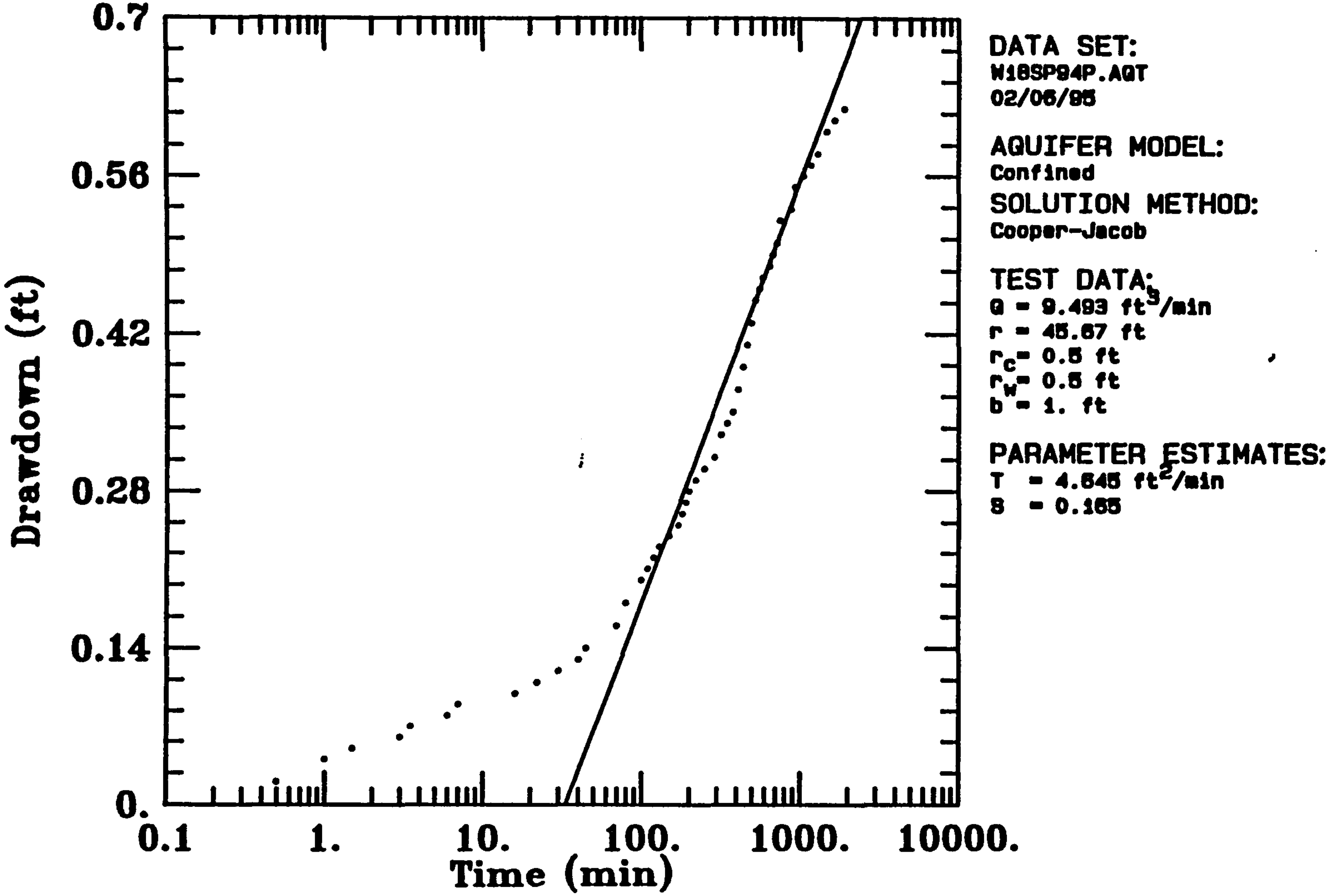

Figure 30. Jacob-Cooper Curve for Well AL-18 for June 1994.

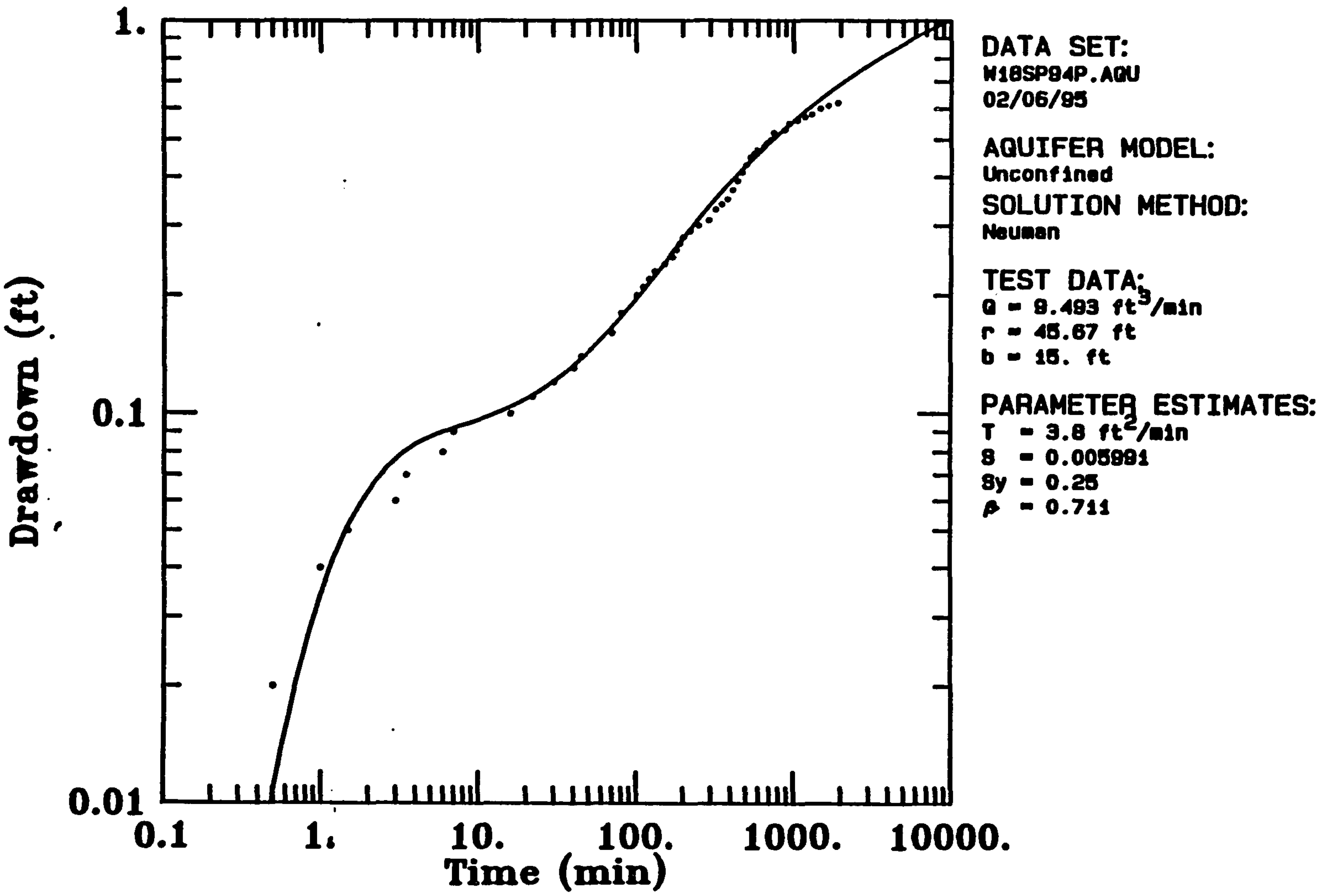

Figure 31. Neuman Method Curve for Well AL-18 for June 1994.

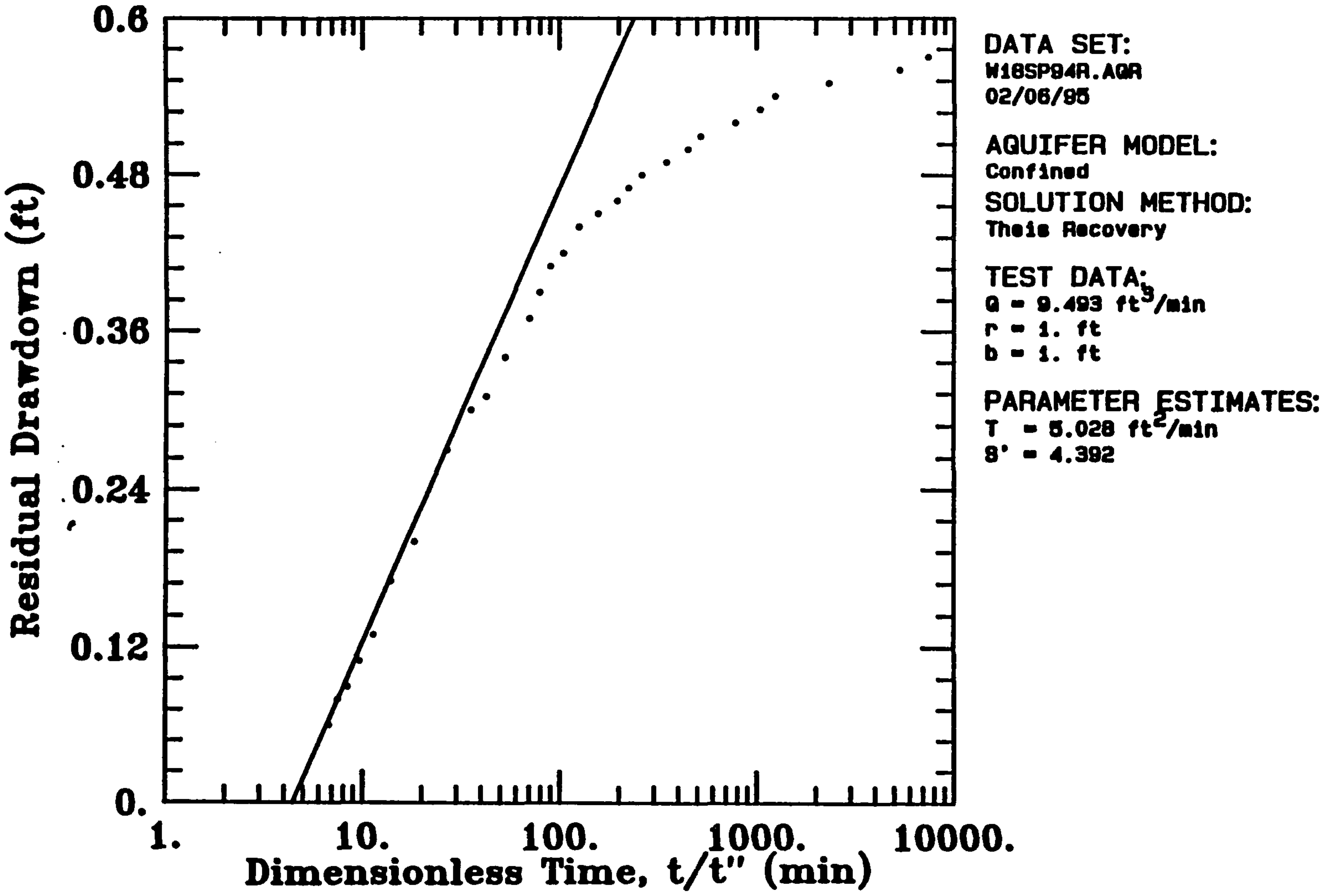

Figure 32. Theis Recovery Curve for Well AL-18 for June 1994.

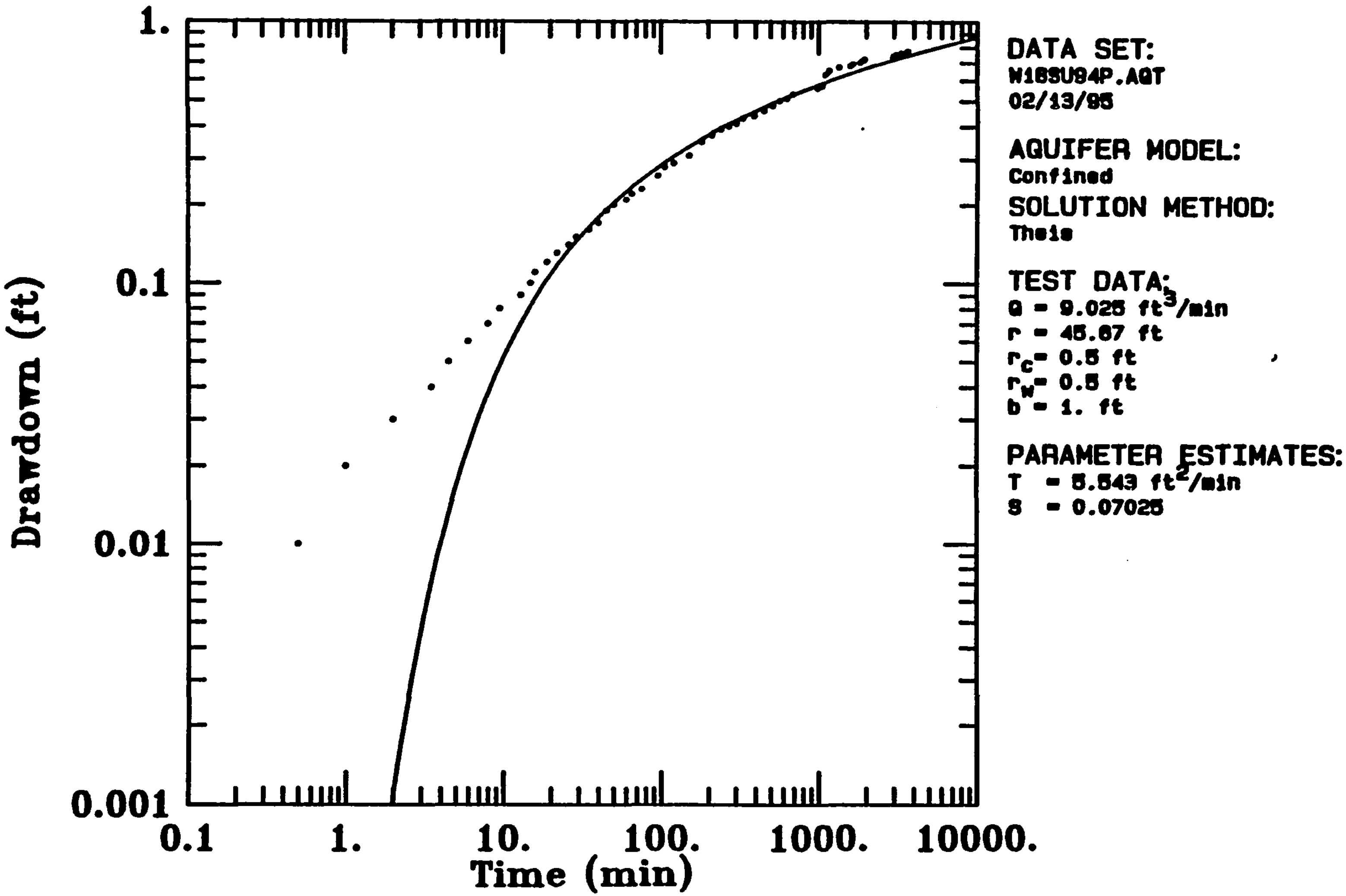

Figure 33. Theis Curve for Well AL-18 for August 1994.

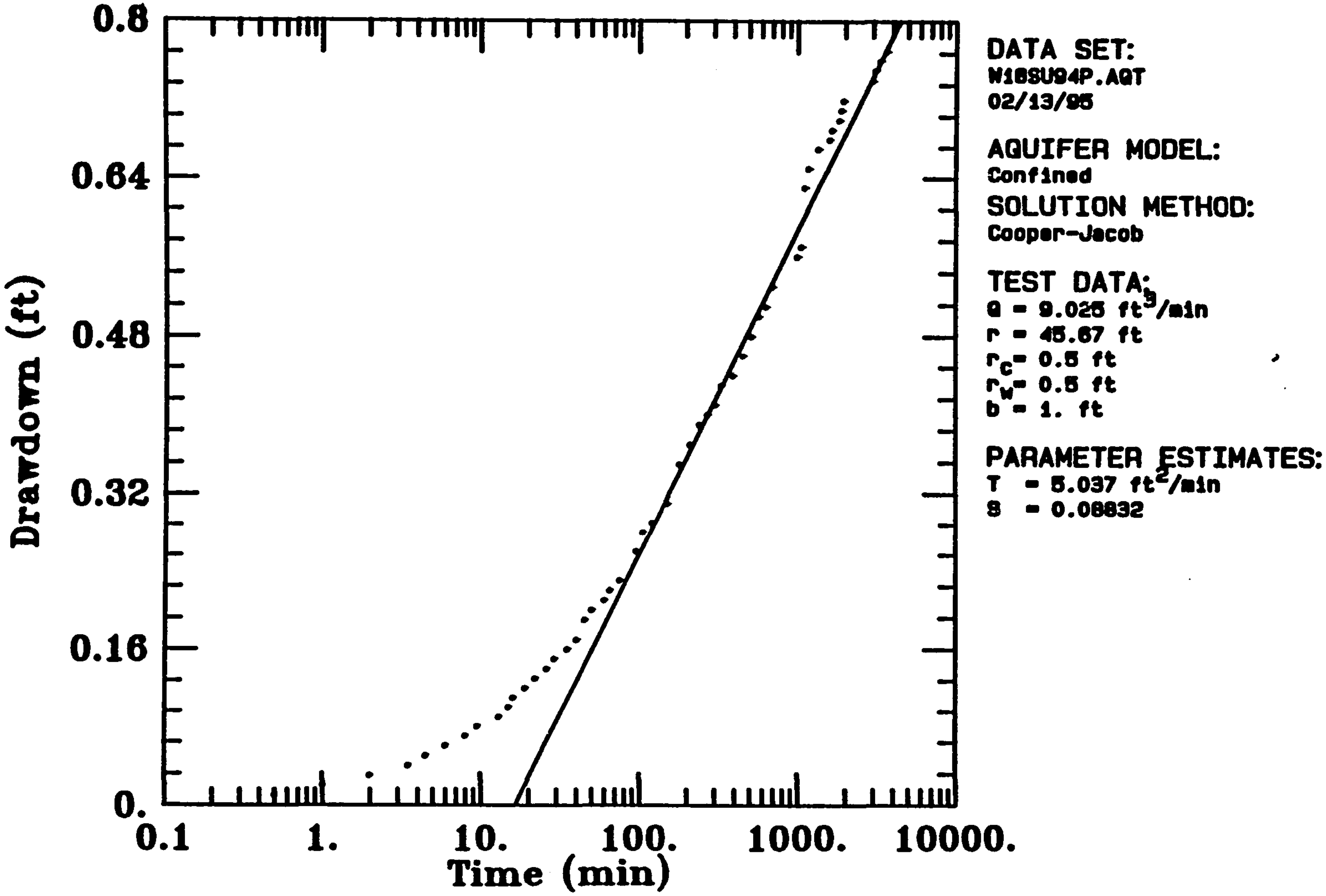

Figure 34. Jacob-Cooper Curve for Well AL-18 for August 1994.

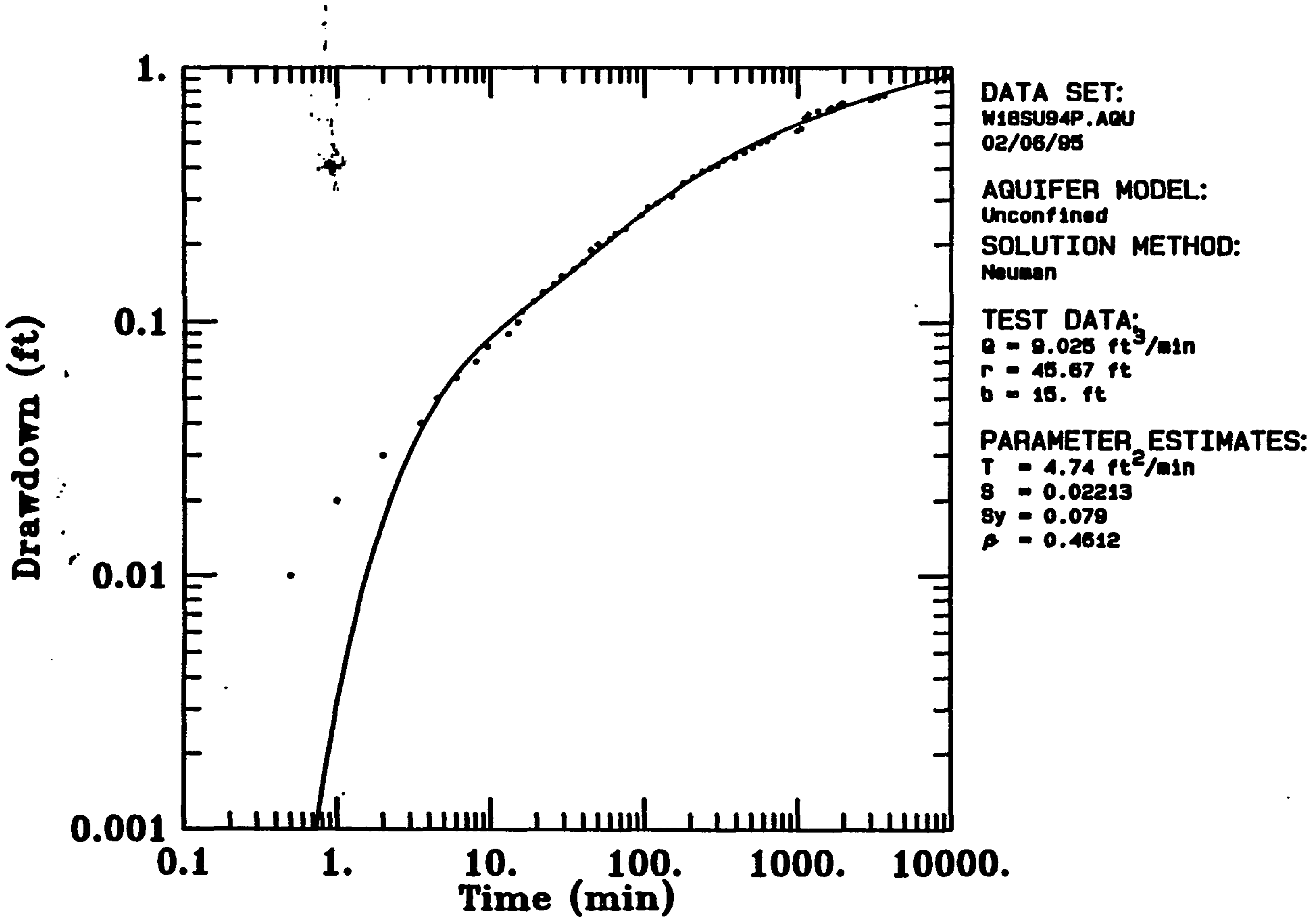

Figure 35. Neuman Method Curve for Well AL-18 for August 1994.

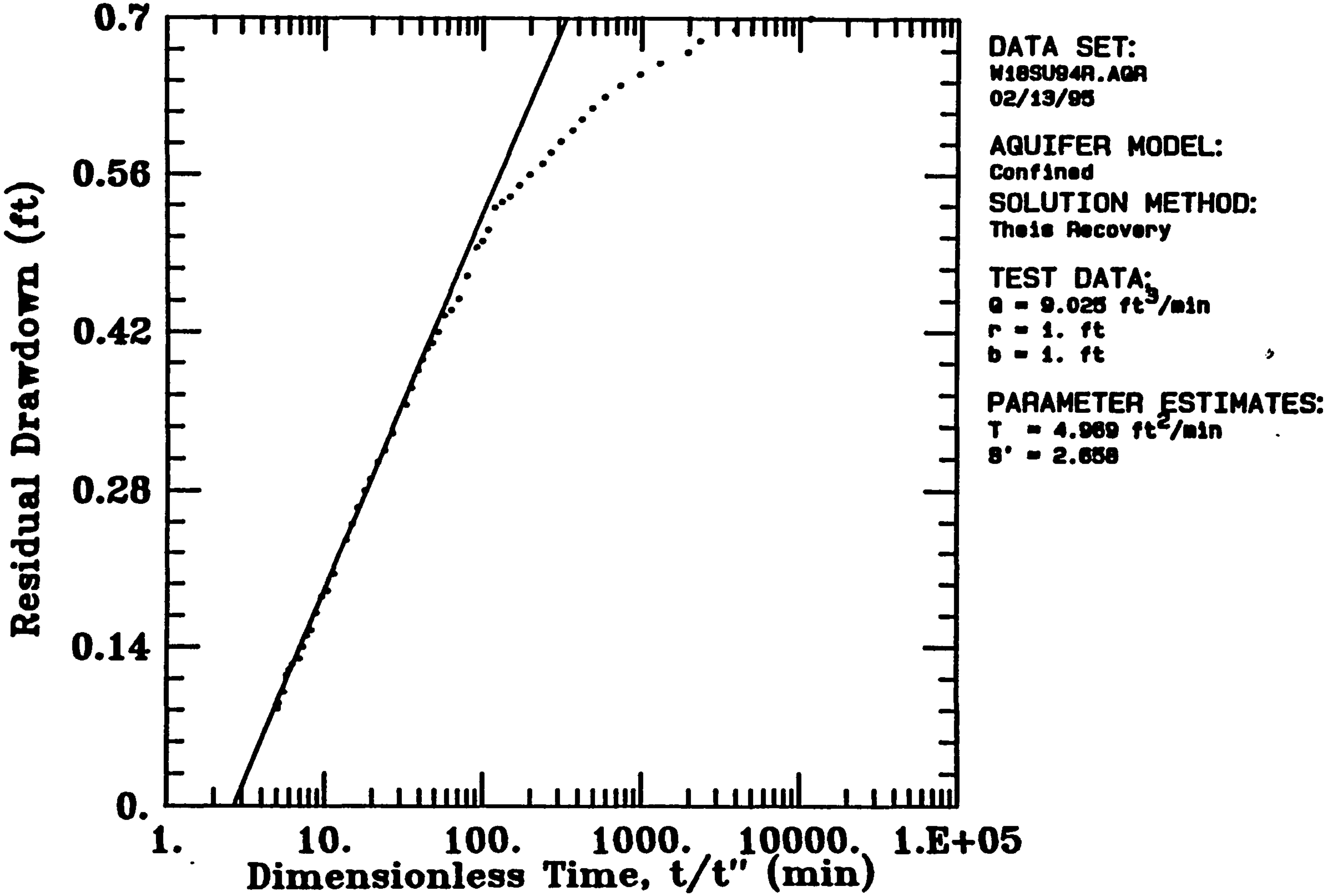

Figure 36. Theis Recovery Curve for Well AL-18 for August 1994.

Appendix D

T and S Results From AL-27

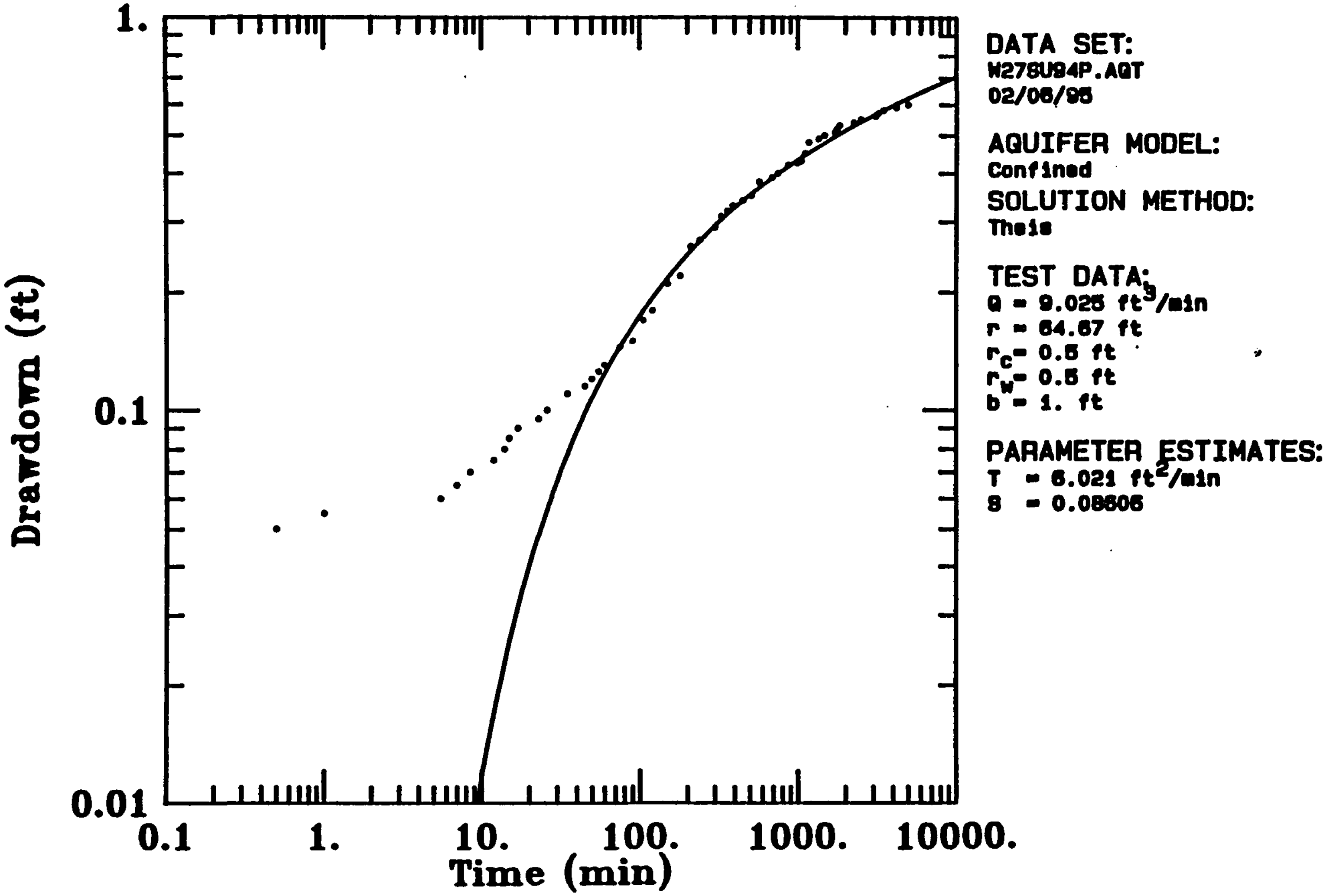

Figure 37. Theis Curve for Well AL-27 for August 1994.

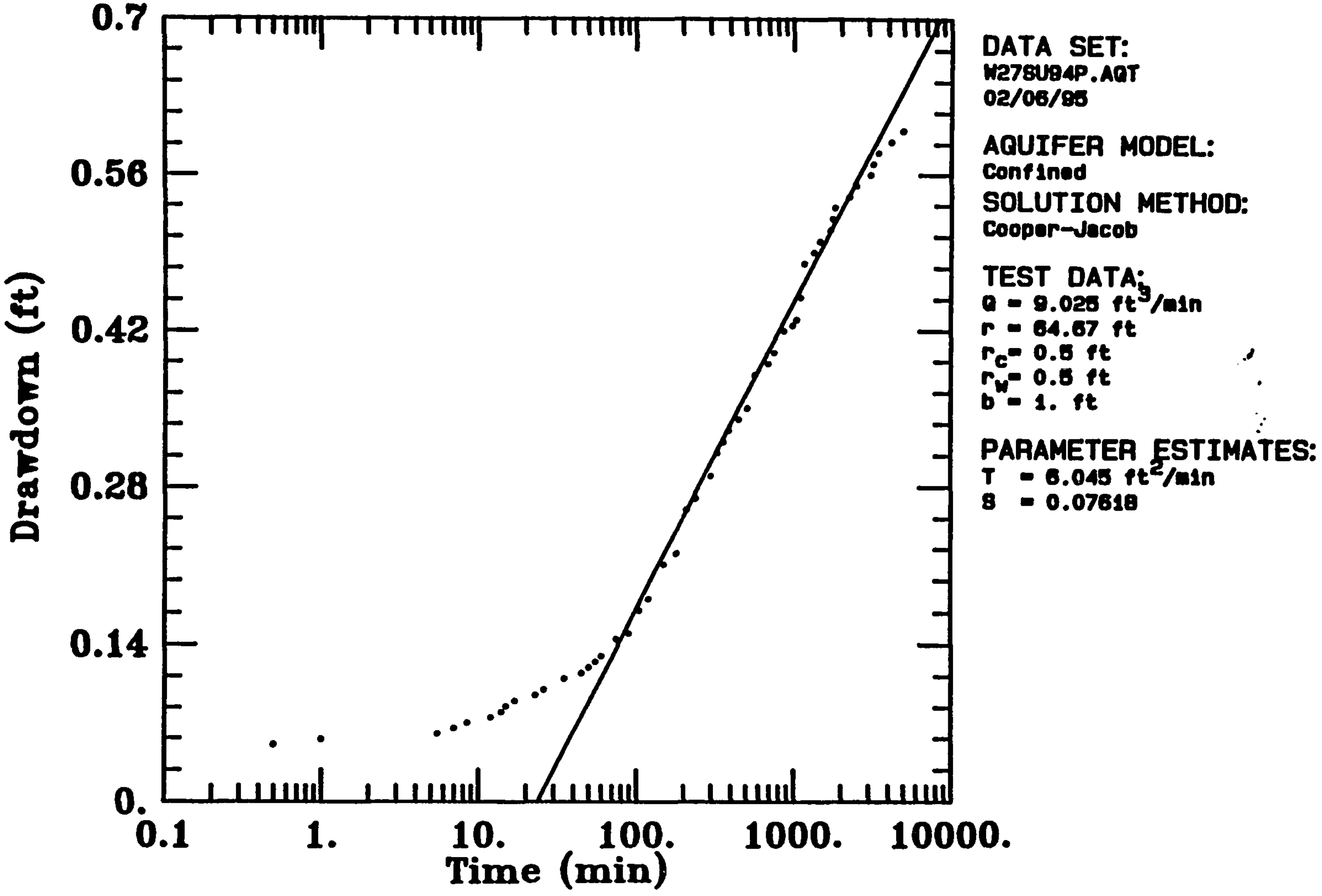

Figure 38. Jacob-Cooper Curve for Well AL-27 for August 1994.

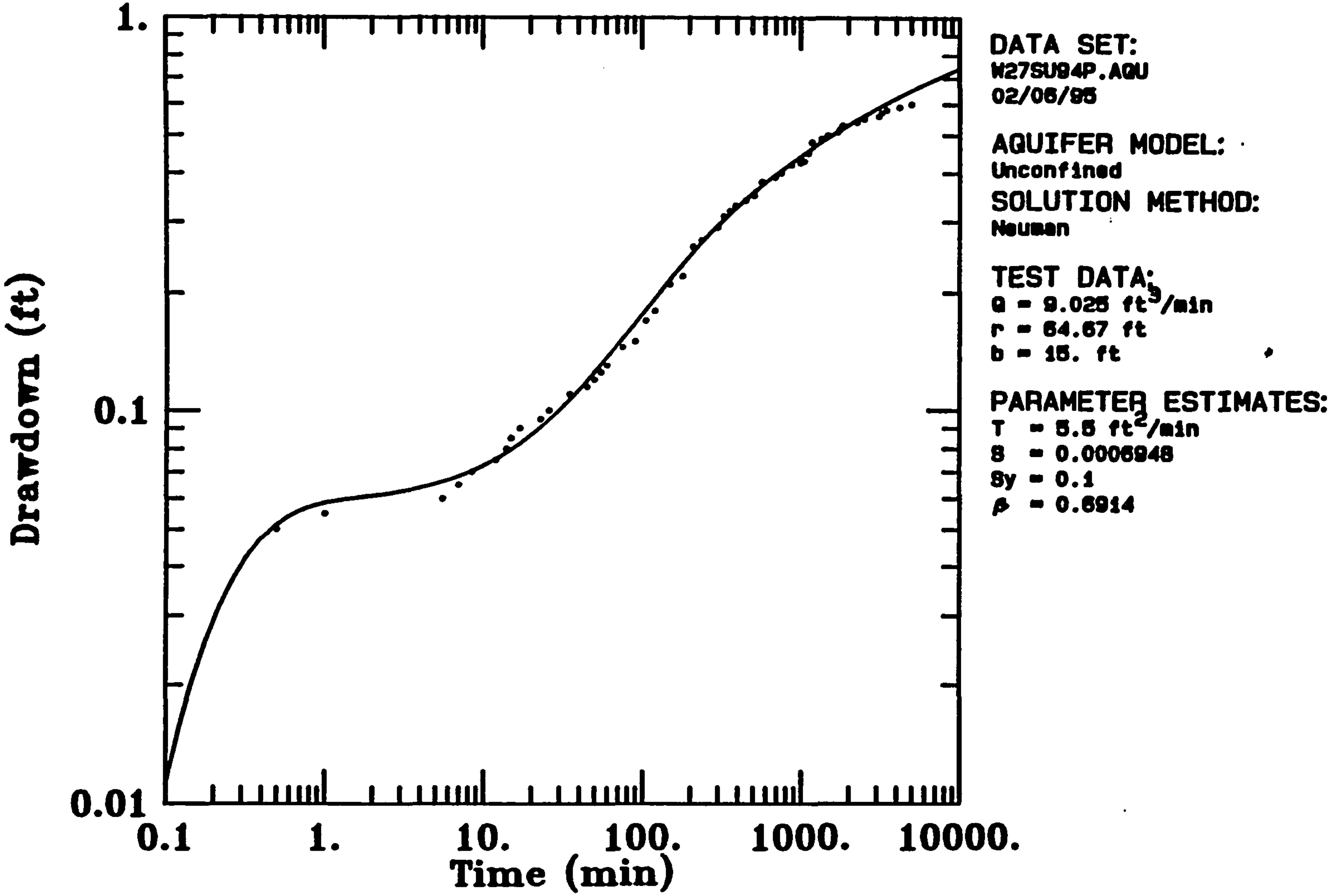

Figure 39. Neuman Method Curve for Well AL-27 for August 1994.

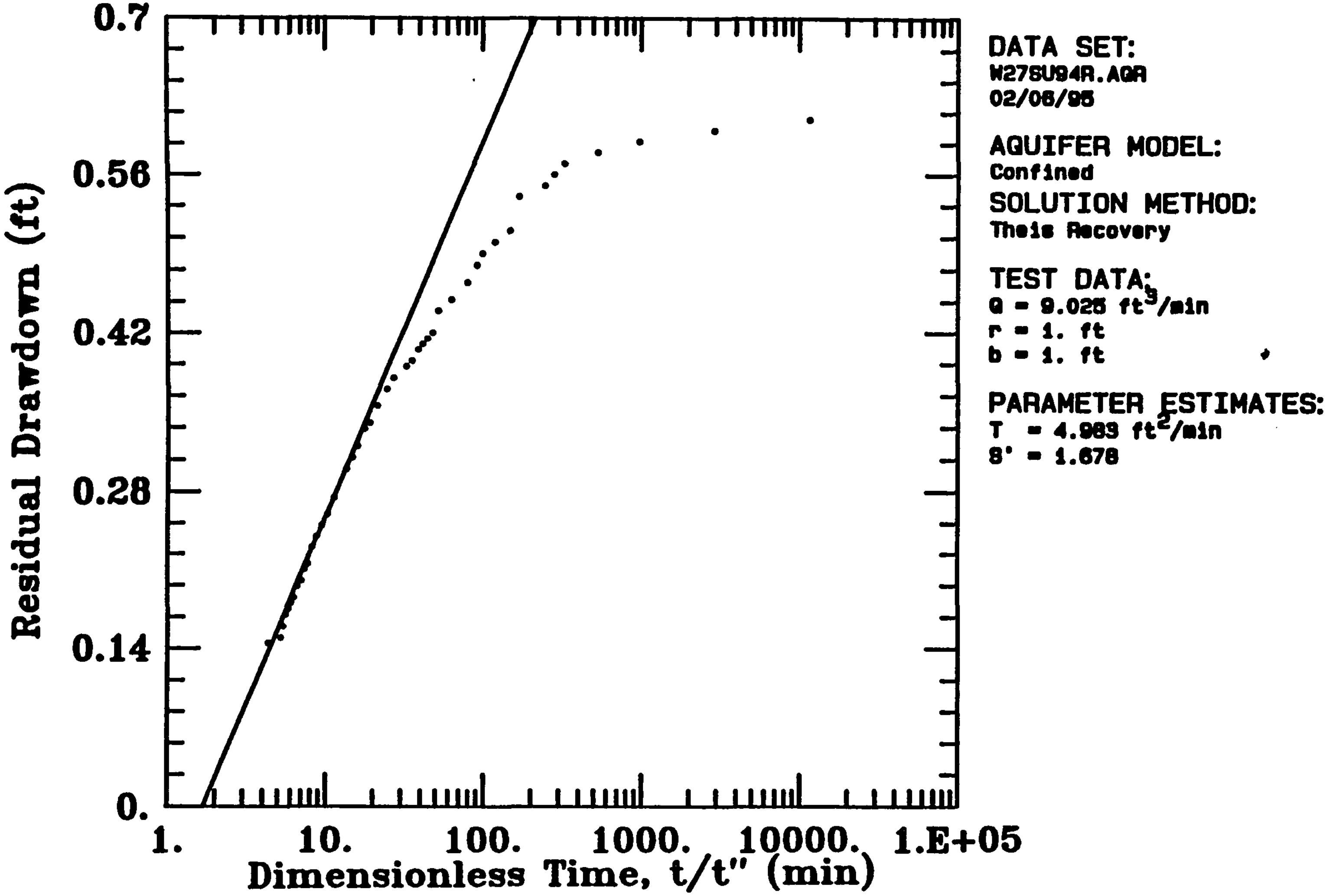

Figure 40. Theis Recovery Curve for Well AL-27 for August 1994.

Appendix E

T and S Results From AL-28

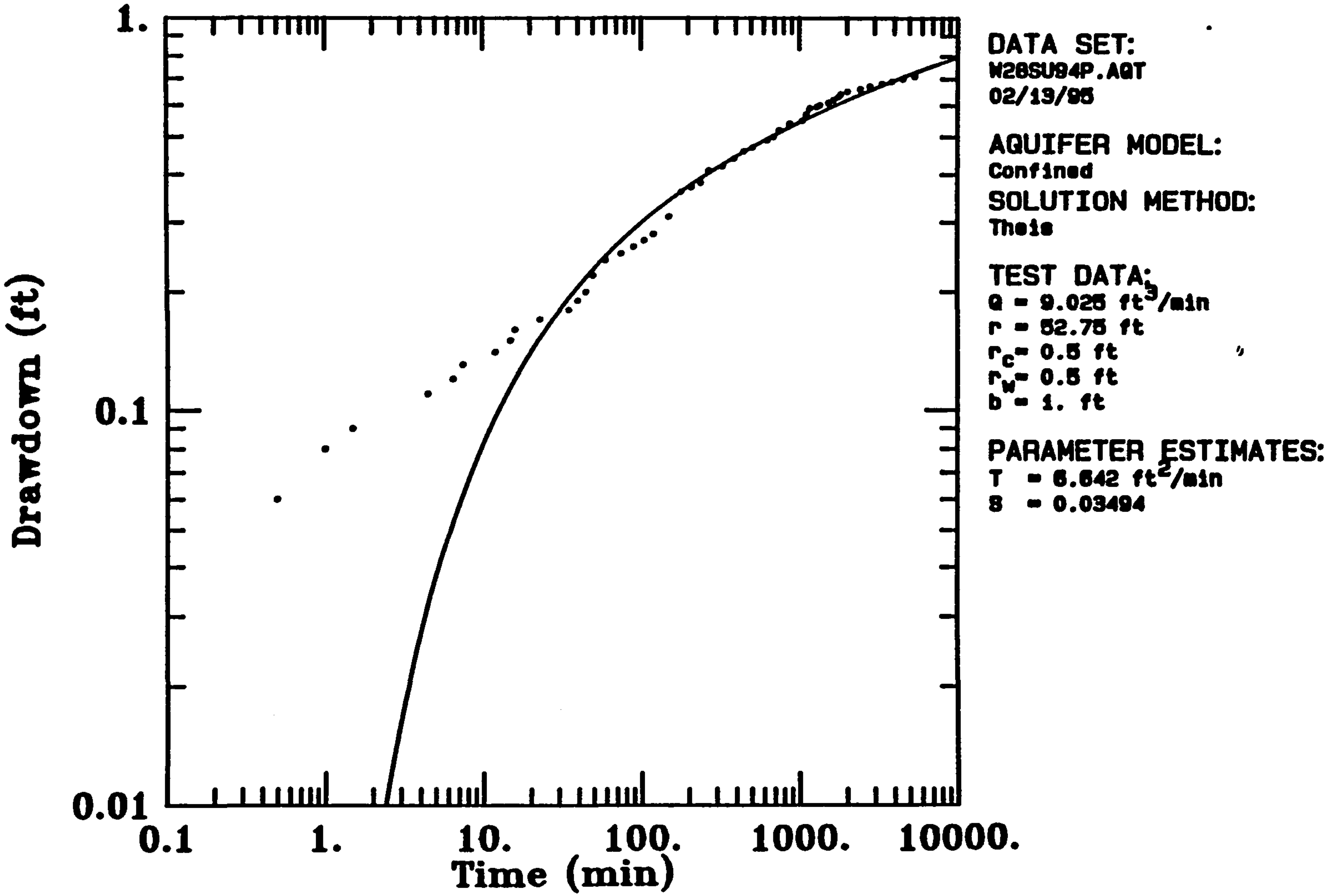

Figure 41. Theis Curve for Well AL-28 for August 1994.

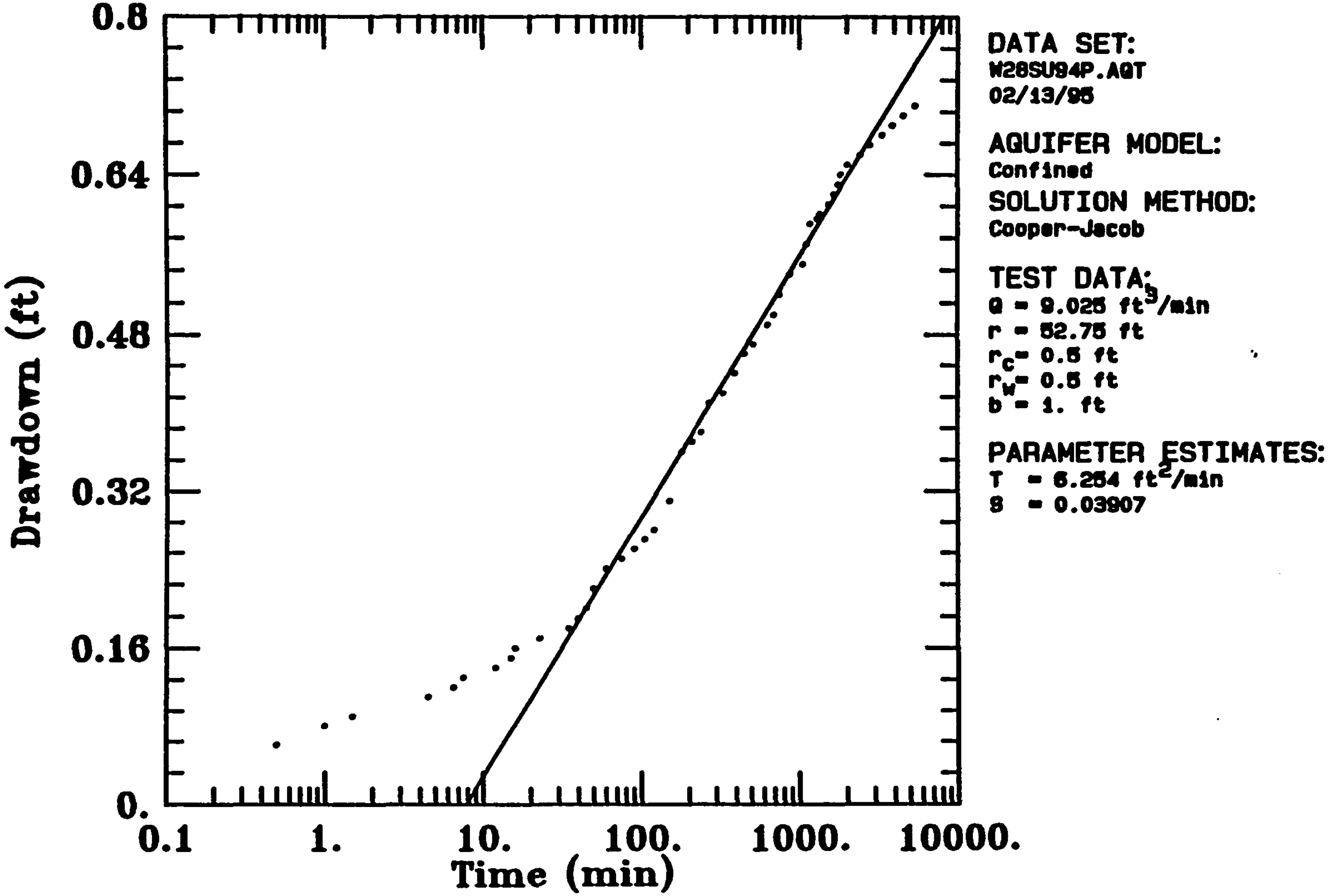

Figure 42. Jacob-Cooper Curve for Well AL-28 for August 1994.

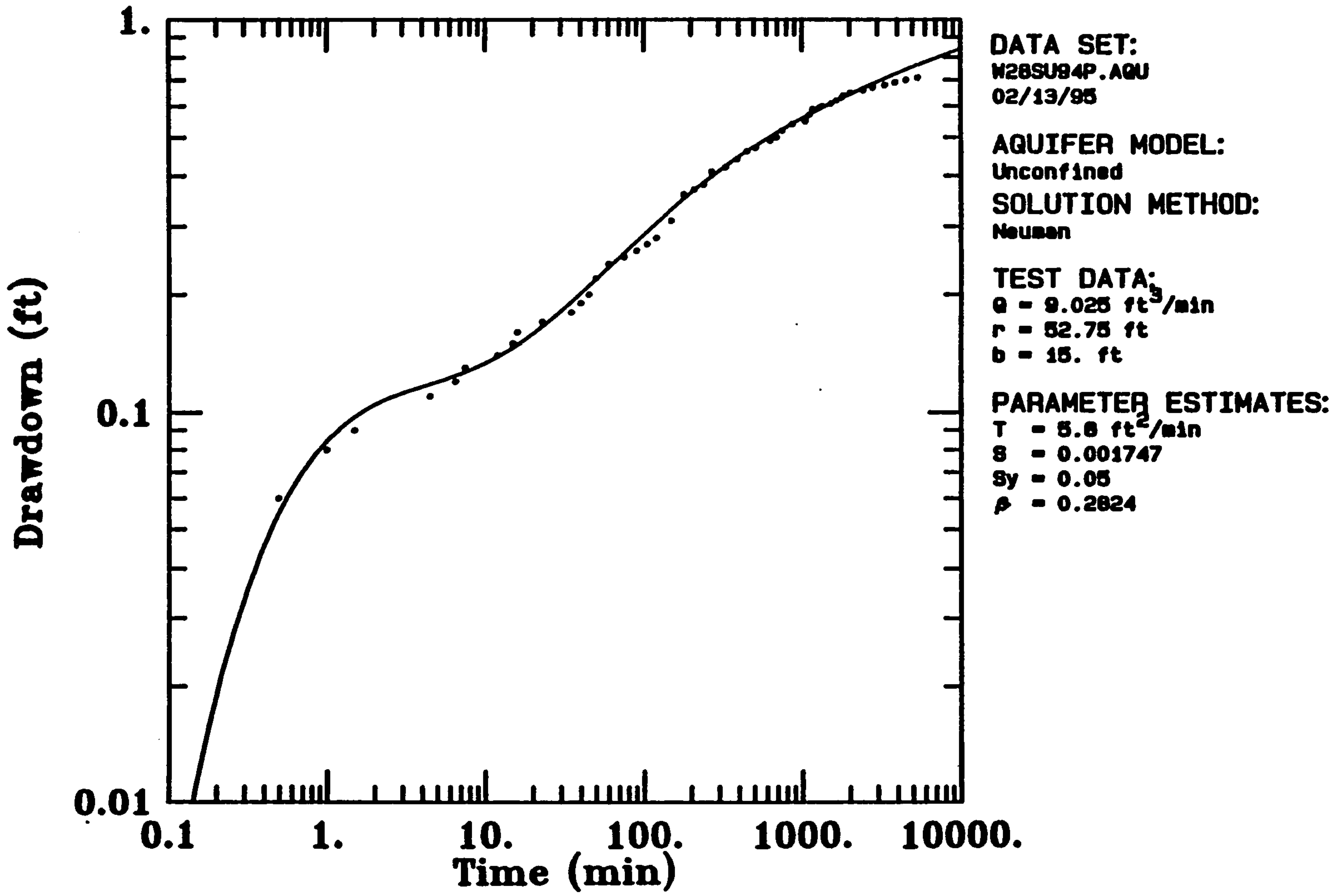

Figure 43. Neuman Method Curve for Well AL-28 for August 1994.

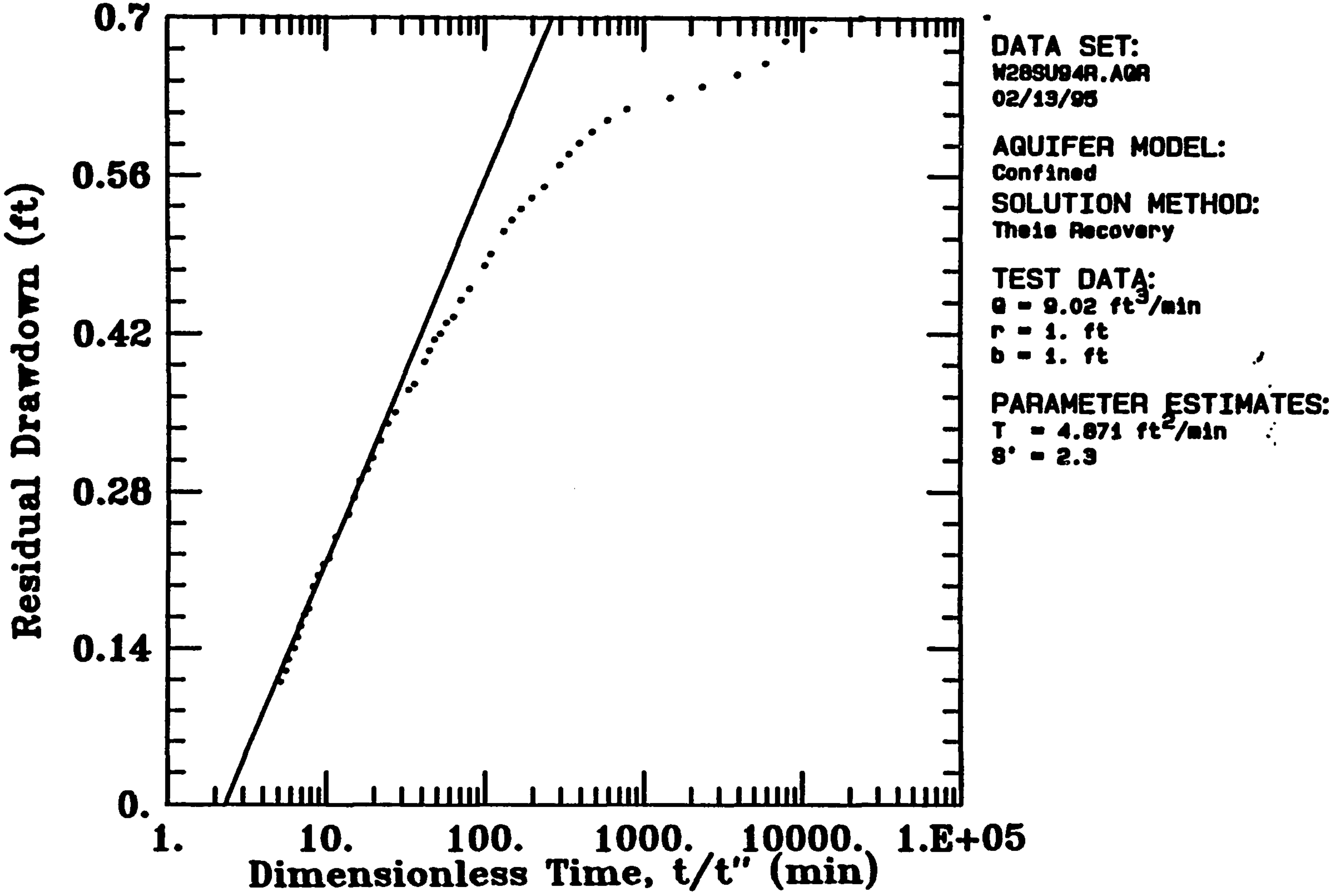

Figure 44. Theis Recovery Curve for Well AL-28 for August 1994.

Appendix F

Site Map

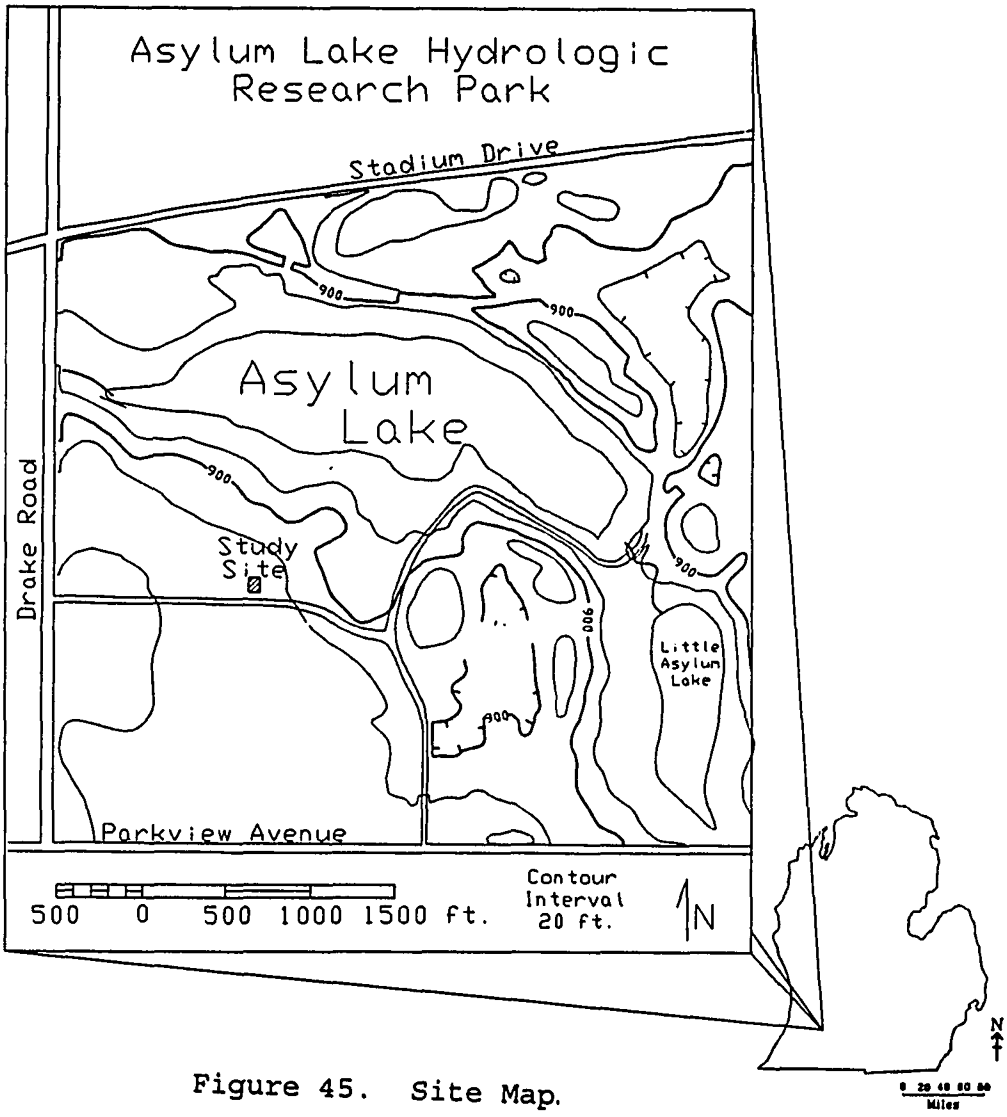

Figure 45. Site Map.

Appendix G

Well Configuration Diagrams

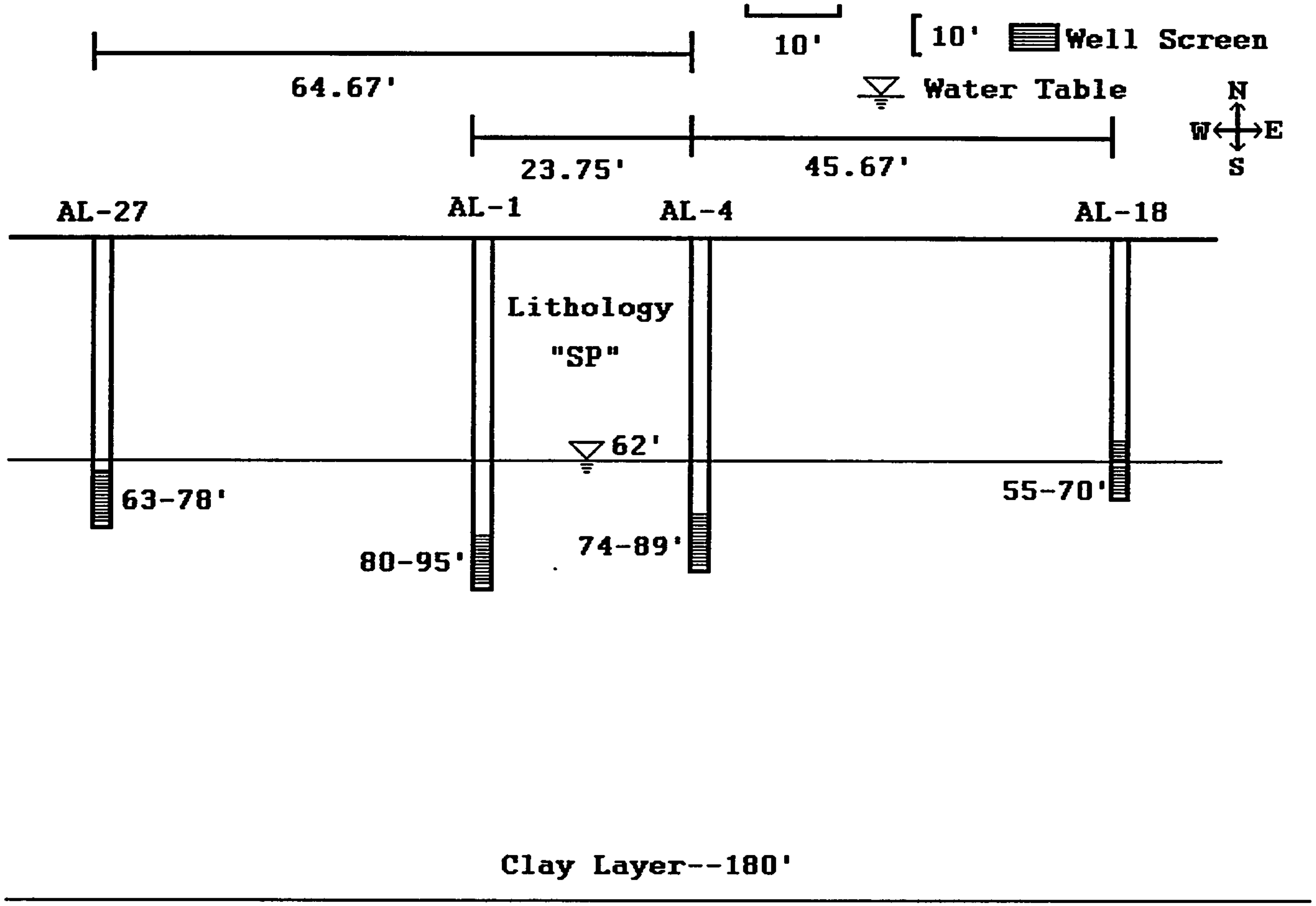

Figure 46. West-East Well Configuration Cross-Section.

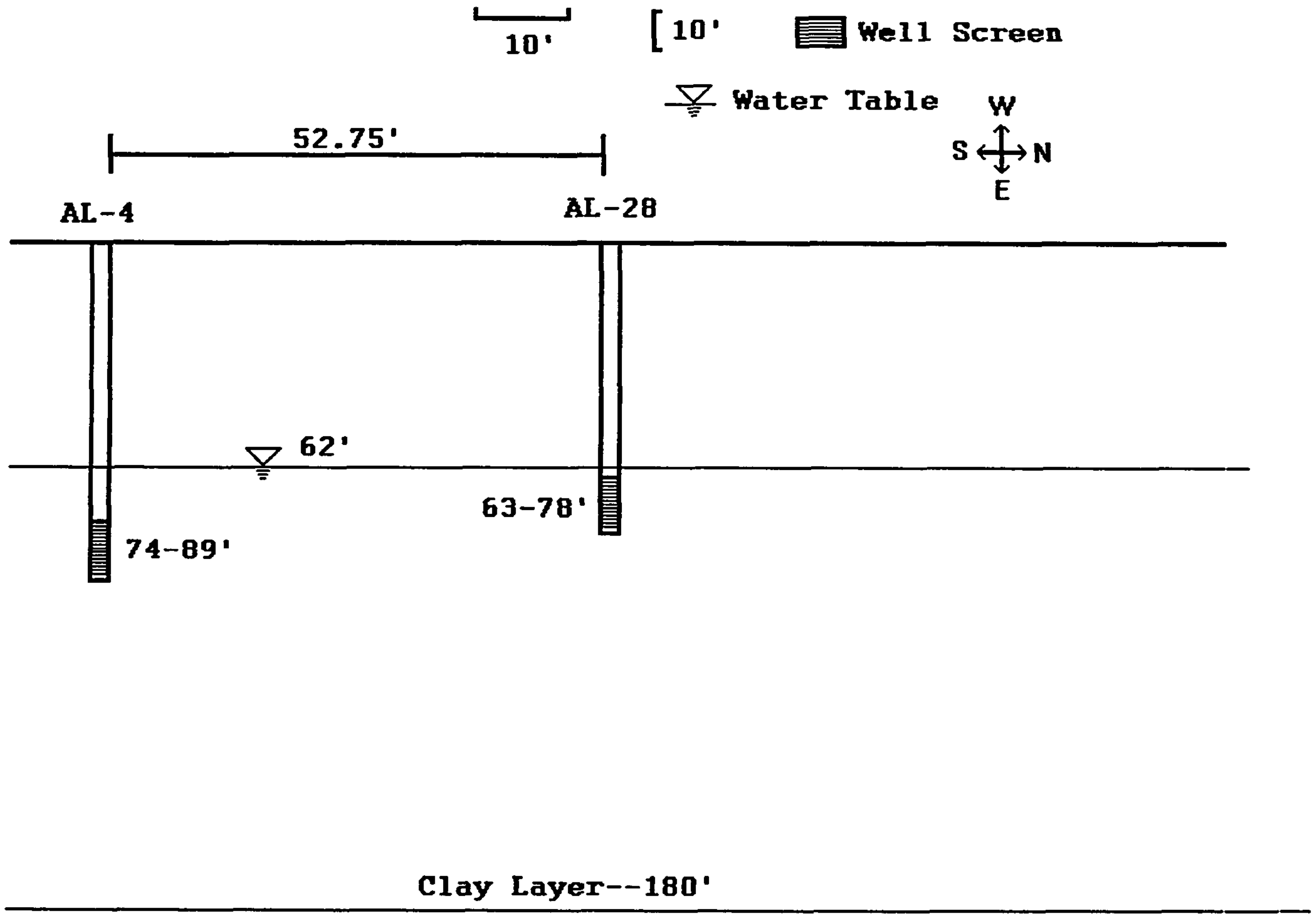

Figure 47. South-North Well Configuration Cross-Section.

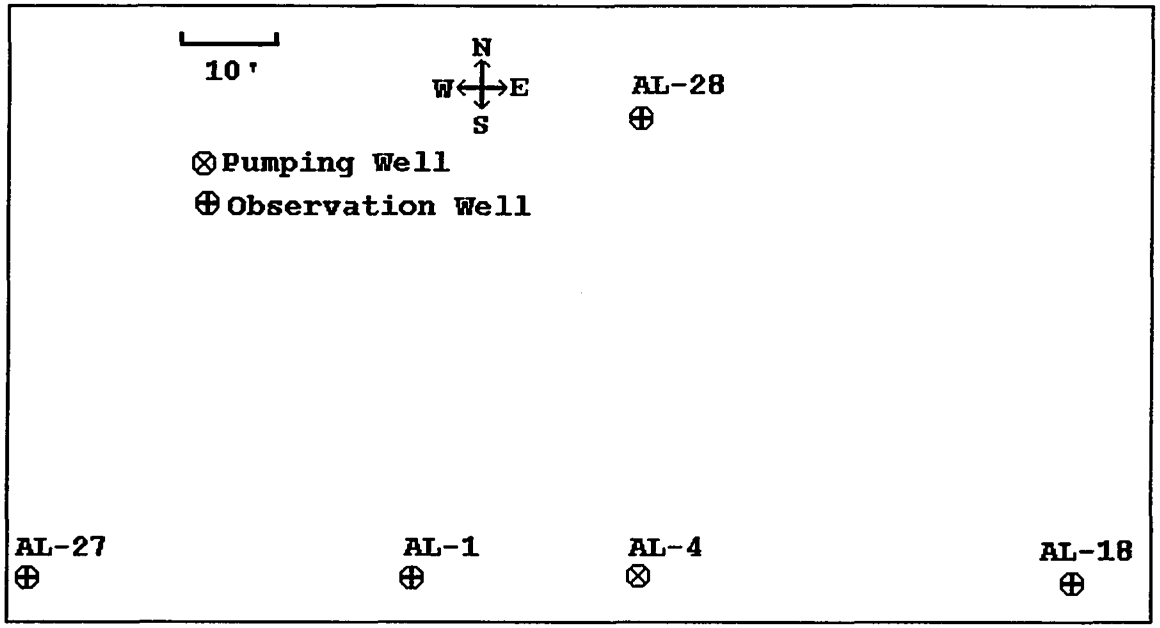

Figure 48. Well Nest Configuration.

Appendix H

Well Log

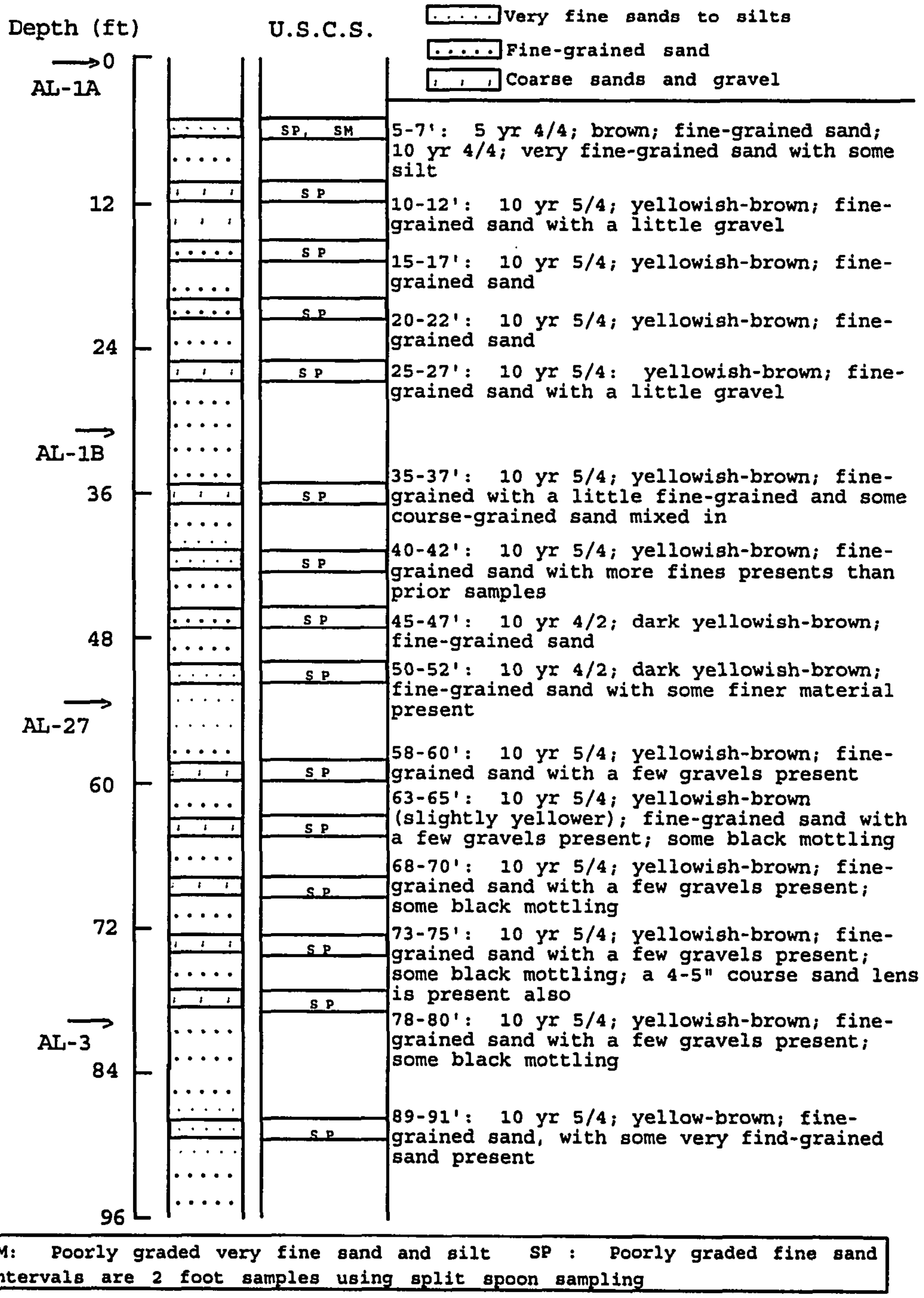

Figure 49. Composite Well Log for Asylum Lake Area.

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