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# Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System

P. D. Thorne
D. R. Newcomer

November 1992

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

Pacific Northwest Laboratory
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UNITED STATES DEPARTMENT OF ENERGY
*under Contract DE-AC06-76RLO 1830*

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**Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.**

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UC-402,403

# SUMMARY AND EVALUATION OF AVAILABLE HYDRAULIC PROPERTY DATA FOR THE HANFORD SITE UNCONFINED AQUIFER SYSTEM

P. D. Thorne
D. R. Newcomer

November 1992

Prepared for
the U.S. Department of Energy
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Richland, Washington 99352

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## SUMMARY

Improving the hydrologic characterization of the Hanford Site unconfined aquifer system is one of the objectives of the Hanford Site Ground-Water Surveillance Project. To help meet this objective, hydraulic property data available for the aquifer have been compiled, mainly from reports published over the past 40 years. Most of the available hydraulic property estimates are based on constant-rate pumping tests of wells. Slug tests have also been conducted at some wells and analyzed to determine hydraulic properties. Other methods that have been used to estimate hydraulic properties of the unconfined aquifer are observations of water-level changes in response to river stage, analysis of ground-water mound formation, tracer tests, and inverse ground-water flow models.

To assess the reliability of published hydraulic property estimates determined from constant-rate pumping tests, selected tests were reanalyzed using updated techniques. Analysis methods for constant-rate pumping tests are based on assumptions about the aquifer and well configurations that are not completely met for most tests. Therefore, it is important to apply the analysis method to a range of test data for which the assumptions apply and where the results are not significantly affected by less than ideal test conditions. Recently developed diagnostic techniques utilizing log-log plots of the derivative of the test data are helpful in identifying the range of data where semilog straight-line analysis methods apply and where nonideal well or aquifer effects are significant.

Available hydraulic property estimates indicate that the transmissivity of tested permeable intervals within the unconfined aquifer ranges from less than 10 to more than 500,000 $ft^2/d$. Corresponding values of equivalent hydraulic conductivity were calculated by dividing the transmissivity values by the estimated thickness of the permeable zone. The resulting hydraulic conductivity ranged from less than 1 to more than 5000 ft/d. Storativity and specific yield values could only be determined from a few multiple-well tests. These results ranged from $7 \times 10^{-5}$ to 0.45.

Reanalysis of selected constant-rate tests showed that straight-line methods had sometimes been applied to data for which the method was not valid. Of the eight reanalyzed tests, the original results were very nearly matched for four. One test reanalysis resulted in an estimated range for transmissivity that was about 25% to 50% less than the original analysis result. One reanalysis resulted in a maximum limiting value for transmissivity and another resulted in a minimum limiting value. Because of limited test duration and nonideal conditions, it was not possible to determine an exact transmissivity from these tests. The original test analysis results were within the possible range of transmissivity but are not considered accurate. No valid analysis was possible for one of the reanalyzed tests. For this test, pumping was conducted in one piezometer tube within a well and the water level was measured in another piezometer tube separated vertically by sand fill.

## CONVERSION TABLE

Most of the information in this report was originally reported in English units. Therefore, English units are used as the primary convention in the text, figures, and tables. For converting English units to metric, the following conversion table is provided:

| Multiply | By | To Obtain |
|---|---|---|
| inches | 2.540 | centimeters |
| feet | 0.3408 | meters |
| miles | 1.6093 | kilometers |
| gallons | 3.7854 | liters |
| $feet^2$/day | 0.0929 | $meters^2$/day |
| pounds/$inches^2$ | 6.8948 | kilo-Pascals |

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# 1.0 INTRODUCTION

Ground-water movement beneath the Hanford Site provides a pathway for the transport of radioactive and hazardous wastes that have been discharged in various locations on the site since 1944. The Hanford Ground-Water Surveillance Project, operated by Pacific Northwest Laboratory (PNL),[a] is responsible for predicting the rate of movement of contaminants in ground water and determining the discharge of contaminants to the Columbia River. To meet these objectives, detailed characterization of the ground-water flow system is needed. Ground-water flow in the uppermost aquifer is of primary importance because most wastes have been discharged at or near the ground surface.

The spatial distributions of hydraulic properties for the uppermost aquifer are part of the data needed for understanding ground-water flow and contaminant transport. The uppermost, generally unconfined, aquifer system at the Hanford Site is located in unconsolidated to semiconsolidated sediments overlying the basalt bedrock. Parts of the aquifer are locally confined or semiconfined. However, because the entire suprabasalt aquifer system is interconnected on a site-wide scale, it has commonly been referred to as the Hanford "unconfined" aquifer, while aquifers located within the Columbia River Basalts have been included in the confined aquifer system. This nomenclature is used in this report.

The primary aquifer properties affecting ground-water flow are hydraulic conductivity, specific storage, and aquifer thickness. Transmissivity is the product of hydraulic conductivity and aquifer thickness, and storativity is the product of specific storage and aquifer thickness. For unconfined aquifers, both the storativity associated with elastic aquifer response and the specific yield from dewatering of the aquifer are important components of total aquifer storativity. In addition, effective porosity is an important parameter in determining ground-water velocity and rates of contaminant transport. When combined with information on boundary conditions and

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hydraulic gradient, the distributions of these hydraulic properties provide a complete description of the ground-water flow system. Aquifer thickness is most commonly determined from the logging of geologic materials recovered during well drilling. Aquifer thickness may also be determined from downhole or surface geophysical measurements. Transmissivity, storativity, and specific yield (for unconfined aquifers) are usually determined by using wells to observe the water-level changes in response to an applied or natural stress on the aquifer. In the case of aquifer pumping tests and slug tests, the stress is applied by adding or removing water at a well. Natural stresses may result from changes in the water level of a surface-water body hydraulically connected to the aquifer, or from earth tides or atmospheric pressure changes.

Hundreds of aquifer pumping tests and slug tests have been conducted on wells at Hanford to determine hydraulic properties. However, the accuracy of the results are questionable for many of these tests. This is mainly because of the complexity of the flow system and the simplifying assumptions inherent in the analysis methods. Many tests have also been affected by inadequate and irregular pumping rates, short durations, noisy data, and less than ideal well construction. Observation well data are generally required to determine storativity and specific yield, and few multiple-well tests have been performed.

The objective of this report is to compile and evaluate available hydraulic property data for the unconfined aquifer at Hanford. A summary of Hanford Site hydrogeology is given in Section 2.0. Section 3.0 describes the test and analysis methods that have been applied to determine hydraulic properties for the unconfined aquifer at the site. Section 4.0 provides a review of documents containing hydraulic property estimates from hydrologic tests and from inverse ground-water flow modeling. A few tests that have not yet been documented are also discussed. Section 5.0 summarizes the available hydraulic property data for the Hanford Site unconfined aquifer. Selected tests have been reanalyzed using updated methods. These analyses are presented in Section 6.0.

## 2.0 HYDROGEOLOGIC SETTING

The Hanford Site (Figure 1) lies adjacent to the Columbia River in the Pasco Basin, a structural depression defined by surrounding basalt anticlines. Within the Pasco Basin, late Miocene- to Pleistocene-aged fluvial, lacustrian, and glaciofluvial sediments overlie a thick sequence of basalt flows of the Columbia River Basalt Group. During the late-Miocene to mid-Pliocene, a sequence of intercalated fluvial and lacustrian deposits of the Ringold Formation partially filled the subsiding Pasco Basin. Pleistocene-aged glaciofluvial sediments, informally named the Hanford formation, were deposited over the Ringold Formation by both catastrophic and normal flood events. More detailed descriptions of the Hanford Site geology are provided in Myers and Price (1979) and DOE (1988).

Except at basalt outcrops, the uppermost aquifer at Hanford lies mainly within the Ringold and Hanford formations. The Hanford formation consists of unconsolidated beds and lenses of silt, sand, and gravel, while the underlying Ringold Formation consists of unconsolidated to weakly cemented beds and lenses of clay, silt, sand, and gravel. The Ringold sediments are generally more consolidated, contain more silt, and are about 10 to 100 times less permeable than the sediments of the overlying Hanford formation. However, sand and gravel layers with relatively high permeability are also present within the Ringold Formation and permeable strata of the aquifer sometimes cross the division between these two main stratigraphic units. In an effort to provide more detailed characterization of the aquifer, recent attempts have been made to define individual strata, or lithofacies, that possess similar hydrogeologic characteristics (Poeter and Gaylord 1990; Lindsey 1991). This methodology holds promise for improving the accuracy of ground-water flow models, particularly three-dimensional flow models, of the unconfined aquifer.

Ground water in the unconfined aquifer at Hanford generally flows from recharge areas in the west toward the Columbia River on the eastern and northern boundaries of the site (DOE 1988). Prior to waste-water disposal operations at the Hanford Site, the uppermost aquifer was almost entirely within the Ringold Formation and the water table only extended into the Hanford formation at a few locations (Newcomb et al. 1972). However,

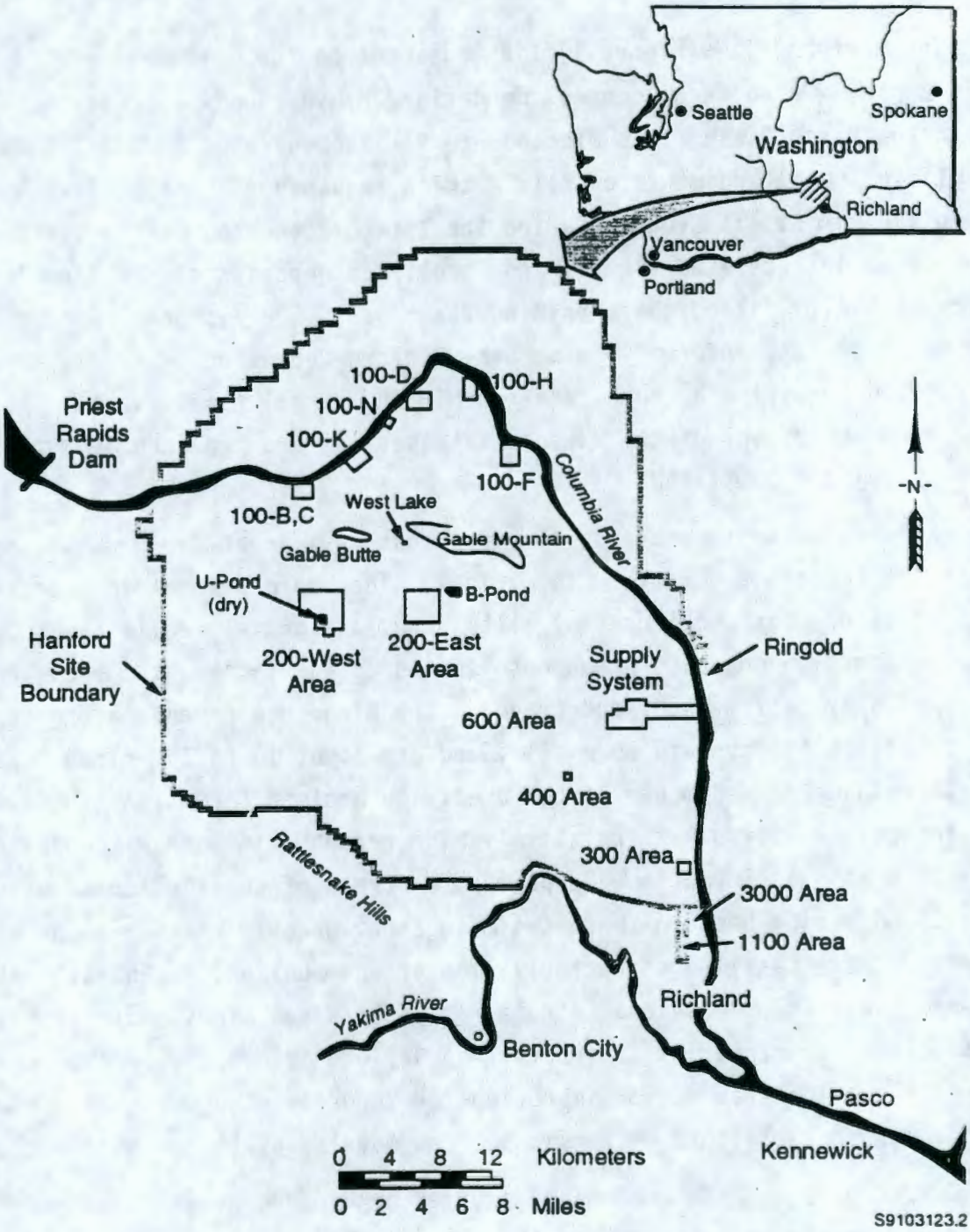


FIGURE 1. Hanford Site Location Map

waste-water discharges have increased the water-table elevation and created ground-water mounds under the two main waste-water disposal areas near the 200-East and 200-West areas. The water table has risen about 90 ft under a disposal area in the 200-West Area, and about 30 ft under disposal ponds near the 200-East Area. The volume of water that has been discharged to the ground at the 200-West Area is actually less than that discharged at the 200-East Area (Zimmerman et al. 1986). However, the lower permeability of the aquifer in the vicinity of the 200-West Area has inhibited ground-water movement in this area and resulted in a higher ground-water mound. Because of the increased ground-water elevation, the water table is now in the Hanford formation over much of the eastern portion of the Hanford Site.

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# 3.0 HYDROLOGIC TEST AND ANALYSIS METHODS

Several types of hydrologic tests have been conducted to determine hydraulic properties of the unconfined aquifer at Hanford. Pumping tests have been conducted at many wells using either a single-well configuration, where aquifer drawdown and recovery is measured in the pumped well, or a multiple-well configuration, where aquifer response is measured at one or more observation wells. Single-well pumping tests have been conducted more frequently because of the expense of installing multiple wells. Many single-well slug tests have also been conducted, especially during the past decade. These tests are generally performed more quickly and with less elaborate equipment than pumping tests. They also have an advantage in areas of ground-water contamination because it is not necessary to remove large volumes of ground water. However, single-well slug tests can only be analyzed over a relatively narrow range of transmissivity and the results apply to only a small area surrounding the well. A multiple-well slug test method that avoids these problems to some extent has been used by Spane (1992a).

In addition to these standard hydraulic test methods, a few estimates of hydraulic properties have been obtained from analysis of

- tracer test results
- water-level responses to changes in Columbia River elevation
- formation of ground-water mounds under waste-water disposal areas.

Descriptions of the test and analysis methods used for determining hydraulic properties of the unconfined aquifer at Hanford are provided in this section.

## 3.1 CONSTANT-RATE DISCHARGE TESTS

Constant-rate discharge (or pumping) tests have probably been the most commonly employed method of determining hydraulic properties at Hanford. For this method, water is removed from a well at a constant rate and the associated drawdown and recovery water levels over time are measured at the pumping well and/or in one or more nearby observation wells.

The mathematical equation describing drawdown, s, in an aquifer resulting from transient radial flow of compressible ground water to a well pumped at a constant rate was given by Theis (1935) as

$$s = \frac{Q}{4\pi T} W(u)$$

where T = transmissivity of the aquifer [$L^2/T$]
Q = constant discharge rate [$L^3/T$].

The dimensionless well function, W(u), is defined as:

$$W(u) = \int_u^\infty \frac{e^{-u}}{u} du$$

where $u = \frac{r^2 S}{4Tt}$ [dimensionless]

and where r = radial distance to the pumping well [L]
S = storativity of the aquifer [dimensionless].

The Theis equation makes several assumptions: 1) the aquifer is confined, homogeneous, isotropic, and of infinite lateral extent, 2) the well is a line-sink (i.e., has no storage) and completely penetrates the aquifer, and 3) flow is laminar. A number of other equations have been presented for cases where one or more of these assumptions is not met. The Boulton (1963) and Neuman (1974 and 1975) equations account for delayed yield from unconfined aquifers. The image-well method (Ferris et al. 1962) may be used for analysis of tests in bounded aquifers. Corrections for the effects of vertical flow gradients caused by partially penetrating wells have been presented by Hantush (1962), Dagan (1967), Kipp (1973), and Neuman (1974).

Most of the constant-rate pumping tests conducted at Hanford have been analyzed using the Theis equation. These analyses applied either the type-curve matching method (Theis 1935) or semilog straight-line methods (Theis 1935; Cooper and Jacob 1946). Other Hanford tests (Kipp and Mudd 1973) have utilized type-curve matching with the unconfined aquifer solution of Boulton

(1963) and some have applied corrections for partial penetration of the pumping well and for aquifer dewatering at the pumped well. Fortunately, as discussed by Theis (1935), not meeting some assumptions of the Theis solution often has only a minor influence on the results of hydraulic property determination. It is important, however, to recognize when nonideal well or aquifer effects are significant. These effects may be discerned by preparing a diagnostic plot of the test data and comparing it to characteristic curves associated with various nonideal conditions. Log-log plots of water level versus time have traditionally been used for diagnostic purposes and recently the derivative of the water-level or pressure change has also been used as a diagnostic tool (Bourdet et al. 1984).

Type-curve matching methods are generally applicable only to data from observation wells. Constant-rate tests should ideally have the benefit of at least one observation well completed in the same aquifer and located near enough to the pumped well that responses can be measured. Most tests at Hanford, however, have had to rely on measurements of aquifer drawdown and recovery solely at the pumped well. Errors may have been introduced in some cases by applying type-curve matching methods for analysis of pumping well data. Friction loss at the pumping well may cause an additional component of drawdown independent of the aquifer response. This causes the data to be shifted vertically on the log-log plot employed in type-curve matching and introduces error in the calculated transmissivity and storativity values. Attempts have been made to determine the friction loss component through step-drawdown tests and then correct the drawdown measurements prior to type-curve matching (Kipp and Mudd 1973). However, the semilog straight-line method is considered a more reliable technique for analyzing data from a pumping well.

As indicated by Cooper and Jacob (1946), semilog straight-line methods are only valid for data corresponding to small values of the parameter u. It is generally accepted that the method is valid when $u < 0.01$. However, in some cases the error introduced by using data corresponding to somewhat larger values of u in straight-line analysis is minor (Chapuis 1992). The semilog methods may be applied to drawdown or recovery data. The most likely source of error in this technique is to attempt to fit a straight line to data collected before the straight-line approximation applies (large u), or to data

that do not reflect radial-flow conditions in an infinite-acting aquifer. Often, more than one straight segment will appear on a semilog plot because of nonideal aquifer conditions.

The diagnostic log-log plots mentioned above are useful in identifying the radial flow part of the test data and regions of data affected by nonideal conditions. The newly developed derivative plotting technique is particularly helpful in determining data where semilog analysis is valid (Bourdet et al. 1984). A log-log plot of the head response versus time is prepared and the derivative of the semilog plot is then calculated and graphed on the log-log plot along with the water-level data. For recovery data, the "Agarwal equivalent time function" (Agarwal 1980) or some other superposition function should be used in calculating the derivative. This accounts for the effect of the pumping period and causes the recovery data to fall on a straight line (constant derivative) on the semilog plot. The effects of various aspects of the well-aquifer system show up on the derivative plot and can be easily correlated with features of the log-log plot that have traditionally been used to diagnose test behavior. Figure 2 shows log-log drawdown and derivative responses that are characteristic of some commonly encountered aquifer conditions. The early data, occurring before the straight-line approximation is valid or where wellbore storage is dominant, produces a steep upward-trending derivative. The derivative normally decreases during transition from wellbore storage to radial flow, and stabilizes at a constant value when radial infinite-acting flow conditions are established. The stable derivative reflects the straight line on the semilog plot for infinite-acting radial flow. Delayed yield and double-porosity aquifers may show two stable derivative sections at the same vertical position, separated by a "valley" representing the transition from one storage value to the other.

Pressure derivative plots are also useful in identifying boundaries. A linear no-flow boundary will result in a doubling of the magnitude of the derivative. If radial flow is established before the influence of the boundary is seen, a stable derivative will occur for a time followed by an upward shift to twice the original value. Constant-head boundaries show up as

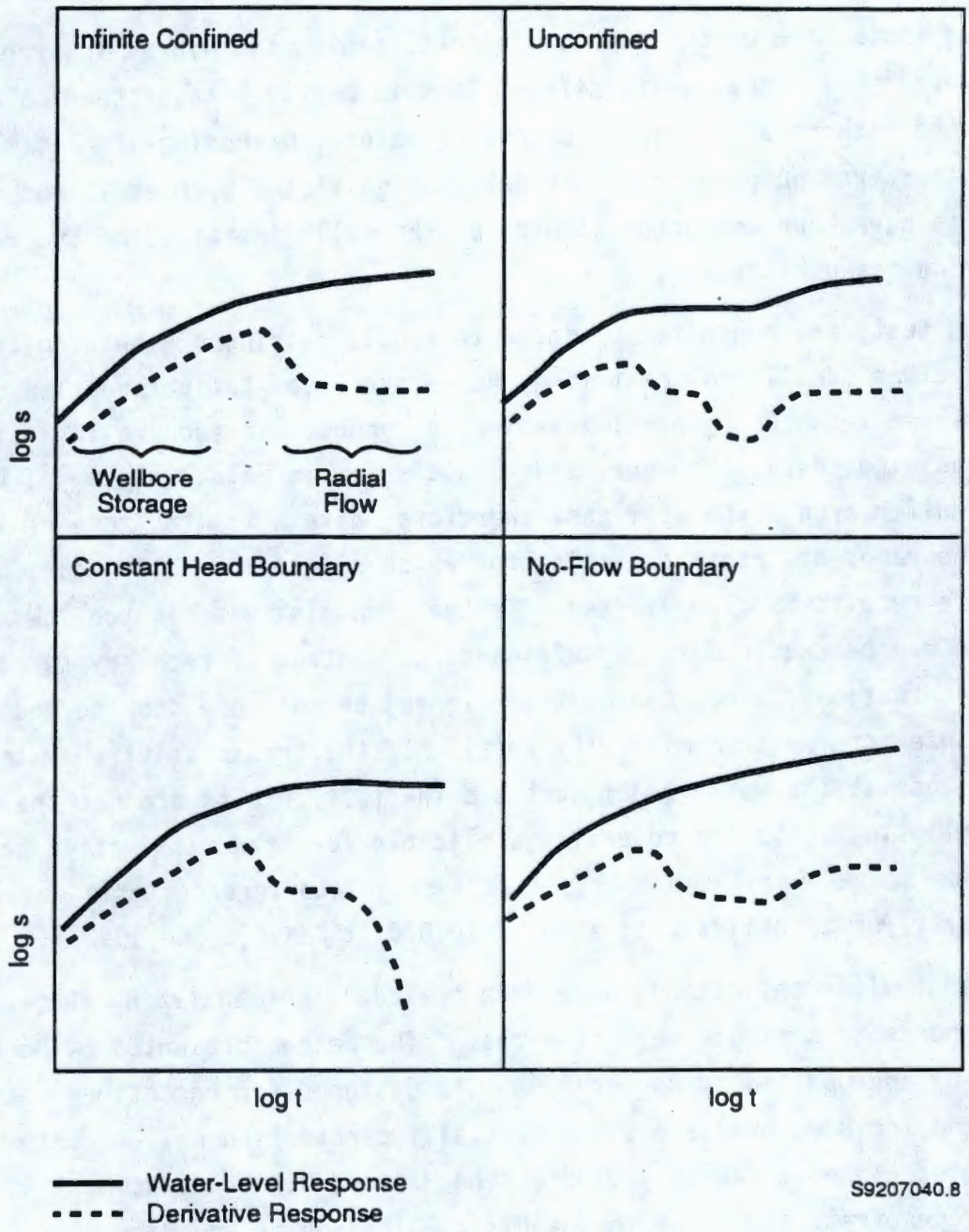


FIGURE 2. Characteristic Log-Log Plots of Water-Level and Semilog Derivative Response for Various Flow Systems

a downward trend in the derivative, which may be preceded by a stable derivative if radial flow conditions occur before the boundary effect becomes dominant.

## 3.2 SLUG TESTS

Slug tests have become popular for determining the hydraulic properties of aquifers at hazardous waste sites. This is partly because they do not require the withdrawal of large volumes of water. Disposing of contaminated ground water from pumping tests may pose a significant problem at such sites. Slug tests have been conducted at many of the wells installed on the Hanford Site during the past decade.

Slug tests are conducted by instantaneously raising or lowering the water level in a well and monitoring the recovery to static formation conditions. These tests are generally easier to conduct and require less time than aquifer pumping tests. However, slug tests stress a relatively small volume of the aquifer around the well and, therefore, have a limited zone of influence. The range of transmissivities for which single-well slug tests give analyzable results is also limited. If the transmissivity is too low, weeks or months may be required for a sufficient percentage of recovery to occur. In these situations, steps can be taken to reduce wellbore storage and speed the response for low-transmissivity tests. If the transmissivity is too high, friction loss at the well is dominant and the test results are not analyzable. Single-well slug tests are generally applicable for transmissivities below 1000 $ft^2/d$ (Spane 1992a) and multiple-well slug interference tests may provide good results for transmissivities up to 10,000 $ft^2/day$ (Spane 1992a).

Several different methods have been presented for analyzing the water-level response to a single-well slug test. The method presented by Bouwer and Rice (1976) and updated by Bouwer (1989) is designed for unconfined aquifer testing and includes provisions for partially penetrating wells. This analysis technique is commonly used on the Hanford Site because most wells partially penetrate the unconfined aquifer. The Bouwer and Rice (1976) analysis method and the similar Hvorslev (1951) method are based on equations describing steady-state radial flow of an incompressible fluid. Hydraulic conductivity (K) is given by

$$K = \frac{r_c^2 \ln(R_e/r_w)}{2L_e} \frac{1}{t} \ln\frac{y_o}{y_t} \qquad [L/T]$$

where $r_c$ = radius of the casing [L]

$r_w$ = radius of the well [L]

$L_e$ = length of the open well section [L]

$R_e$ = effective radius of influence [L]

$t$ = time since the test began [T]

$y_t$ = water level - static water level [L]

$y_o$ = induced water-level change at beginning of test [L].

For the Hvorslev method, the effective radius ($R_e$) is assumed to be equal to the length of the open interval. Bouwer and Rice (1976) provide empirical formulas for determining $\ln(R_e/r_w)$, based on the results of electrical analog studies of different flow system geometries.

For both analysis methods, water-level data are plotted on a logarithmic scale versus time on an arithmetic scale. Based on the above equation, the result should be a straight line, at least over a section of the plot corresponding to early time. The quantity [ln(yo/yt)]/t can be determined graphically from the straight-line portion and used to calculate K. In practice, near borehole effects, such as a gravel pack or other altered permeability zone near the well, sometimes cause a deviation from the predicted single straight line (Bouwer 1989).

A slug test analysis method based on non-steady radial flow of a compressible fluid in a confined aquifer was presented by Cooper et al. (1967). They present type curves of dimensionless head response, $H_D$, versus a dimensionless time parameter, $\beta$, for various values of a dimensionless wellbore storage parameter, $\alpha$. These parameters are defined by

$$H_D = H/H_o \quad \text{[dimensionless]}$$

$$\beta = Tt/r_c^2 \quad \text{[dimensionless]}$$

$$\alpha = r_w^2 S/r_c^2 \quad \text{[dimensionless]}$$

where $H$ = observed head - pretest static head [L]

$H_o$ = instantaneous head change at start of test [L]

$t$ = time since start of test [T]

$r_c$ = radius of well casing where water level change occurs [L]

$r_w$ = effective radius of well [L].

Test data are plotted in the form H/Ho versus log t, and matched to the dimensionless type curves to determine values for $\alpha$ and $\beta$. Transmissivity and storativity can then be calculated by rearranging the above equations for $\alpha$ and $\beta$. However, in practice, the method does not give reliable estimates of storativity because the shape of the curves differ only slightly for changes in $\alpha$ of an order of magnitude (Cooper et al. 1967). Although this method is based on the response of a fully penetrating well in a confined aquifer, acceptable results may be obtained for unconfined aquifers and partially penetrating wells as long as the vertical flow component is small and the saturated thickness of the aquifer does not change significantly during the test (Walter and Thompson 1982).

A "slug-interference" test, which uses observation wells to monitor the aquifer response to a slug test, has recently been conducted on the Hanford Site (Spane 1992a). This method gives analyzable results for aquifers that are too transmissive for a single-well slug test. This test is discussed in more detail in Section 4.5.

## 3.3 OTHER METHODS

Other methods that have been applied to determine hydraulic properties for the unconfined aquifer at Hanford include

- analysis of ground-water mound formation resulting from waste-water discharges
- analysis of aquifer water-level changes in response to river-stage fluctuations
- multiple-well tracer tests and single-well dilution tests
- inverse numerical models.

The application of these methods at Hanford is discussed in Section 4.0. These methods, with the exception of tracer tests, are based on measuring aquifer responses over a large area of the aquifer. They have the advantage of incorporating aquifer heterogeneity over this larger area into the results. However, the analysis of responses to river stage can only give a value for aquifer dispersivity T/S and transmissivity may be determined only by assuming a storativity value.

# 4.0 REVIEW OF UNCONFINED AQUIFER TESTING AT HANFORD

Ground water in sediments underlying the Hanford Site was studied before the start of nuclear production activities because of the importance of ground water to the area's early settlers. Since the 1940s, studies of ground water at Hanford have mainly been concerned with the potential for offsite transport of radionuclides and other hazardous materials discharged to the ground or stored at the Hanford Site. In both types of study, the determination of aquifer hydraulic properties is important. Hydraulic properties control the amount of water that can be obtained from a well and they also control the rate of transport of hazardous constituents through the ground water. Some previous Hanford ground-water investigations were designed to characterize a limited area around a particular waste site while others were to define ground-water flow over the entire site. This section summarizes reports containing hydraulic property data and gives information about some hydrologic characterization activities that have not been previously presented in formal reports. Results of the hydrologic tests are summarized in Section 5.0.

## 4.1 INVESTIGATIONS BEFORE 1950

An early study of ground water in the vicinity of the communities of White Bluffs and Hanford was made by Jenkins (1922). The objective was to determine if the ground-water supply of the area was adequate to support sustained irrigation of tracts of land designated for the Soldier Land Settlement Project. This study preceded the discovery of many of the basic principles of ground-water hydraulics, such as the relationship described by Theis (1935) between the rate of drawdown in a well and the hydraulic properties of the aquifer. Therefore, no estimates of hydraulic parameters are provided in the report. Data were collected on local wells and showed that only small drawdowns were observed when most wells were pumped. One example well was pumped at about 1100 gal/min and reached an apparently steady drawdown of about 2 ft. From observations of well logs, water levels, and local geology, Jenkins (1922) concluded that the alluvial gravels (now informally referred to as the Hanford formation) were recharged by water from the Columbia River. Recharge of the aquifer occurred principally during the period that the river

was at its highest seasonal level. Seasonal fluctuations were much greater than today because the upstream dams had not yet been built. He also concluded that "the migration or seepage of water through the sands and gravels of the district takes place fairly rapidly." The Ringold Formation, underlying these coarser sediments, was regarded as essentially impermeable.

Piper (1944) evaluated the ground-water supply that was developed to meet the needs of the thousands of construction workers residing at Hanford Barracks (near Hanford Townsite) and the town of Richland during the early days of the Hanford Reservation. Twelve wells with combined capacity of about 6000 gal/min were being used at the Hanford Barracks. Piper (1944) gives specific capacity values for these wells ranging from 1.9 to 114 gal/min per foot of drawdown per foot thickness of "water-bearing gravel." He also regarded the Ringold Formation as forming an essentially impermeable base to the aquifer contained within the gravel, sand, and boulders of the Hanford formation. An average transmissivity of 4700 $ft^2/d$ was estimated from pumping tests on nine of the water-supply wells. However, the estimate was qualified by the statement that for such high-permeability materials, the available test data were "inadequate for close evaluation of the coefficient (transmissivity) for any single well." The results of these tests are not included in the listing of hydraulic test data in Section 5.0.

Parker and Piper (1949) report on the results of an extensive well drilling program undertaken to evaluate the effects of waste-water discharge. Geologic logs from the 28 wells included in the study helped to define the subsurface geology of the site. No quantitative measurements of hydraulic properties were made. The relative permeabilities of the various geologic units were estimated based on grain size and degree of cementation. The work of Piper (1944) was referenced.

## 4.2 HYDROLOGIC TESTS REPORTED DURING 1950 TO 1970

The results of early pumping tests in North Richland (Hart 1951) and at the 100-K Area (Strand and Hart 1952) are reported by Newcomb and Strand (1953). One of these tests was at well 199-K-10 in the 100-K Area. This well was completed in the Ringold Formation and resulted in "two possible figures" for transmissivity of 2400 or 6680 $ft^2/d$. The ambiguity may be due to a

boundary or delayed yield response. The storativity was determined to be 0.0002. The North Richland well was identified as 3000F and was completed in the Hanford formation. A transmissivity of 144,400 $ft^2/d$ was calculated.

Newcomb and Strand (1953) estimated the porosity and transmissivity of the Ringold aquifer in the vicinity of the 200-West Area from the characteristics of the ground-water mound that formed as a result of waste-water disposal. Porosity was determined by dividing the volume of water discharged over a 4.5 yr period (1948-1953), corrected for evaporation, by the total volume change of the ground-water mound over the same period. An average porosity of 11% resulted. A porosity of 11% was also determined from a similar analysis of the 200-East Area ground-water mound.

Transmissivity was determined for the Ringold aquifer near the 200-West Area by applying a form of Darcy's Law (Wenzel 1942) to the flow across a closed water-level contour encircling the mound. The flow rate across the contour was assumed to be equal to the discharge rate to waste-disposal facilities, corrected for evaporation. The hydraulic gradient was averaged around the closed contour. An average transmissivity of 3330 $ft^2/d$ was found by applying this procedure to two contours around the 200-West Area mound. A calculation of transmissivity was not attempted for the 200-East Area aquifer because the ground-water mound had risen into the much more permeable Hanford formation and because reduced rates of discharge had caused a lowering of the mound.

Newcomb and Strand (1953) also applied the method described by Ferris (1952) to calculate hydraulic properties from the response of wells to river fluctuations. The responses of three wells in the 300 Area were analyzed. This method gives a result for aquifer diffusivity (T/S). Therefore, storativity values had to be assumed to calculate the transmissivity. The estimated transmissivity ranged from 115,000 to 230,000 $ft^2/d$ for assumed storativities from 0.1 to 0.2, respectively.

Bierschenk (1957) described the analysis and results of three pumping tests. One of these was the earlier test in the Ringold Formation at the 100-K Area reported by Newcomb and Strand (1953). The other two tests were in highly permeable parts of the Hanford formation at wells 699-62-43, north of

Gable Mountain, and 699-55-50, south of Gable Mountain. These tests were relatively long with pumping periods of 48 and 169 h, respectively. Both drawdown and recovery data were available from the pumped wells and from nearby observation wells for each of these tests.

For well 699-55-50, the observation well data were analyzed by both the type-curve matching and straight-line methods. The resulting transmissivity values were 400,000 $ft^2/d$ for both the type-curve and straight-line methods. Both methods resulted in calculated storativity of 0.20. Only type-curve matching was used to analyze the data from well 699-62-43 because the late-time data deviated from the expected response for an infinite, homogeneous, and isotropic aquifer. The drawdown showed a flattening at late time. The deviation was attributed to a recharge (constant-head) boundary by Bierschenk (1957) and image well theory was applied in an attempt to locate the boundary. However, there is no geologic evidence of such a boundary and a similar effect on the data may be caused by delayed yield or by leakage from underlying sediments. Average transmissivity of 50,800 $ft^2/d$ and average storativity of 0.06 were determined from type-curve matching of data from the observation wells.

Bierschenk (1959) provides the results of an additional multiple-well pumping test and 22 single-well pumping tests. The multiple well test was conducted on well 699-31-53, which penetrates about 10 ft of Hanford formation and 110 ft of underlying Ringold Formation. Results from all of the tests are listed in Section 5.0. Transmissivity was also estimated from specific capacity data for 50 additional wells. This information has not been reproduced in this report. Most of the older wells at Hanford are completed by perforating the casing and tests often show large drawdowns attributable to friction head-loss at the well. Because specific capacity is determined by dividing the flow rate by the drawdown in a well, friction head-loss may have a large effect on the observed specific capacity.

Results of three tracer tests are also reported in Bierschenk (1959). Fluorescein was used as the tracer in all three tests and they were conducted under natural gradient conditions. Hydraulic conductivity values were calculated, assuming an effective porosity of 10%, based on both the time to the first observation of measurable tracer concentration and the time to the

maximum observed concentration of tracer. The higher conductivity value, based on the time to first detection, was interpreted as the hydraulic conductivity of the most permeable beds in the tested formation and the hydraulic conductivity based on arrival of the peak concentration was interpreted as the average for the formation. The principles of hydrodynamic dispersion are better understood today and reveal that, even in a homogeneous aquifer, some tracer will move faster than the average ground-water velocity because of different microscopic flow paths in the porous media. Therefore, the time of peak concentration at the observation well should be used in calculating hydraulic conductivity. One test was between wells 50 ft apart at 699-62-43, just north of Gable Mountain. A hydraulic conductivity of 3880 ft/d was determined from peak breakthrough for this test. The other two tests were conducted in the area south of the 200-East Area. One of these tests used well 699-28-41 as the tracer injection well and 699-19-43 as the observation well. The other test used well 699-24-33 for tracer injection and wells 699-14-27 and 699-20-20 for observation of tracer breakthrough. Hydraulic conductivity calculated from breakthrough of the peak tracer concentration ranged from 8400 to 14,000 ft/d in this area.

Biershenk (1959) also analyzed the water-level responses at 10 wells to annual changes in the level of the Columbia River. Aquifer transmissivity values were estimated using the method of Ferris (1952). This method results in calculation of aquifer diffusivity (T/S). Therefore, a storativity value had to be assumed to calculate transmissivity. A storativity of 0.10 was assumed for seven wells and a value of 0.06 was assumed for the other three wells based on results of a nearby pumping test. The estimated transmissivities ranged from 2000 to 300,000 $ft^2/d$ and corresponding values of hydraulic conductivity ranged from 20 to 7600 ft/d. These results were regarded as "tentative." They were, however, of the same order of magnitude as results obtained from pumping tests.

From the results of all the available test results, Biershenk (1959) concluded that the hydraulic conductivity of the Hanford sediments ranges from about 1300 to more than 8000 ft/d and that the hydraulic conductivity of the Ringold Formation ranges from about 10 to 80 ft/d.

## 4.3 HYDROLOGIC TESTS REPORTED DURING 1970 TO 1980

Newcomb et al. (1972) provided a comprehensive report of the geology and hydrology of the Hanford Site. Test results from Parker and Piper (1949) and from the five well tests reported earlier by Newcomb and Strand (1953) and Bierschenk (1957) are referenced.

The analysis results of 25 pumping tests performed during 1969 are presented by Kipp and Mudd (1973). Curve matching techniques were used to analyze the data based on various assumed flow models. Plots of the data and matching curves were provided in an appendix of their report. Four of the wells had also been tested in the late 1950s and a comparison of the results is given. Results of these tests have been included in the tables in Section 5.0 of this report. However, the listed hydraulic property values for some of these wells are based on subsequent reanalysis that are believed to be more accurate. Also, some of the tests have been reanalyzed for this report (see Section 6.0) and the result of the reanalysis is listed for these wells.

Deju (1974) reanalyzed data from several pumping tests of both the unconfined and confined aquifers. He discusses some of the problems with the design of the tests and with previous analyses. Deju (1974) states "I compiled the original data obtained during all pumping tests conducted in the Hanford Reservation...information was then carefully reanalyzed and only those tests deemed accurate are reported." A total of 17 tests of the unconfined aquifer are presented. Presumably, these are the tests that were considered to be accurate. Some of the same tests were also reanalyzed for this report (see Section 6.0).

A report by Deju and Summers (1975) estimated areal distributions of hydraulic conductivity and transmissivity for the Hanford Site. Separate distributions were presented for values based on the results of pumping tests in 48 wells and for values based on analyses of the types of materials identified in driller's well logs. The well-log analysis included 153 wells. A number was calculated for each well log by multiplying the total length of each material (coarse gravel/pebbles, gravel/sand and gravel, sand, fine sand, clay/silt) intersected below the water table by a weighting factor. The weighting factor was based on an assumption that each category was 10 times as

transmissive as the next-finer-grained category. The relationship between transmissivity and the calculated number was determined by plotting the transmissivity values from pumping tests at 34 of the wells against the numbers calculated from logs of those wells. A straight line was then fit to the data and the relationship was used to estimate transmissivity for the remaining 119 wells. The results have not been reproduced for this report because of the large uncertainty in assigning hydraulic properties based on the well logs.

Kipp et al. (1976) provided an updated report on application of the Variable Thickness Transport (VTT) ground-water flow model to the unconfined aquifer at the Hanford Site. This model required distributions of hydraulic properties, which were calculated using the Transmissivity Iterative Routine (TIR) developed by Cearlock et al. (1975). The TIR is described in more detail in Section 4.8.

Lindberg and Bond (1979) report pumping tests of three wells in the 300 Area. These tests were conducted to support an application of the VTT ground-water model in this area. Transmissivity values were determined from straight-line analysis of both the drawdown and recovery data. Neither the raw data, nor details of the analyses, are provided in their report. The results of the pumping tests have been included in the tables in Section 5.0.

## 4.4 HYDROLOGIC TESTS REPORTED DURING 1980 TO 1990

Graham et al. (1981) provided a comprehensive analysis of hydrogeology in the "separations area," an 82-$mi^2$ area including and surrounding the 200-East and 200-West areas. Results of 11 constant discharge and recovery tests conducted on 10 wells in the separations area prior to 1976 were compiled. All but one of these tests was previously reported in Kipp and Mudd (1973) or Deju (1974). In addition, five pumping tests conducted at four different wells in the separations area between 1976 and 1980 were analyzed in the report. The results of those tests are listed in the tables in Section 5.0.

Eddy et al. (1983) report that 27 tests were conducted at 25 wells during the period 1973 to 1981. A map (Figure 3) was provided showing the test well locations. Some of these wells had been previously tested. The results were reportedly used to update the "Hanford transmissivity matrix" and

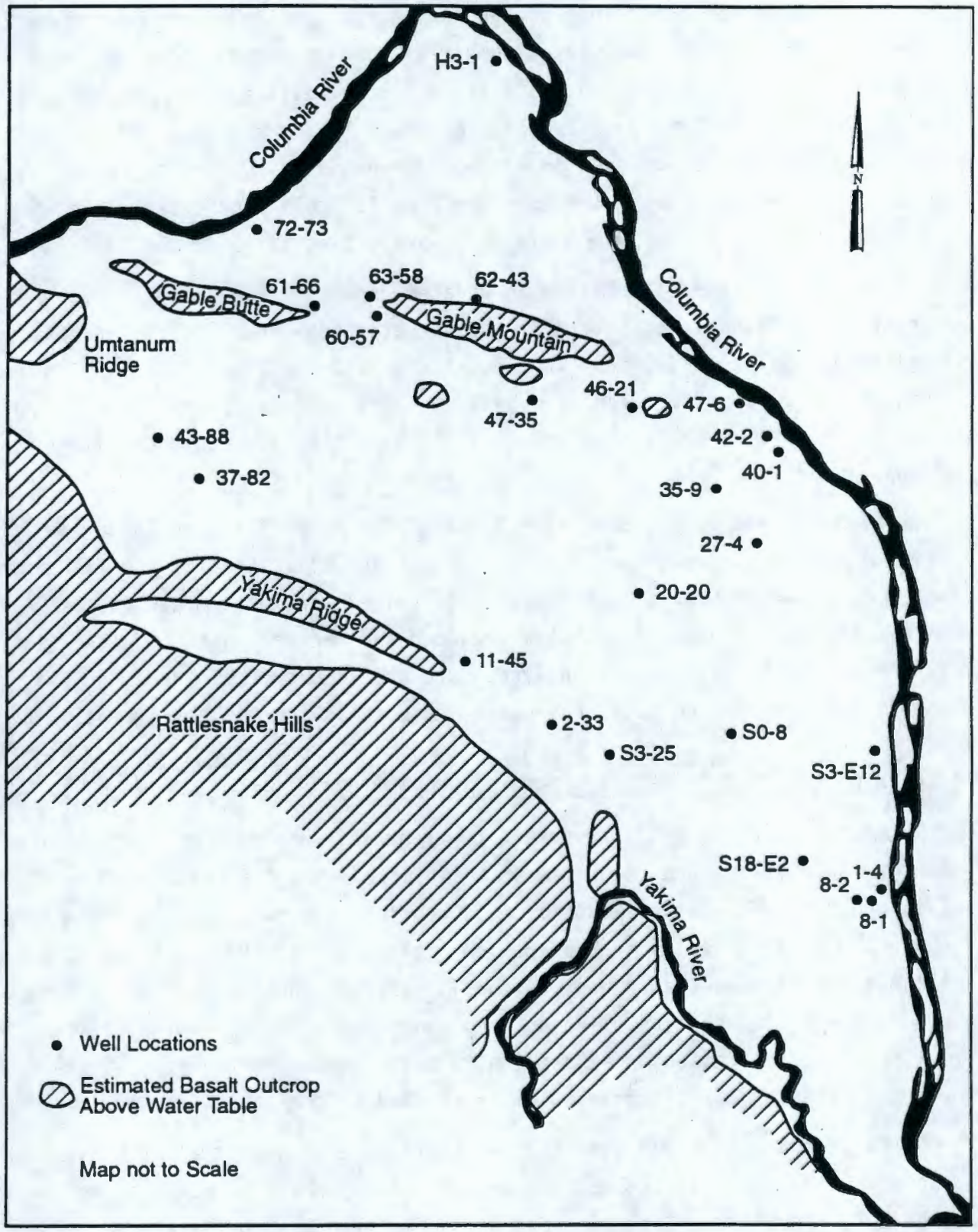


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FIGURE 3. Locations of Wells Tested from 1973 to 1981 (Eddy et al. 1983)

provide input for the Hanford VTT ground-water flow model. However, test results are not provided in Eddy et al. (1983).

Graham et al. (1984) give the results of pumping tests performed on six wells in the unconfined aquifer in 1982. These tests were part of an assessment of intercommunication between the unconfined and upper confined aquifers in the area of B Pond and Gable Mountain Pond. Several other wells completed in the upper-confined aquifers were also tested. Constant discharge pumping tests were performed without the benefit of observation wells and only the drawdown data were analyzed for the unconfined wells. Recovery data were also analyzed for some of the confined aquifer tests and slug tests were performed on several other confined aquifer wells. Results of those tests are listed in the tables in Section 5.0.

Weekes et al. (1987) conducted three aquifer tests at wells 699-25-33A and 699-26-35C to help characterize the Nonradioactive Dangerous Waste Landfill located in the central part of the Hanford Site. Tests were conducted over two separated depth intervals at well 699-26-35C. Some observation well data were available in the tested zone and in adjacent formations. Vertical hydraulic conductivity was also estimated from the results.

Pumping tests of 13 newly drilled wells in the 300 Area were reported by Schalla and Wallace (1988). Seven of the tests were severely affected by the nearby Columbia River acting as a recharge boundary and/or by changes in river stage that affected the water level in the well during the test. Therefore, only the six test results considered reliable are included in the listings of data in Section 5.0.

Liikala and Aaberg (1988) reported the results of aquifer tests performed on 17 wells near the 183-H Solar Evaporation Basins in the 100-H Area. Six constant-rate tests were conducted. However, one of these test results was not considered reliable because of the apparent dewatering of a high-permeability zone within the test interval. Transmissivity and hydraulic conductivity values determined from the other tests appear in Section 5.0. Both Theis (1935) type-curve matching and straight-line data analysis techniques were applied, and, in some cases, the result from curve matching was taken as the better value. However, as discussed in Section 2.0, the Theis

technique may not be valid for data from the pumping well. Some of the tests may also have been affected by water-level changes in response to the stage of the nearby Columbia River. Liikala and Aaberg (1988) document that several of the wells respond to changes in river level. The results of those tests have not been reanalyzed or examined in detail for this report.

Fruland et al. (1989) report pumping tests of two wells (699-24-34A and 699-24-35) in the Hanford formation at the solid waste landfill in the central part of the site. The high transmissivity of the test formation resulted in small drawdowns (0.6 and 1.2 ft) that quickly stabilized. Therefore, pumping was terminated after 2 h or less for both tests. Recovery of water levels was too fast for analysis of the recovery data. Therefore, transmissivity was calculated from drawdown measurements by applying both the Theis type curve method and the semilog straight-line method. Because measurements were made in the pumping well, the straight-line method is probably more appropriate and those results are listed in Section 5.0.

The results of aquifer tests on 13 wells near the 200-East Area and 19 wells near the 200-West Area are presented by Last et al. (1989). Those tests were conducted as part of the Resource Conservation and Recovery Act (RCRA) investigations of the Low-Level Burial Grounds in these two areas. The wells were designed mainly for sampling purposes and hydrologic testing was of secondary importance. Therefore, test conditions were not ideal. For example, many of the wells were partially penetrating. The rate and duration of pumping were also limited. Analyzable data were not obtained from tests at three of the wells in the 200-East Area because the transmissivity was high and the pumping rates were too low to create an analyzable drawdown. Tests at two of the wells in the 200-West Area were not analyzable because the transmissivity was low and wellbore storage effects were dominant. One of the wells was tested by the slug withdrawal method. All the others were tested using constant-rate discharge methods. Results of the tests that were successfully analyzed are included in the listings in Section 5.0.

## 4.5 TEST RESULTS REPORTED SINCE 1990

A series of slug tests were conducted by Newcomer et al. (1990) on seven wells in the 200-East Area and two wells in the 200-West Area. Those tests

were conducted as part of the RCRA monitoring program for single-shell waste tanks located on the Hanford Site. Pumping tests were not performed because of the difficulties in disposing of contaminated ground water that would be produced during pumping. The slug tests were performed using a slugging rod and the total change in water level was low (less than 2 ft) for most of the tests. The authors state that the results of some tests may have been affected by turbulent flow conditions caused by the very fast early recovery of the water level. The Bouwer and Rice (1976) analysis method was applied.

Westinghouse Hanford Company (WHC) (1990) reports the results of constant-rate discharge tests of three wells and slug tests of seven wells near B Pond. The constant rate tests were analyzed by the semilog straight-line method. A slugging rod was used to produce the initial water-level change for the slug tests. The level of stress was small for the slug tests, ranging between 1 and 7 ft. Four of the tested intervals were considered locally confined and the data were therefore analyzed using the Cooper et al. (1967) method. The other three slug tests were analyzed using the Bouwer and Rice (1976) method.

Newcomer et al. (1992) and Trent (1992) provided compilations of hydrologic data available for the 200-West Area. Trent (1992) also provided analysis details for slug tests of five wells at the 216-S-10 facility.

Gilmore et al. (1992) calculated the volumetric discharge of ground water through a section of the unconfined aquifer near the 100-N Area. Hydraulic property data were needed as input. Because of the wide range of reported hydraulic conductivity values from two wells in this area, a reanalysis of the existing test data was undertaken. This resulted in revised estimates of transmissivity and hydraulic conductivity for wells 699-77-54 and 699-87-55. The data table in Section 5.0 reflects the revised values for those two wells.

Spane (1992a) conducted a field test evaluation of the slug-interference test method. This method may be useful for characterizing highly permeable aquifers that are not amenable to single-well slug tests and where the presence of contamination makes it undesirable to remove large volumes of ground water. A slug withdrawal test was conducted at a stress well while two

observation wells about 50 ft away were used to monitor the interference response. The results of the analyses of the two observation well responses yielded transmissivity values of 145 and 310 $ft^2/d$. The difference in results may reflect the different completion depths of the two observation wells and the heterogeneity of the aquifer. The slug-interference results were similar to results of single-well slug test analysis of the stress well response.

Spane (1992b) reported the results of slug tests conducted in the Ringold Formation at one of the "Savage Island Wells" (699-42-E9A) just east of the Columbia River. At the time of the test, the well was open to a 37 ft interval from 195 to 232 ft below ground surface. The estimated range of transmissivity for the tested interval was 30 to 65 $ft^2/d$. This range was determined from fitting to the Cooper et al. (1967) type curves. The fiber glass casing in this well was subsequently damaged and the well had to be abandoned.

## 4.6 RECENT TESTS AT THE 200-BP-1 OPERABLE UNIT

As part of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) investigations for the 200-BP-1 Operable Unit on the Hanford Site, a series of pumping tests was conducted at well 699-53-55C. The tests were conducted during the period January 16-18, 1992, and consisted of a step-drawdown test and two constant rate discharge tests. Recovery data were obtained for the step-drawdown test and one of the constant discharge tests. Observation well data were available from two wells, 699-53-55A and 699-53-55B. A preliminary analysis of these tests has been conducted by PNL. However, the results have not yet been presented in a published report. The preliminary analysis is summarized in this section.

A number of complicating factors affected the test data and made analysis difficult. These factors included

- antecedent effects (i.e., pressure transients from preceding test events)
- incomplete recovery before the start of the next pumping event
- drainage of water from the pump column back into the well at the end of each pumping event, causing a sudden head increase

- partial penetration of the aquifer by both the pumped and observation wells
- possible flow boundaries caused by the channel-deposit nature of the formation in this area.

Because of these complications, quantitative analysis was performed only for recovery following the step-drawdown test. Antecedent head changes affecting this test could be extrapolated from pre-test measurements and a correction applied to the test data. The antecedent effects on the other two tests were more complex and could not be removed. Hydraulic properties determined from the analysis of the step-drawdown recovery were used in a simulation of the entire test sequence to determine their validity.

Recovery from the step-drawdown test was analyzed by the straight line method (Cooper and Jacob 1946) after first making a diagnostic log-log plot of the recovery data and derivative. Figure 4 shows the diagnostic plot of the data from well 699-53-55A and a superimposed curve calculated from the Theis (1935) equation assuming a transmissivity of 68,000 $ft^2/d$ and a storativity of 0.46. The derivative plot indicated radial flow conditions between recovery times of about 40 and 120 min. The data after 120 min indicate a possible no-flow boundary response. Figure 5 shows the straight-line analysis of the step-drawdown recovery data from observation well 699-53-55A. The line was fit to the data between 40 and 120 min. Resulting transmissivity was 66,300 $ft^2/d$ and storativity was 0.46. Analysis of data from observation well 699-53-55B and from the pumping well gave similar results for transmissivity. However, the straight-line analyses did not provide realistic results for storativity.

## 4.7 RECENT TESTS AT THE 300-FF5 OPERABLE UNIT

Multiple-well constant-discharge tests, a constant-head discharge test, and slug tests were conducted at two cluster sites in the 300 Area. Cluster site 4 was tested during April 1992 and cluster site 7 tests were conducted during June 1992. The results of these tests will be documented in a subsequent WHC report.

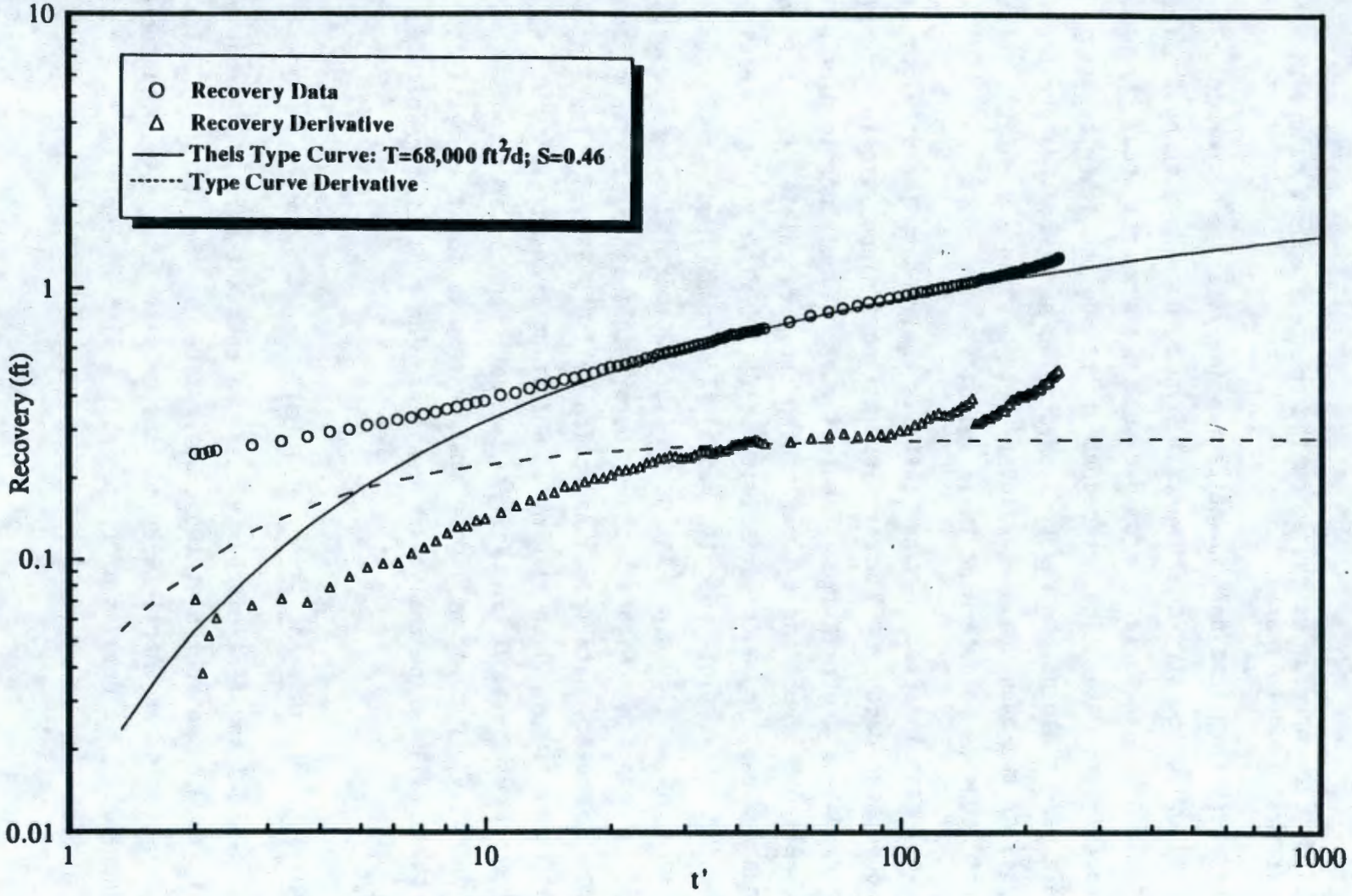


FIGURE 4. Log-Log Diagnostic Plot of Recovery Data and Derivative for Well 699-53-55A Following the Step-Drawdown Test

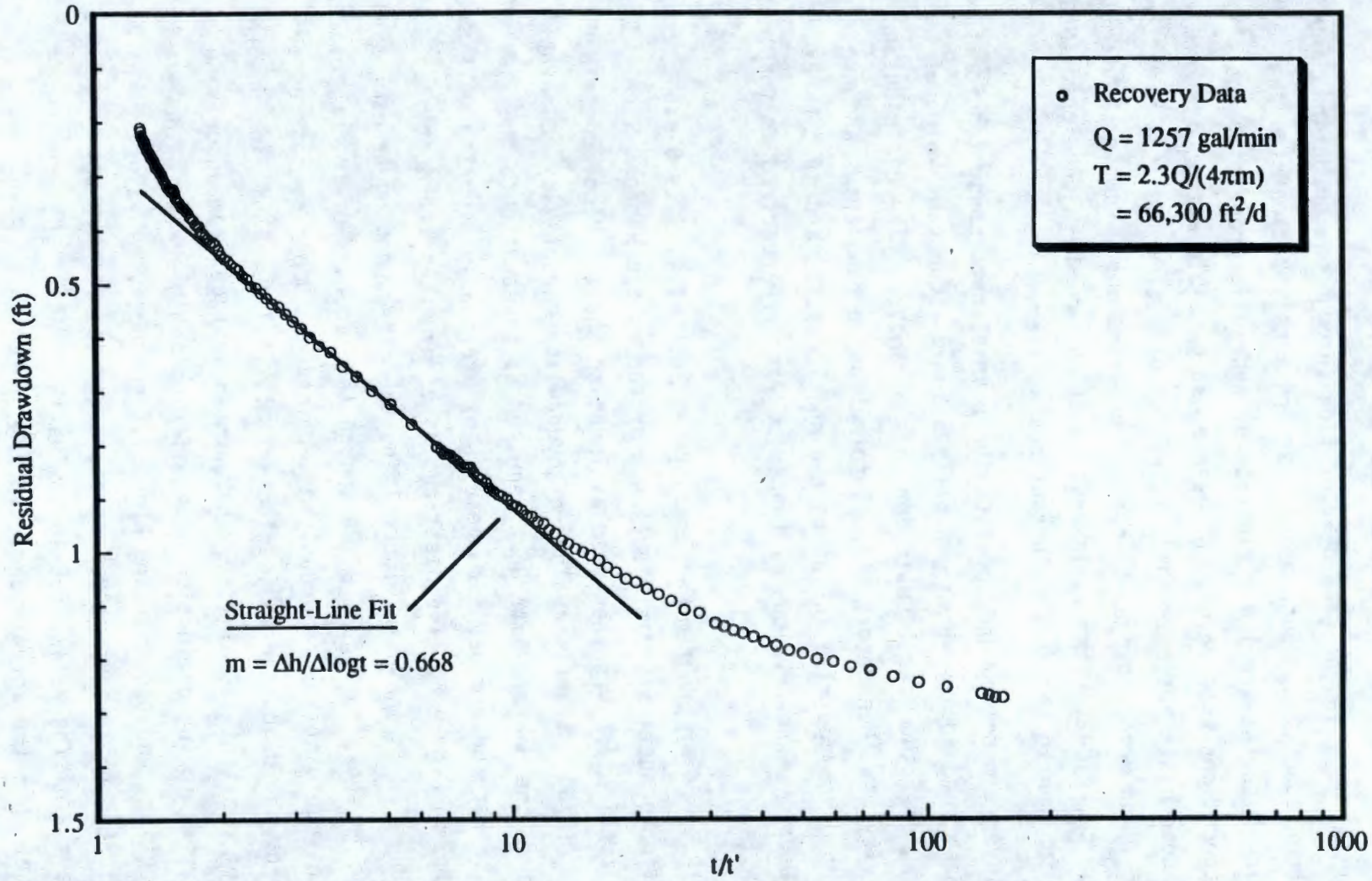


FIGURE 5. Semilog Straight-Line Analysis of Recovery Data Following the Step-Drawdown Test for Well 699-53-55A

## 4.8 RESULTS OF MODEL CALIBRATION AND INVERSE MODELING

Numerical modeling of ground-water flow through the unconfined aquifer has also been conducted. Such models require a calibration step that attempts to determine both the areal distribution of hydraulic properties and the boundary conditions that result in the closest possible match to a known hydraulic-head distribution. The calibration of a flow model is often done by making trial and error changes in hydraulic parameters. However, automated calibration techniques known as inverse modeling have been developed (Neuman 1980) and applied to the Hanford unconfined aquifer.

The inverse modeling and model calibration efforts conducted for the Hanford unconfined aquifer have generally assumed a constant value of storativity because of the lack of data for this parameter. The distribution of transmissivity was then determined. Information on boundaries and areas of recharge and discharge also influence the model results and must be known or assumed. Usually, known values of transmissivity are required as input at several locations.

The TIR computer program was used by Cearlock et al. (1975) to estimate the hydraulic conductivity distribution over the entire Hanford Site. The generated distribution was then used as input to the VTT Model described by Kipp et al. (1976). Starting values of hydraulic conductivity at points scattered over the Hanford Site were required as input data to the TIR. These starting data were determined from results of previously reported well tests and are shown in Figure 6. The distribution of hydraulic conductivity determined from the TIR is shown in Figure 7 and the corresponding transmissivity distribution is shown in Figure 8. Although the accuracy of the calculated distributions could not be rigorously determined, a number of sources of possible error are discussed in Cearlock et al. (1975). These include the assumption of constant storativity, the unknown leakage from underlying aquifers, errors in the definition of aquifer bottom elevation, the measured head distribution, and the starting hydraulic conductivity values. The model results indicated that input values of starting data for hydraulic conductivity for a few of the wells, 699-18-5, 699-18-7, 699-1-18, and 699-35-9, might be lower than the actual conductivities. The aquifer test data for

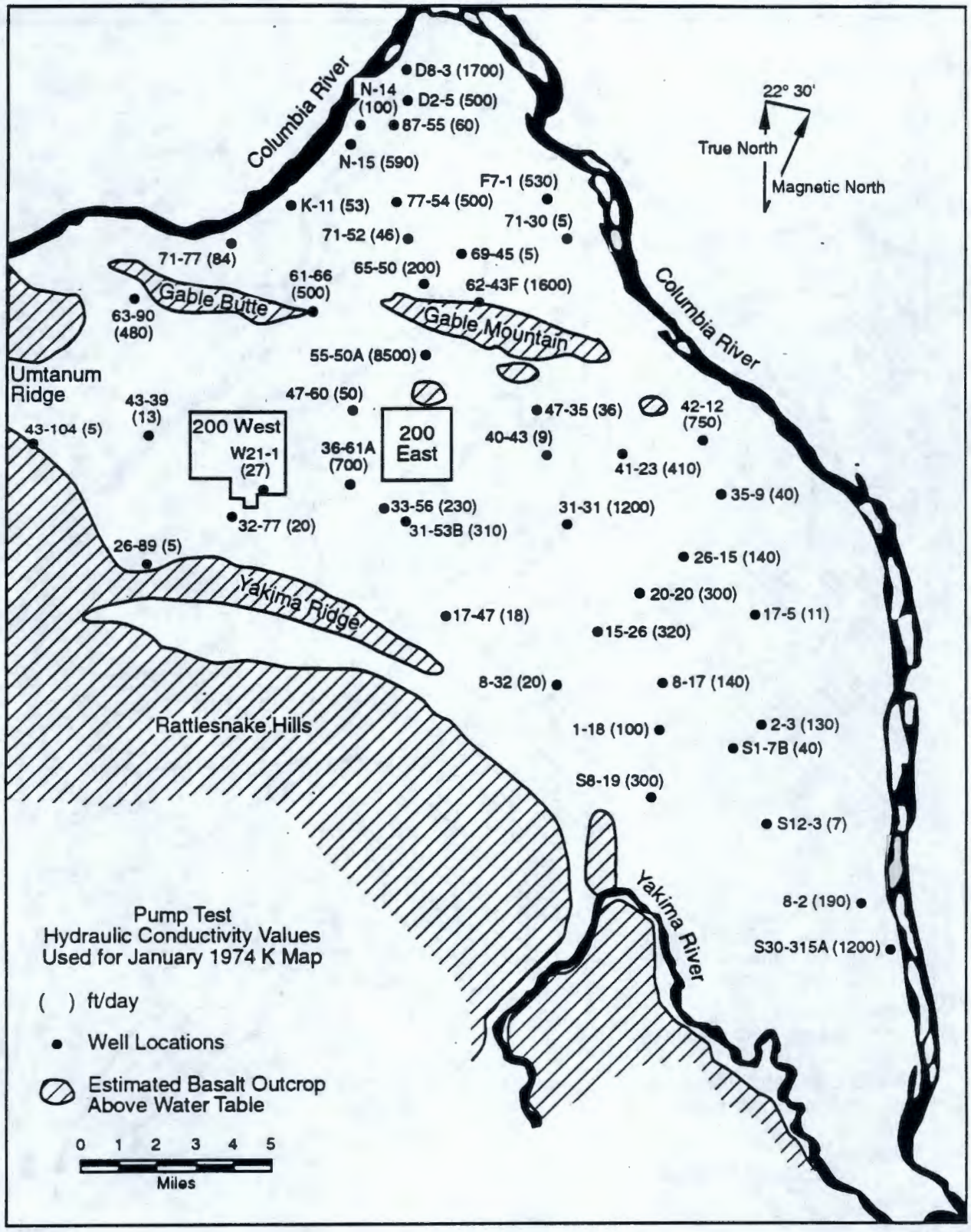


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FIGURE 6. Measured Hydraulic Conductivities Used in the Variable Thickness Transport (VTT) Model (Kipp et al. 1976)

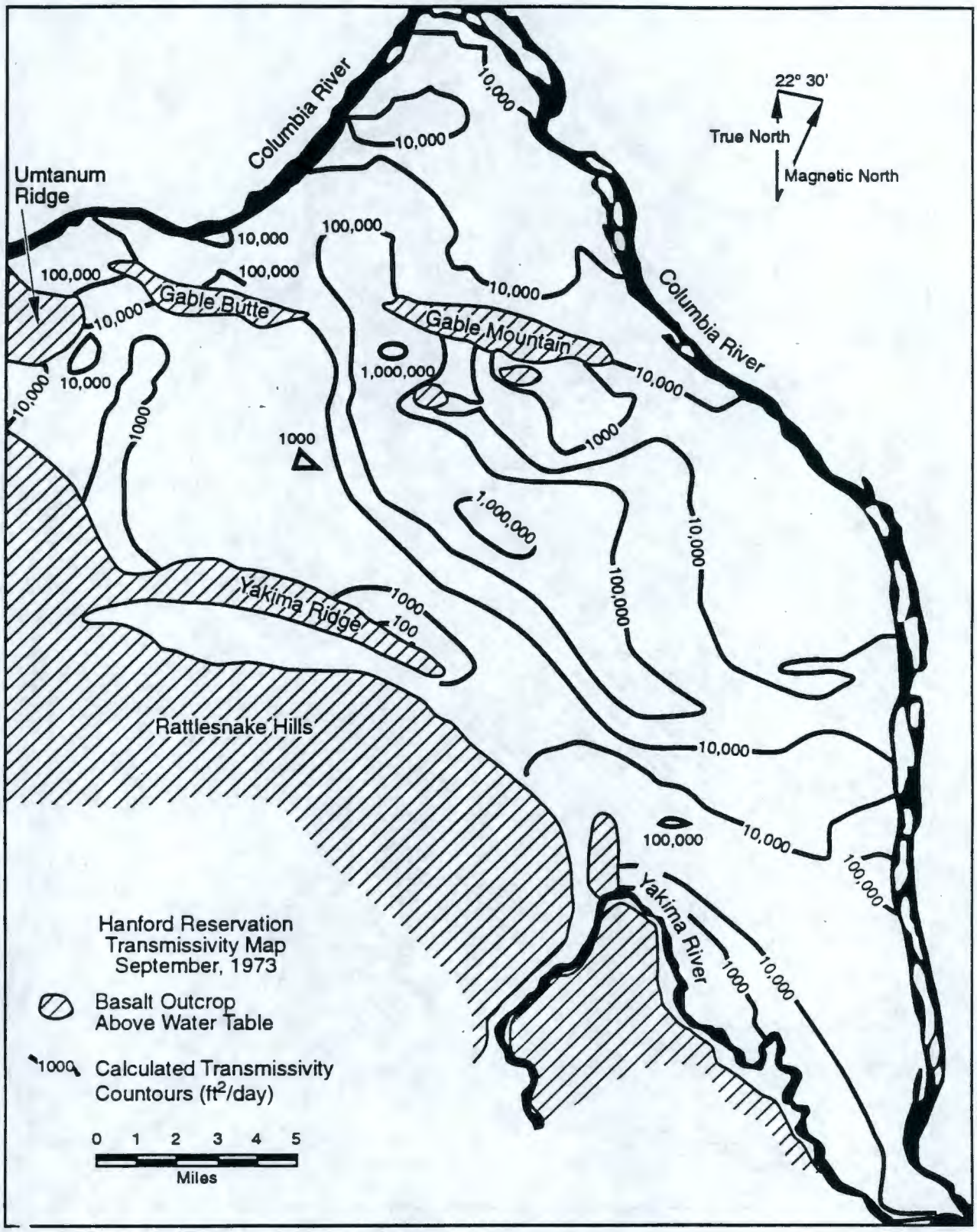


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FIGURE 7. Transmissivity Distribution Calculated from the Transmissivity Iterative Routine (Cearlock et al. 1975)

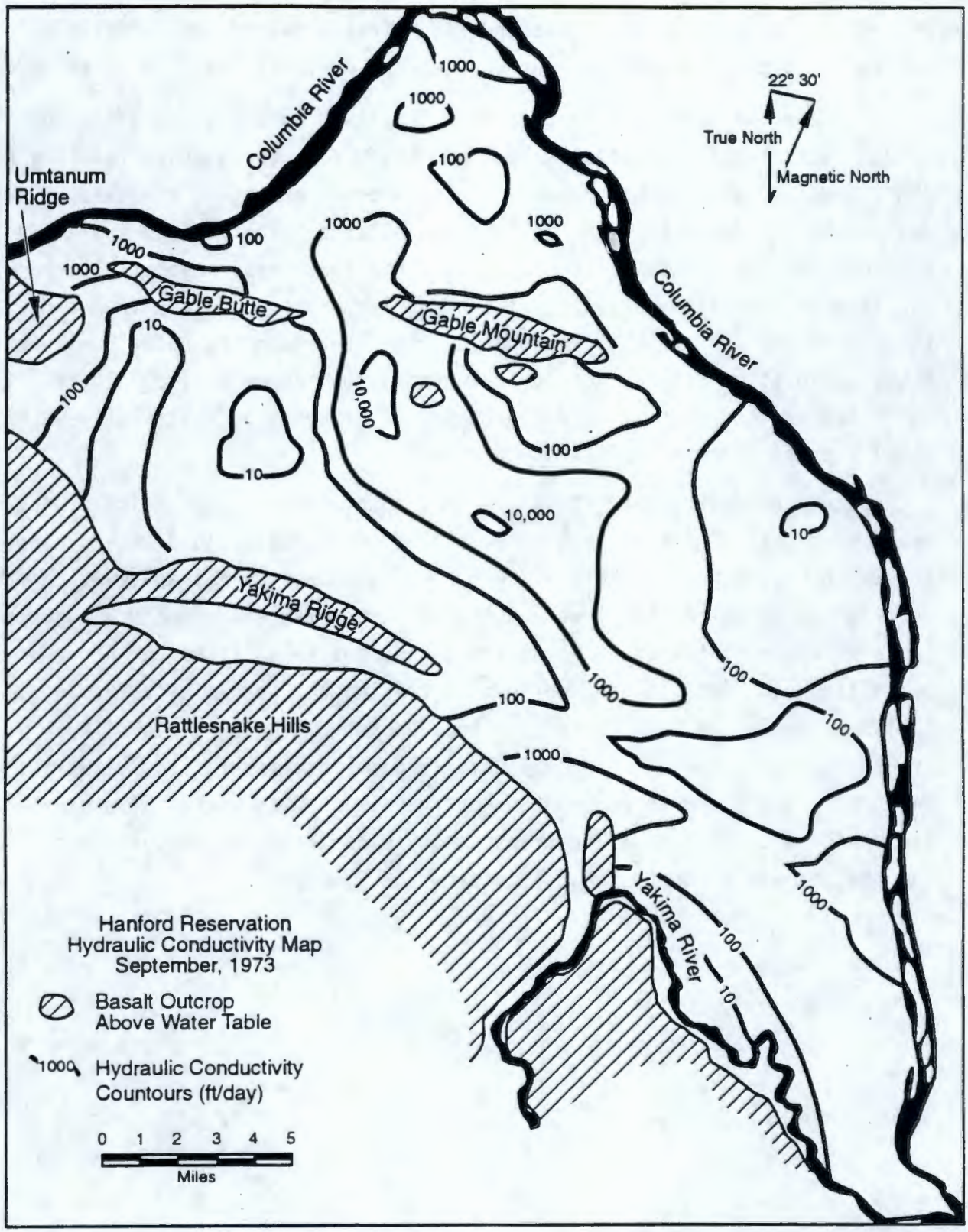


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FIGURE 8. Hydraulic Conductivity Distribution Calculated from the Transmissivity Iterative Routine (Cearlock et al. 1975)

well 699-35-9 was reanalyzed and indicated that a hydraulic conductivity of 740 ft/d could be calculated, rather than the original input value of 40 ft/d.

A numerical model was used by Hall (1981) to simulate the effect on ground-water levels of decommissioning U-Pond, a waste disposal facility near the 200-West Area that had received large amounts of water. Results of previously reported tests on eight wells are tabulated. The average hydraulic conductivity from these tests was 19 ft/d and the average storativity reported for five of the tests was 0.03. The hydraulic property values from individual tests were used as input to the model at the corresponding nodes. However, model calibration runs indicated that nondistributed hydraulic conductivity of 22.5 ft/d and storativity of 0.085 at the other nodes best simulated water-level changes observed in the study area.

Jacobson and Freshley (1990) performed an inverse calibration of the two-dimensional finite element model called the Coupled Fluid, Energy, and Solute Transport Code (CFEST). The method developed by Neuman (1980) and modified by Jacobson (1985) was applied. This numerical procedure adjusts the transmissivity distribution to give the best possible fit to the known hydraulic-head distribution, while also keeping the transmissivity distribution close to the input values at known points. Input values of known transmissivity were determined by compiling well test data from 52 wells. The input data are shown in Figure 9. Four runs were made with different recharge and boundary conditions. The transmissivity distribution calculated by the run that provided the best match is shown in Figure 10.

FIGURE 9. Measured Transmissivity Values Compiled for the Inverse Modeling Effort (Jacobson and Freshley 1990)

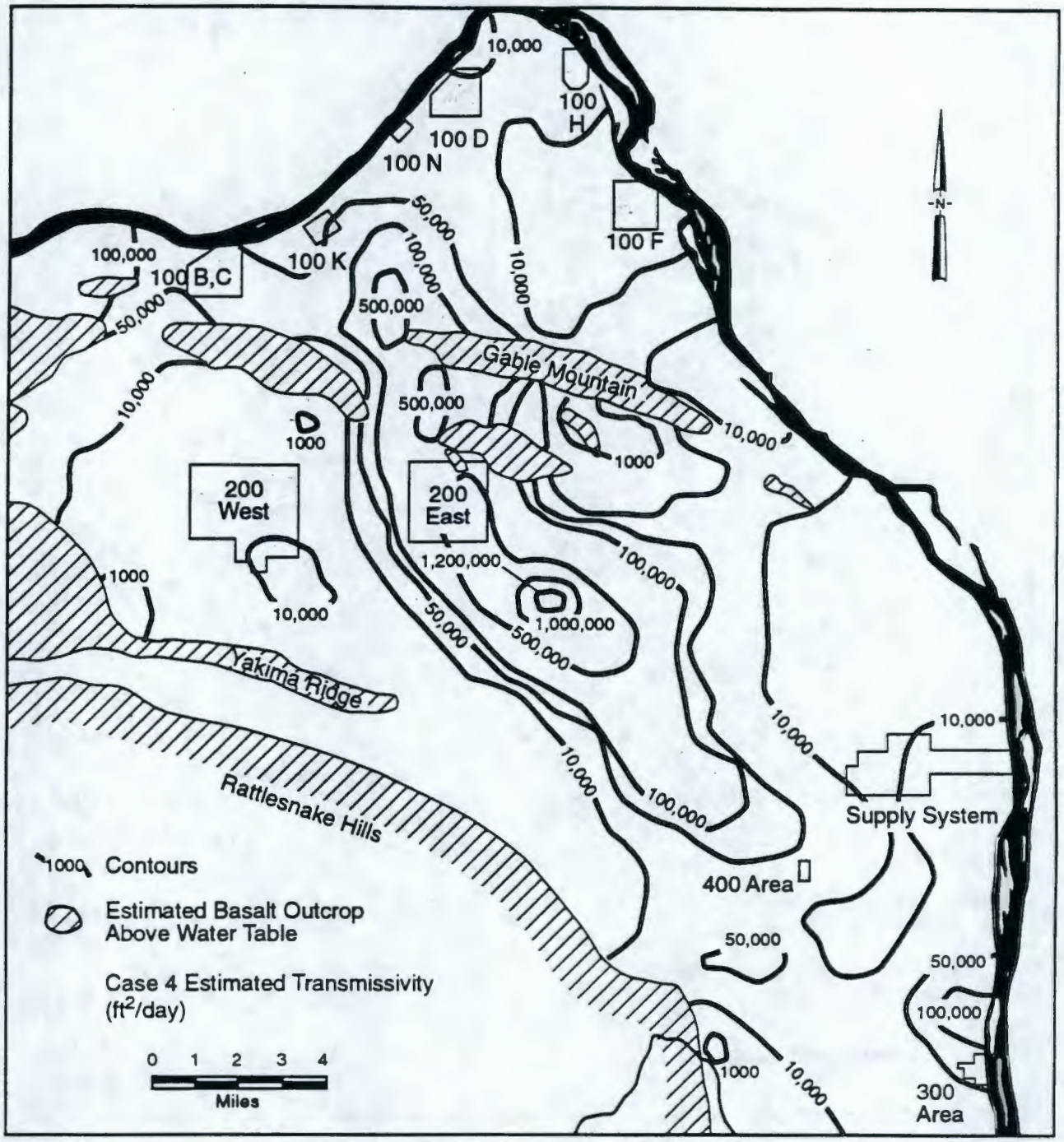


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FIGURE 10. Transmissivity Distribution Estimated by the Inverse Calibration of the CFEST Model (Jacobson and Freshley 1990)

## 5.0 SUMMARY OF TEST RESULTS FOR THE UNCONFINED AQUIFER

Hydrologic tests have been carried out under many different programs and projects at Hanford. The resulting data are not readily available from a single source. They are contained in project files and various published and unpublished test reports. The quality of the data also varies over a wide range. This section represents an attempt to compile the available hydraulic property data determined from aquifer pumping tests, slug-tests, and other methods. Some test results were not included because the original analysts did not consider the results valid or a large uncertainty in the results was noted. There are, without a doubt, some valid test data that have not been included because of oversight. Also, test activities are ongoing at the site and results of some tests conducted before this report were not available in time for inclusion.

Table 1 lists the results of constant-rate pumping tests. Some wells have been tested more than once and the data from some tests have been reanalyzed one or more times. In cases where more than one analysis result was available, the result believed to be most accurate was listed. For pumping tests reanalyzed in the following section, results of the reanalysis are presented. Table 2 lists results from slug tests of wells in the unconfined aquifer.

Analysis of the well tests in Tables 1 and 2 resulted in determination of transmissivity and, in the few multiple-well cases, storativity and/or specific yield. An equivalent hydraulic conductivity was calculated from the transmissivity by dividing by the effective aquifer thickness. However, this is not a simple conversion for most Hanford Site wells, which may be open to a variety of saturated sedimentary facies with varying hydraulic properties. In most cases, the aquifer thicknesses listed in the tables were taken from the original test reference. They were generally determined by summing the thicknesses of the sediments that are hydraulically connected with the well and appear to be relatively permeable based on geologic logs. This total permeable thickness was then used in calculating an average hydraulic conductivity. However, the actual hydraulic conductivity of individual zones within the tested section may be higher or lower.

TABLE 1. Results of Constant-Rate Discharge Tests of Wells in the Unconfined Aquifer System at Hanford

| WELL | TEST DATE | ANALYSIS METHODS | OPEN INTERVAL (ft) | TRANSMISSIVITY ($ft^2/d$) | AQUIFER THICKNESS (ft) | HYDRAULIC CONDUCTIVITY (ft/d) | STORATIVITY | REFERENCE |
|---|---|---|---|---|---|---|---|---|
| 199-H3-2A | 10/27/86 | TC,SL | 41-51 | 19,000 | 10 | 1,900 | - | Li,88 |
| 199-H4-10 | 09/18/86 | TC,SLR | 29-38 | 53,500 | 9 | 5,940 | - | Li,88 |
| 199-H4-11 | 10/06/86 | TC,SL | 43-53 | 1,070 | 15 | 71 | - | Li,88 |
| 199-H4-12A | 10/20/86 | TC,SL | 38-48 | 2,670 | 13 | 213 | - | Li,88 |
| 199-H4-15A | 11/06/86 | TC,SL | 32-42 | 2,340 | 12 | 195 | - | Li,88 |
| 199-K-10 | 10/01/52 | TC/TCR | 155-165 | 4,500 | 85 | 53 | 7x10-5 | Bi,57 |
| 299-E26-8 | 03/23/82 | SL | 226-246 ? | 6.6 | ? | ? | - | GLF,84 |
| 299-E27-8 | 08/19/87 | SL | 247-257 | >68,000 | 28 | >2,400 | - | La,89 |
| 299-E27-9 | 08/15/87 | SLR | 234-244 | 35,000 | 23 | 1,500 | - | La,89 |
| 299-E27-10 | 08/11/87 | SLR | 230-240 | 35,000 | 24 | 1,500 | - | La,89 |
| 299-E28-15 | /68 ? | TC,SLR | ? | 135,000 | 37 | 3,685 | - | G81 |
| 299-E28-27 | 09/29/87 | SL | 291-301 | >48,000 | 37 | >1,300 | - | La,89 |
| 299-E32-4 | 09/21/87 | SL | 298-308 | >9,500 | 40 | >240 | - | La,89 |
| 299-E33-12 | 05/11/82 | SL | 230?-233 ? | 130 | ? | ? | - | GLF,84 |
| 299-E33-28 | 10/21/87 | SL | 268-278 | >53,000 | 21 | >2,500 | - | La,89 |
| 299-E33-29 | 09/17/87 | SL | 279.5-289.5 | >51,000 | 24 | >2,100 | - | La,89 |
| 299-E33-30 | 09/24/87 | SL | 267-277 | >56,000 | 22 | >2,500 | - | La,89 |
| 299-E34-3 | 08/05/87 | SL,SLR | 203-213 | 14,000 | 10 | 1,400 | - | La,89 |
| 299-E34-2 | 08/07/87 | SLR | 230-240 | 85,000 | 17 | 5,000 | - | La,89 |
| 299-W6-2 | 11/05/87 | SLR | 228-248 | 500 | 242 | 2 | - | La,89 |
| 299-W7-1 | 07/15/87 | SL,SLR | 233-243 | 1,200 | 270 | 4.5 | - | La,89 |
| 299-W7-2 | 09/16/87 | SLR | 212-222 | 740 | 260 | 3 | - | La,89 |
| 299-W7-4 | 11/12/87 | SL,SLR | 203-233 | 3,000 | 265 | 11.5 | - | La,89 |
| 299-W7-5 | 11/21/87 | SL | 208-228 | 170 | 250 | 0.7 | - | La,89 |
| 299-W7-6 | 10/14/87 | SLR | 231-241 | 40 | 245 | 0.16 | - | La,89 |
| 299-W8-1 | 07/11/87 | SLR | 257-267 | 80 | 274 | 0.3 | - | La,89 |
| 299-W10-13 | 09/14/87 | SLR | 227.5-237.5 | 3,500 | 221 | 16 | 0.009 | La,89 |
| 299-W10-14 | 10/26/87 | SLR | 427-447 | 900 | 218 | 4 | - | La,89 |
| 299-W15-15 | 08/21/87 | SLR | 245-255 | 10,000 | 230 | 43 | - | La,89 |
| 299-W15-16 | 08/20/87 | TC,SLR | 227.5-237.5 | 12,000 | 230 | 52 | 0.03-0.04 | La,89 |

TABLE 1. (contd)

| WELL | TEST DATE | ANALYSIS METHODS | OPEN INTERVAL (ft) | TRANSMISSIVITY ($ft^2/d$) | AQUIFER THICKNESS (ft) | HYDRAULIC CONDUCTIVITY (ft/d) | STORATIVITY | REFERENCE |
|---|---|---|---|---|---|---|---|---|
| 299-W15-18 | 07/21/87 | SLR | 232-242 | 14,000 | 243 | 58 | - | La,89 |
| 299-W18-21 | 07/14/87 | SLR | 215.5-225.5 | 51,000 | 250 | 200 | - | La,89 |
| 299-W18-22 | 08/26/87 | SLR | 437.5-447.5 | 420 | 248 | 1.7 | - | La,89 |
| 299-W18-23 | 06/22/87 | SL,SLR | 241-251 | 25,000 | 246 | 102 | - | La,89 |
| 299-W18-24 | 07/17/87 | TC | 230-240 | 17,000 | 243 | 70 | 0.001 | La,89 |
| 299-W21-1 | /69 ? | TC | 220-290 | 5,400 | 200 | 27 | - | K&M,73 |
| 399-1-4 | ? | SLR | 23-70 ? | 70,000 | ? | | - | L&B,79 |
| 399-8-1 | ? | SLR | 35-83 ? | 350,000 | ? | | - | L&B,79 |
| 399-8-2 | ? | SLR | 43-106 ? | 40,000 | ? | | - | L&B,79 |
| 499-S0-7 | 08/12/78 | TC | 221-396 | 10,500 | 400 ? | 26 ? | - | Undocumented |
| 499-S1-7A | 01/05/70 | TC/SL | 165-200 ? | 19,000 | 400 ? | 47 ? | - | Undocumented |
| 499-S1-7B | 06/05/82 | SLR | 230-380 ? | 6,700 | 400 ? | 17 ? | - | Undocumented |
| 699-S12-3 | 09/29/58 | SLR | 68-88 | 350 | 40 | 9 | - | D,74 |
| 699-S8-19 | ? | ? | 104-132 ? | 11,000 | 50 | 270 | - | Bi,59 |
| 699-S3-25 | 06/01/79 | SL,SLR | 114-172 ? | 930 | 44 | 21 | - | Undocumented |
| 699-1-18 | /58 ? | SLR | 109-265 ? | 10,000 | 165 | 60 | - | Bi,59 |
| 699-2-3 | /69 ? | TC | - | 25,000 | 60 | 420 | - | K&M,73 |
| 699-2-33A | 05/24/79 | SLR | 130-180 | 4,600 | 44 | 105 | - | Undocumented |
| 699-8-17 | 06/10/58 | SLR | 106-166 | 35,000 | 55 | 640 | - | D,74 |
| 699-8-32 | 10/13/69 | TC,TCR | 150-184 | 1,000 | 50 | 20 | - | K&M,73 |
| 699-10-54A | 02/01/77 | SLR | 103-146 | 9,700 | 28 | 346 | - | Undocumented |
| 699-15-26 | /58 ? | SLR ? | ? | 71,000 | 220 | 320 | - | Bi,59 |
| 699-17-5 | 09/19/58 | SLR | 45-72 ? | 1,100 | 45 | 25 | - | Bi,59 |
| 699-17-47 | 06/23/69 | SLR | 175-340 | 5,100 | 105 | 49 | - | Reanalysis |

TABLE 1. (contd)

| WELL | TEST DATE | ANALYSIS METHODS | OPEN INTERVAL (ft) | TRANSMISSIVITY ($ft^2/d$) | AQUIFER THICKNESS (ft) | HYDRAULIC CONDUCTIVITY (ft/d) | STORATIVITY | REFERENCE |
|---|---|---|---|---|---|---|---|---|
| 699-20-20 | 10/07/58 | SL,SLR | 105-155 | 32,000 | 200 | 160 | - | Bi,59 |
| 699-24-33 | ? | ? | 116-164 | 390,000 | 45 | 8,600 | - | Undocumented |
| 699-24-34A | 01/31/87 | SL | 122.5-137 | 350,000 | 60 | 5,800 | - | F,89 |
| 699-24-35 | 02/20/87 | SL | 128-143 | 270,000 | 60 | 4,500 | - | F,89 |
| 699-25-33A | 12/22/86 | TC | 225-255 | 40-50 | 50 | 1 | - | W,87 |
| 699-26-15 | 06/30/58 | SLR | 34-150 | 8,400 | 48 | 175 | - | Reanalysis |
| 699-26-35C | 10/17/86 | TC,SL | 130-166 | 74,000-240,000 | 60 | 1,200-4,000 | - | W,87 |
| 699-26-35C | 12/20/86 | TC | 187-203 | 2,000-3,000 | 15 | 130-200 | 0.0015 | W,87 |
| 699-26-89 | 06/27/69 | SL,SLR | 198-488 | 525 | 229 | 2 | - | D,74 |
| 699-31-31 | /58 ? | SLR ? | ? | 250,000 | 35 | 7,100 | - | Bi,59 |
| 699-31-53B | 04/22/59 | SLR | 301-423 | 14,000 | 120 | 117 | 0.06 | Reanalysis |
| 699-32-77 | 08/25/69 | TC | 175-290 | 4,500-57,000 | 220 | 21-260 | - | K&M,73 |
| 699-33-56 | 11/25/58 | SL | 317-440 | 1,100 | 88 | 13 | - | Reanalysis |
| 699-35-9 | 02/16/77 | SLR | 117-135 | 14,900 | 50 | 298 | - | Reanalysis |
| 699-36-61A | 07/22/69 | SLR | 358-389 | 3,900 | 65 | 60 | - | D,74 |
| 699-37-82A | 08/15/79 | BC,SL | ? | 270 | 30 | 9 | 0.02, sy = 0.18 | G,81 |
| 699-40-1 | /58 ? | ? | 65-220 ? | 30,000 | 50 | 600 | - | Lu,92 |
| 699-40-33A | /58 ? | SLR? | 106-185 | 200 | 160 | 1.3 | - | Bi,59 |
| 699-41-23 | /58 ? | SLR ? | 65-115 ? | 28,000 | 150 | 190 | - | Bi,59 |
| 699-42-12A | 09/11/58 | SLR | 120-320 | 86,000 | 130 | 660 | - | Bi,59 |
| 699-42-40C | 01/18/82 | TC | 130-170 ? | 430 | ? | - | 0.01 | Reanalysis |
| 699-42-42B | 10/18/88 | SL | 193-203 | 140 | ? | ? | - | WHC,90 |
| 699-43-43 | 09/09/88 | SL | 162-180 | 37,000 | 18 | 2,100 | - | WHC,90 |
| 699-43-88 | 09/11/80 | TC,SL | 177-198 | 970 | 100 | 10 | 0.05 | G,81 |
| 699-44-42 | 09/22/88 | SL | 155-174 | 76,000 | 18 | 4,200 | - | WHC,90 |
| 699-46-21B | 08/04/78 | SLR | 128-151 | 3,900 | 133 | 29 | - | Undocumented |

TABLE 1. (contd)

| WELL | TEST DATE | ANALYSIS METHODS | OPEN INTERVAL (ft) | TRANSMISSIVITY ($ft^2/d$) | AQUIFER THICKNESS (ft) | HYDRAULIC CONDUCTIVITY (ft/d) | STORATIVITY | REFERENCE |
|---|---|---|---|---|---|---|---|---|
| 699-47-35C | 06/14/79 | BC | 67-100 ? | 530 | 44 | 12 | 0.002, sy = 0.15 | G,81 |
| 699-47-60 | 09/03/69 | SLR | 250-277 | 3,300 | 41 | 80 | - | D,74 |
| 699-53-55A | 01/16/88 | SLR | 197-221 | 66,300 | 98 | 660 | 0.45 | Undocumented |
| 699-55-50B | 10/01/56 | TC | 40-100 | 400,000 | 65 | 6,150 | 0.2 | Reanalysis |
| 699-56-53 | 11/11/82 | SL | 190-270 ? | 270 | | | - | GLF,84 |
| 699-60-57 | 08/16/78 | SL | 142-155 | 9,800 | 70 | 140 | - | G,81 |
| 699-61-66 | 02/22/77 | SLR | 116-220 | >40,000 | 104 | >400 | - | D,74 |
| 699-62-43B | 04/06/54 | CM/CMR | 33-63 | 50,800 | 30 | 1,700 | 0.06 | Bi,57 |
| 699-63-90 | 07/16/69 | TC | 115-147 | 40,000-63,000 | 140 | 290-450 | - | K&M,73 |
| 699-65-50 | 05/08/57 | SLR | 55-125 | 64,000 | 35 | 1,800 | - | Bi,59 |
| 699-71-52 | /58 ? | SLR ? | 120-160 | 4,000 | 50 | 80 | - | Bi,59 |
| 699-71-77 | 09/17/69 | TC | 60-288 | 16,000-44,000 | 367 | 84-120 | - | K&M,73 |
| 699-77-54 | 07/23/57 | SL | 70-120 ? | 3,460 | 72 | 48 | - | Gi,92 |
| 699-87-55 | 07/02/69 | SL | 59-92 | 1,950 | 35 | 55 | - | Gi,92 |

Key to References:

Bi,57 Bierschenk 1957
Bi,59 Bierschenk 1959
D,74 Deju 1974
F,89 Fruland et al. 1989
G,81 Graham et al. 1981
Gi,92 Gilmore et al. 1992
GLF,84 Graham et al. 1984
K&M,73 Kipp and Mudd 1973
La,89 Last et al. 1989
Li,88 Liikala and Aaberg 1988
Lu,92 Luttrell et al. 1992
L&B,79 Lindberg and Bond 1979
W,87 Weekes et al. 1987
WHC,90 WHC 1990

Analysis Methods:

TC Theis (1935) curve matching of drawdown data
TCR Theis (1935) curve matching of recovery data
BC Boulton (1963) curve matching
SL Cooper and Jacob (1946) semilog straight line
SLR Theis (1935) semilog straight line for recovery data

TABLE 2. Results of Slug Tests of Wells in the Unconfined Aquifer System at Hanford

| WELL | TEST DATE | ANALYSIS METHODS | OPEN INTERVAL (ft) | TRANSMISSIVITY ($ft^2/d$) | HYDRAULIC CONDUCTIVITY (ft/d) | REFERENCE |
|---|---|---|---|---|---|---|
| 299-E24-19 | 10/02/89 | BR,76 | 285 - 301 | - | 100 - 110 | N,90 |
| 299-E25-40 | 09/29/89 | BR,76 | 257 - 273 | - | 62 - 75 | N,90 |
| 299-E25-41 | 09/29/89 | BR,76 | 262 - 276 | - | 20 - 180 | N,90 |
| 299-E26-9 | 08/13/90 | BR,76 | 195 - 201 | - | 420 | DP,90 |
| 299-E26-11 | 08/28/90 | BR,76 | 200 - 206 | - | 20 | DP,90 |
| 299-E27-13 | 10/20/89 | BR,76 | 261 - 275 | - | 180 - 410 | N,90 |
| 299-E27-14 | 10/20/89 | BR,76 | 250 - 267 | - | 140 - 170 | N,90 |
| 299-E27-15 | 10/19/89 | BR,76 | 245 - 261 | - | 350 | N,90 |
| 299-E32-5 | 11/06/89 | BR,76 | 275 - 292 | - | 590 | Bo,90 |
| 299-E33-33 | 09/27/89 | BR,76 | 232 - 248 | - | 340 | N,90 |
| 299-E34-7 | 10/05/89 | BR,76 | 194 - 204 | - | 78 - 83 | Bo,90 |
| 299-E35-2 | 08/13/90 | BR,76 | 191 - 201 | - | 19 | DP,90 |
| 299-W7-7 | 12/05/89 | BR,76 | 211 - 228 | - | 3 | Bo,90 |
| 299-W7-9 | 03/01/90 | BR,76 | 228 - 241 | - | 2 | Ba,90 |
| 299-W7-10 | 02/13/90 | BR,76 | 225 - 241 | - | 1 | Ba,90 |
| 299-W9-1 | 10/23/87 | BR,76 | 266 - 286 | - | 0.3 | L,89 |
| 299-W10-15 | 11/03/89 | BR,76 | 206 - 222 | - | 33 | N,90 |
| 299-W10-16 | 10/30/89 | BR,76 | 203 - 219 | - | 38 | N,90 |
| 299-W10-18 | 01/16/91 | BR,76 | 202 - 220 | - | 140 | T,92 |
| 299-W15-19 | 10/30/89 | BR,76 | 214 - 235 | - | 1 | Bo,90 |
| 299-W15-20 | 11/03/89 | BR,76 | 220 - 241 | - | 5 - 17 | Bo,90 |
| 299-W15-22 | 01/15/91 | BR,76 | 202 - 222 | - | 50 | T,92 |
| 299-W15-23 | 03/01/90 | BR,76 | 228 - 239 | - | 22 - 30 | Ba,90 |
| 299-W15-25 | 12/18/89 | BR,76 | 230 - 241 | - | 55 | Bo,90 |
| 299-W18-25 | 12/12/90 | BR,76 | 196 - 216 | - | 20 | T,92 |
| 299-W19-31 | 01/17/91 | BR,76 | 207 - 227 | - | 120 | T,92 |
| 299-W19-32 | 01/14/91 | BR,76 | 205 - 225 | - | 4 | T,92 |
| 299-W22-40 | 04/23/90 | BR,76 | 228 - 224 | - | 38 | G,90 |
| 299-W22-41 | 04/23/90 | BR,76 | 229 - 245 | - | 9 | G,90 |
| 299-W22-42 | 04/30/90 | BR,76 | 228 - 243 | - | 13 | G,90 |
| 299-W22-43 | 04/23/90 | BR,76 | 228 - 244 | - | 49 | G,90 |
| 299-W23-13 | 12/12/90 | BR,76 | 199 - 219 | - | 90 | T,92 |
| 299-W23-14 | 05/12/91 | BR,76 | 199 - 218 | - | 1.4 | T,92 |
| 299-W26-8 | 05/31/90 | BR,76 | 200 - 216 | - | 5 | T,92 |
| 299-W26-9 | 05/03/90 | BR,76 | 189 - 205 | - | 30 | T,92 |
| 299-W26-10 | 05/31/90 | BR,76 | 206.5 - 221.7 | - | 75 | T,92 |
| 299-W26-11 | 05/31/90 | BR,76 | 122 - 136 | - | 0.006 | T,92 |
| 299-W26-12 | 05/10/90 | BR,76 | 228.2 - 210.2 | - | 5 | T,92 |
| 699-40-39 | 08/04/89 | BR,76 | 202 - 212 | - | 0.5 | BG,89 |
| 699-41-40 | 05/26/89 | C,67 | 147 - 158 | 0.01 | - | BG,89 |
| 699-41-40 | 08/07/89 | C,67 | 164 - 174 | 2.0 - 3.4 | - | BG,89 |
| 699-43-41E | 06/29/89 | C,67 | 138 - 148 | 15 - 19 | - | BG,89 |
| 699-43-41F | 05/30/89 | C,67 | 166 - 176 | 34 - 45 | - | BG,89 |
| 699-44-43B | 05/19/89 | BR,76 | 173 - 176 | - | 0.3 - 1.4 | BG,89 |
| 699-44-43B | 07/05/89 | BR,76 | 161 - 176 | - | 0.4 - 5.0 | BG,89 |

Key to References:

Ba,90 Barton 1990
Bo Borghese et al. 1990
BG,89 Borghese and Goodwin 1989
DP,74 Doremus and Pearson 1990
G,90 Goodwin 1990
L,89 Last et al. 1989
N,90 Newcomer 1990
T,92 Trent 1992

Analysis Methods:

BR,76 Bouwer and Rice (1976)
C,67 Cooper et al. (1967)

## 6.0 REANALYSIS OF SELECTED PUMPING TESTS

Eight aquifer pumping tests were selected for reanalysis using the techniques described in Section 3.0. Diagnostic plots showing the derivative of the water-level change were used to help identify valid data for semilog straight-line analysis. The objective of the reanalysis effort was to determine the reliability of past hydraulic property estimates.

Tests were selected for reanalysis mainly on the basis of their location in the area south of Gable Mountain and between the 200-East Area and the Columbia River. Most of the waste water and transportable contaminants discharged to the ground in the 200-East Area are expected to move through this area with the ground water and eventually discharge to the Columbia River. Locations of the wells selected for reanalysis are shown in Figure 11.

### Well 699-17-47

Well 699-17-47 was one of 25 wells tested by PNL in 1969 using the constant discharge method (Kipp and Mudd 1973). The test interval in this well extended from the water table, at a depth of 175 ft, to a depth of 340 ft near the top of basalt. The test interval contains a clay unit between 220 ft and 280 ft. The duration of pumping was 7 h at a flow rate of 90 gal/min. Recovery measurements were made for 16.7 h following the end of pumping.

Kipp and Mudd (1973) reported a transmissivity range of 1800 to 3400 $ft^2/d$ based on type-curve analyses of both drawdown and recovery data. The thickness of the permeable part of the test interval was assumed to be 75 ft. Based on this aquifer thickness, an average hydraulic conductivity range of 24 to 45 ft/d was calculated for the permeable section.

Deju (1974) applied the straight-line solution to the first 200 min of drawdown data to estimate a transmissivity value of 5300 $ft^2/d$. This result was divided by the test interval minus the thickness of the clay unit, or 105 ft, to calculate a value of 50 ft/d for average hydraulic conductivity.

Because of influences from pumping-rate variation, the drawdown data were not reanalyzed. A log-log diagnostic plot of the recovery water-level data is shown in Figure 12. The derivative of the water-level recovery is also shown. The derivative was calculated using the Agarwal equivalent time

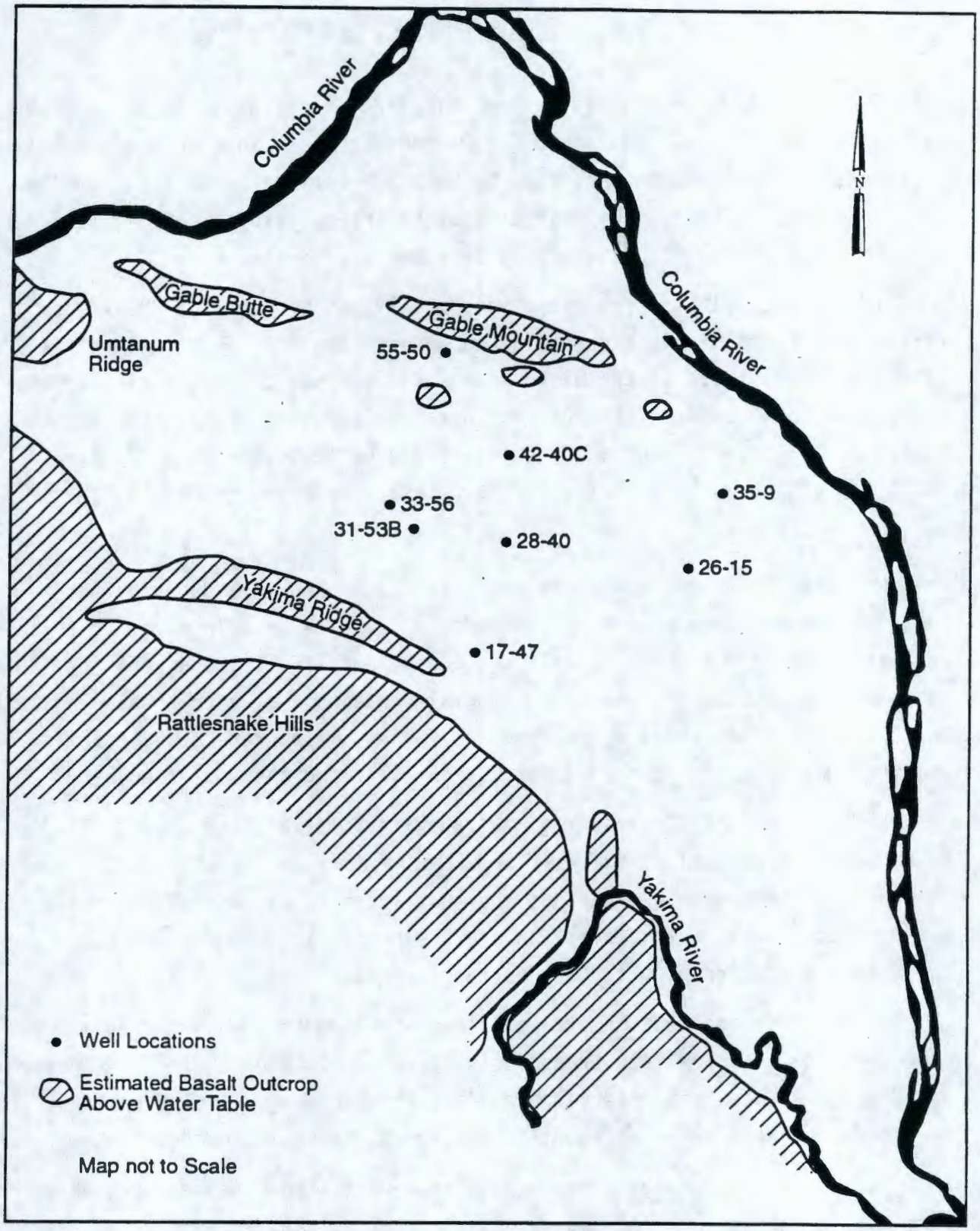


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FIGURE 11. Locations of Hanford Site Wells Selected for Test Reanalysis

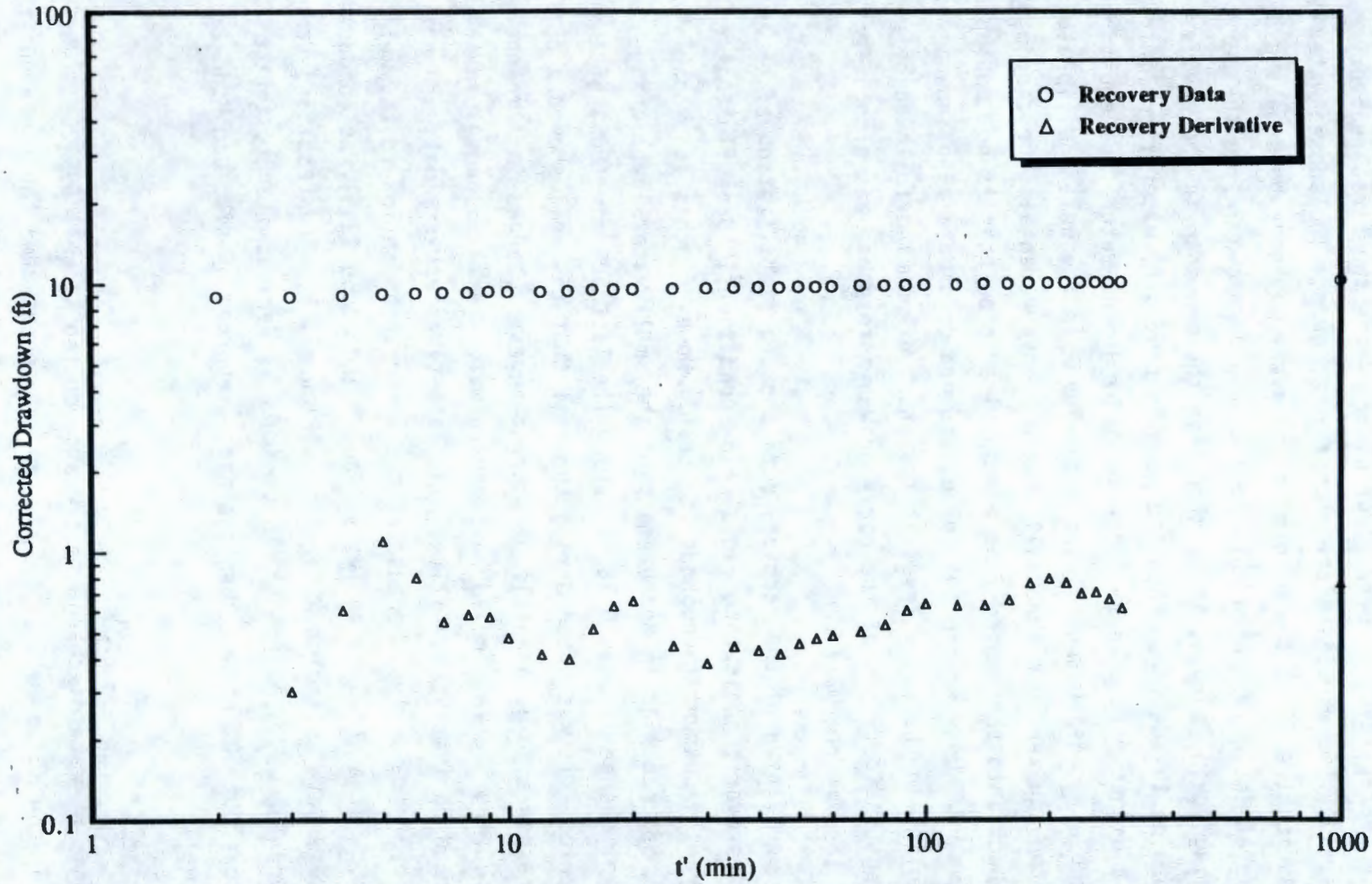


FIGURE 12. Log-Log Diagnostic Plot of the Recovery Data and Derivative for Well 699-17-47

function. The recovery curve appears to be very flat. This is because about 85% of the water-level recovery took place before the first recovery measurement was made, two minutes after stopping the pump. The sudden water-level change during the first few minutes of recovery may have been caused by friction loss at the well. When this occurs, the drawdown inside the perforated well casing during pumping is greater than the drawdown in the aquifer immediately outside the casing. When the pump is shut off, water flows into the well at a higher rate than that predicted by ground-water flow equations. The rapid recovery continues until the water-level in the well equilibrates with that in the aquifer. An abnormally rapid recovery can also be caused by water flowing back into the casing from a pump riser pipe that is not equipped with a check valve. However, in this case, the drawdown data also show a very rapid decline in the water level at the start of pumping followed by a sudden flattening, indicating that the early drawdown response was also affected by friction loss at the well.

The derivative of the recovery data shows a stabilization after about 8 min of recovery, indicating radial flow conditions. Some fluctuation in the derivative is apparent throughout the test. However, this is probably caused by a lack of precision in measurement of the small water-level changes. The water-level change is only 0.26 ft during the last 800 min (80%) of the recovery period. It was noted during the test that the well showed a confined aquifer response to atmospheric pressure changes. Changes in atmospheric pressure during the test could have caused water-level responses in the well and affected derivative stability. The late-time recovery data are not affected by friction loss because of the low rate of inflow to the well. Therefore, a straight-line analysis (Cooper and Jacob 1946) was conducted on the recovery data collected after 8 min (Figure 13). The resulting transmissivity value was 5100 $ft^2/d$. This result is very similar to that of Deju (1974) and about 50% higher than the range reported by Kipp and Mudd (1973) for this well.

Well 699-26-15

A constant-rate discharge test was conducted at well 699-26-15 during the period June 30 to July 1, 1959. The well penetrated the upper 96 ft of the unconfined aquifer. However, because the bottom half of the test zone

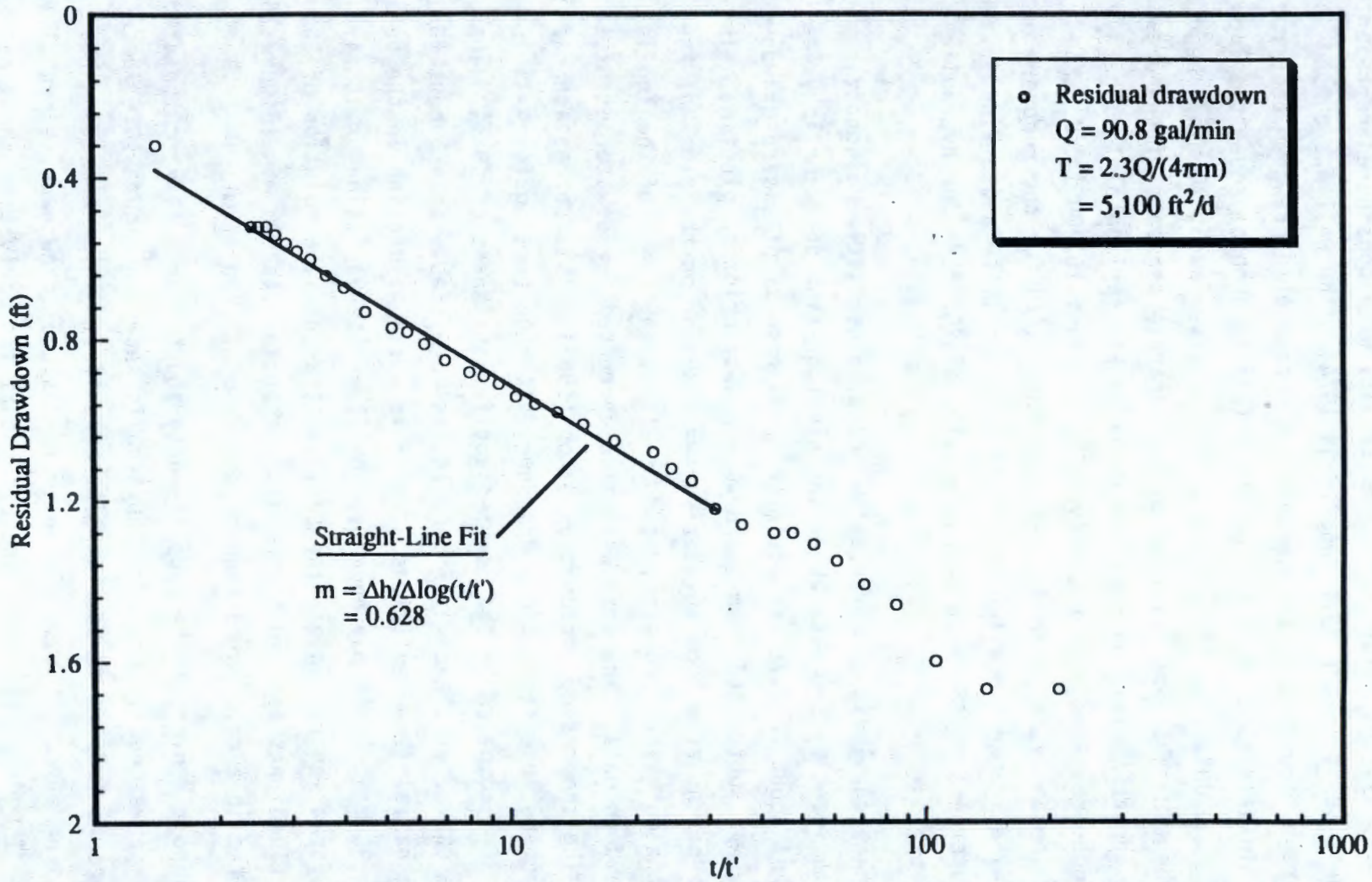


FIGURE 13. Semilog Straight-Line Analysis of Recovery Data for Well 699-17-47

consists of clay, the values of transmissivity were considered representative of the upper 48 ft of the test zone (Deju 1974). The well was pumped for 8 h at an average flow rate of 252 gal/min. A decrease in drawdown occurred at about 40 min after the start of pumping. This is probably due to a flow rate decrease. The data show another perturbation after about 70 min. Deju (1974) applied the straight-line solution to two separate segments of the drawdown data that appear to fall on straight lines on the semilog plot. The average of the slopes resulted in a transmissivity value of 10,200 $ft^2/d$. The straight-line analysis yielded a value of 8880 $ft^2/d$ for the recovery data. Deju (1974) averaged these two values of transmissivity and divided by an aquifer thickness of 48 ft to obtain a value of 200 ft/d for hydraulic conductivity.

For the reanalysis of the drawdown data, a derivative diagnostic plot was used to identify the data where the straight-line solution is valid. A well loss of about 10.2 ft was estimated from results of a step-drawdown test. This value was subtracted from the drawdown data prior to plotting. This correction has no effect on the derivative curve or on the slope of the semilog straight line. However, it does affect the shape of the log-log plot of the drawdown data. The data were also corrected for dewatering of the aquifer using the method proposed by Jacob (1963). This correction has a very small effect because the maximum drawdown, after correcting for well loss, is small (2.9 ft) compared to the assumed aquifer thickness of 48 ft. The derivative curve for drawdown (Figure 14) is more stable after about 90 min, indicating radial flow conditions. There is a slight decline in the derivative after 90 min. This may be caused by flow-rate variation or it may reflect a formation response. The semilog straight-line solution of Cooper and Jacob (1946) was applied to the data recorded after 90 min (Figure 15). This resulted in a calculated transmissivity of 12,700 $ft^2/d$.

A diagnostic plot of the recovery data and the derivative calculated using the Agarwal equivalent time function is shown in Figure 16. These data were also corrected for dewatering of the aquifer. This correction has essentially no effect because of the small residual drawdowns, especially at late time. The diagnostic plot indicates that the derivative shows only minor fluctuations after about 20 min. Therefore, the data corresponding to

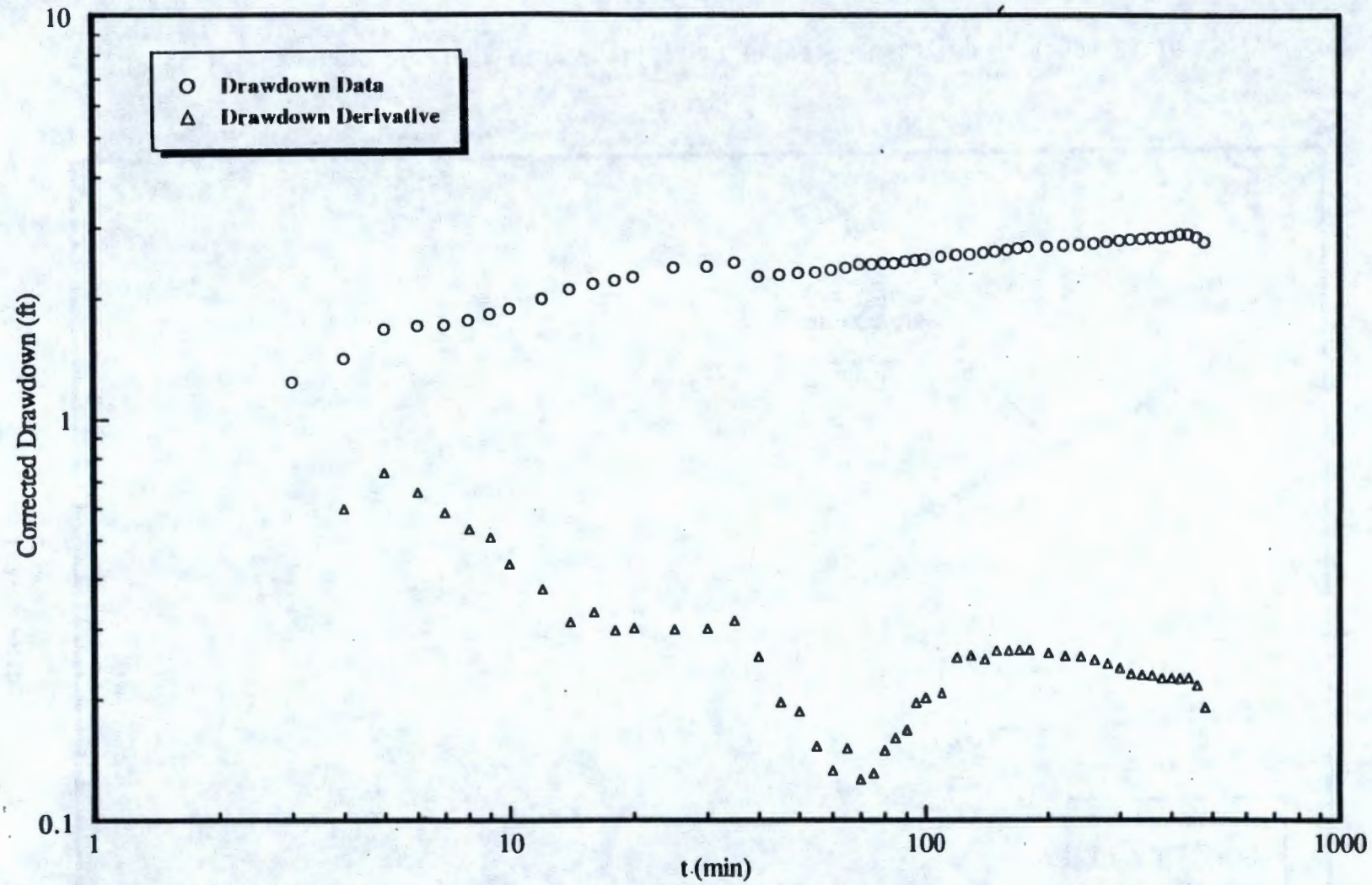


FIGURE 14. Log-Log Diagnostic Plot of the Drawdown Data and Derivative for Well 699-26-15

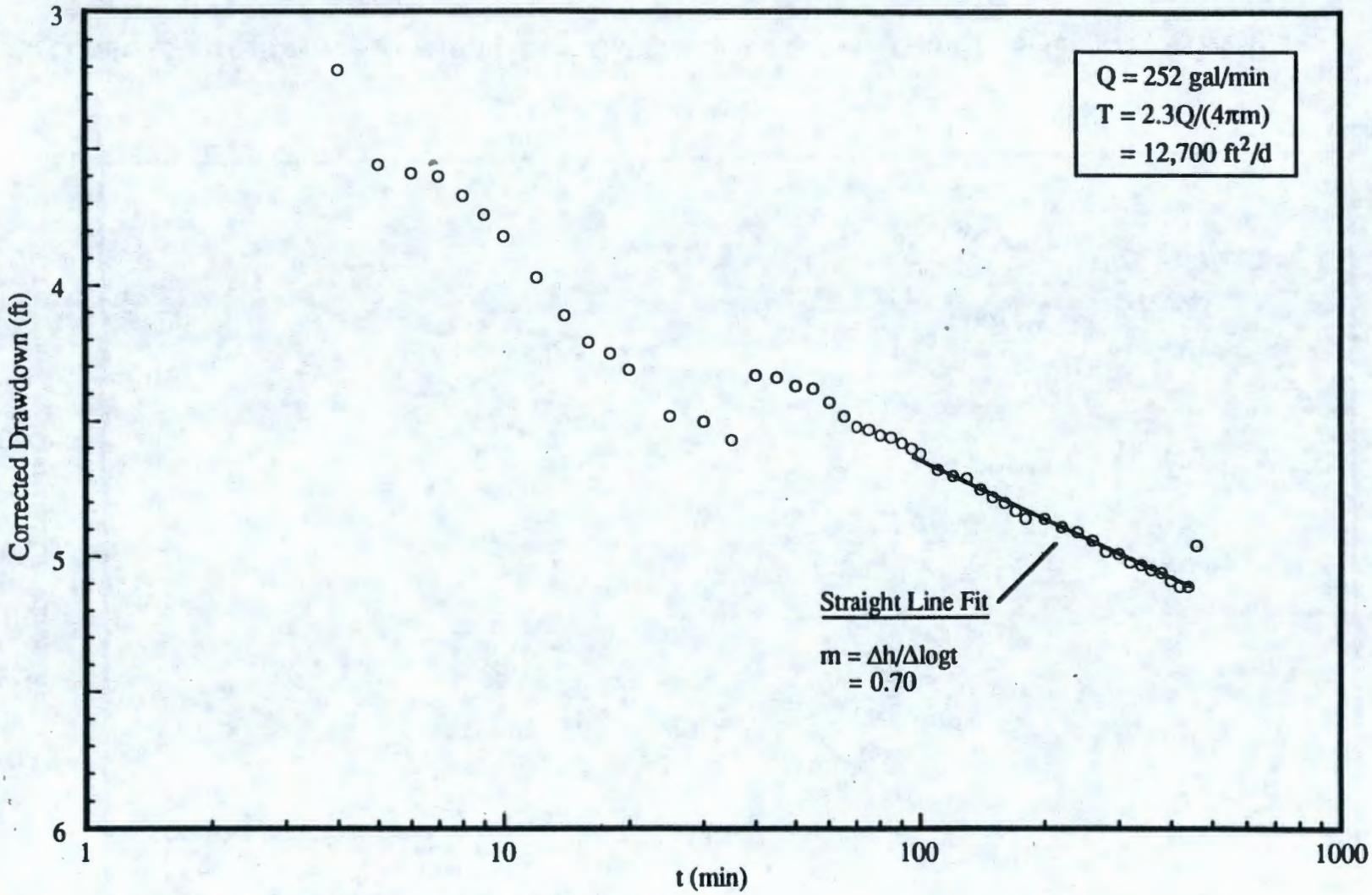


FIGURE 15. Semilog Straight-Line Analysis of Drawdown Data for Well 699-26-15

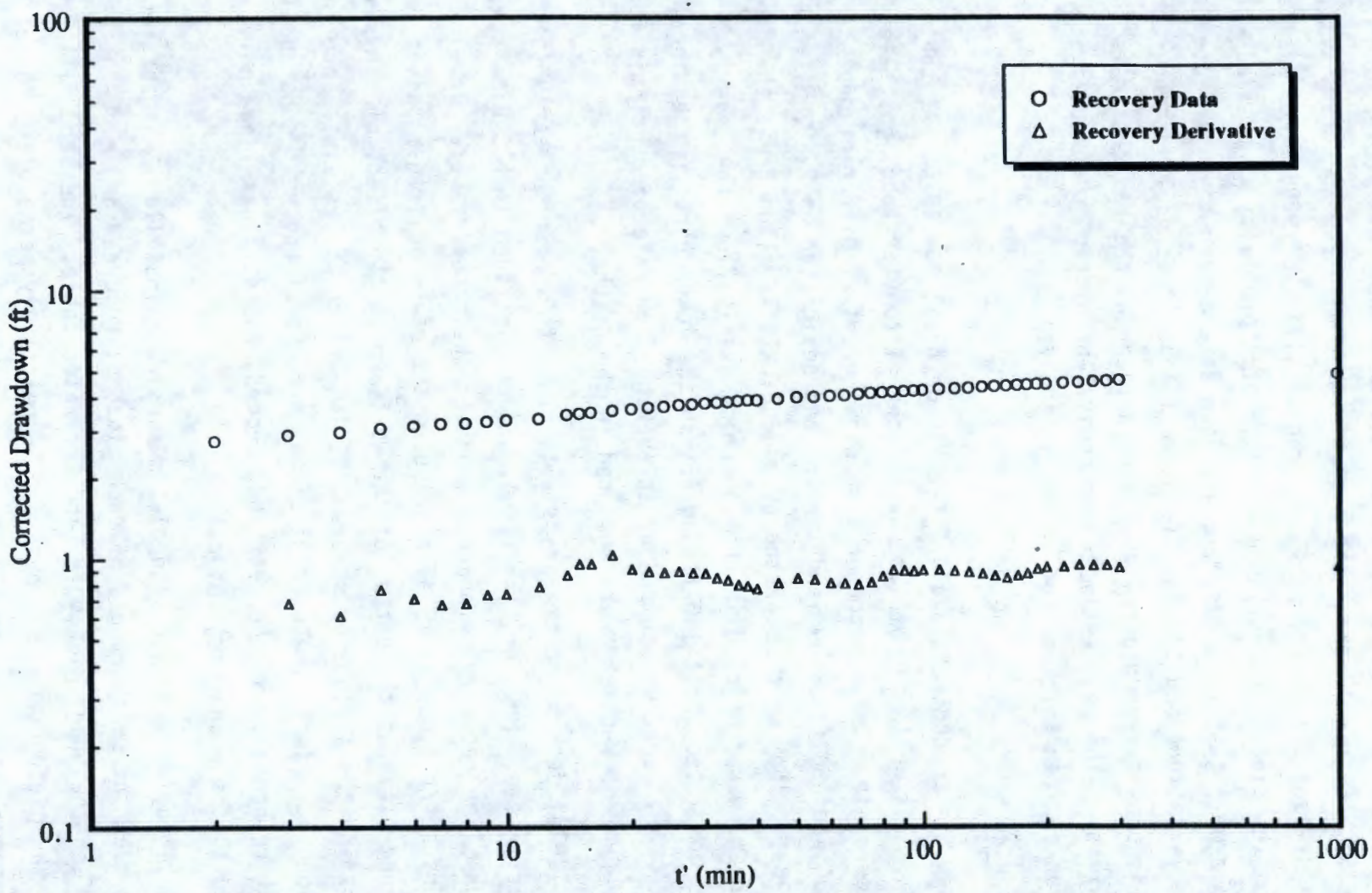


FIGURE 16. Log-Log Diagnostic Plot of the Recovery Data and Derivative for Well 699-26-15

t'>20 min was analyzed using the straight-line method for recovery data (Theis 1935). Figure 17 shows the plot of residual drawdown versus t/t' and the straight-line fit to the data. A transmissivity of 9000 $ft^2/d$ was calculated from the slope. No reliable estimate of storativity is possible from this single-well test. Because the drawdown data appear to be affected by flow-rate variations and by significant well loss, the result of the recovery analysis is considered more reliable and is taken as the best estimate for transmissivity. The best estimate for equivalent hydraulic conductivity, based on an aquifer thickness of 48 ft, is 190 ft/d.

Well 699-28-40

A test was conducted at well 699-28-40 on April 20, 1970. At the time of testing, this well was completed with four piezometer tubes installed in the same borehole. The piezometer screens were set at different depths between 280 and 460 ft below land surface and designated as P, Q, R, and S (McGhan 1989). They were separated by sand backfill. Tube P was the deepest piezometer and was completed in the uppermost basalt flow, the Beverly Member. Tube Q was completed about 100 ft higher, in the lower part of the Ringold Formation. The P tube was pumped at an average flow rate of 6 gal/min for 5 h. Drawdown and recovery were measured in the Q tube.

Deju (1974) determined transmissivity of 5 $ft^2/d$ from the early (t'<5 min) recovery data. However, the result was not included in his data summary. The straight-line recovery method was used and the recovery water level was plotted versus t/t'. Deju (1974) attributed the measured transmissivity to the silts and clays at the bottom of the well and to the effect of the sand fill separating the piezometer screens. This earlier analysis was incorrect in two respects. First, the concept of the effects of the well construction on the test response is not correct and, second, the straight-line analysis was applied to the wrong range of data.

The well casing, in which the piezometers were installed, was apparently perforated over the depth ranges of each piezometer screen and over the entire length between the upper piezometer and the water table. The sand fill separating the piezometers is thought to be relatively permeable. Therefore, the test interval, the aquifer section from which water was pumped, was the

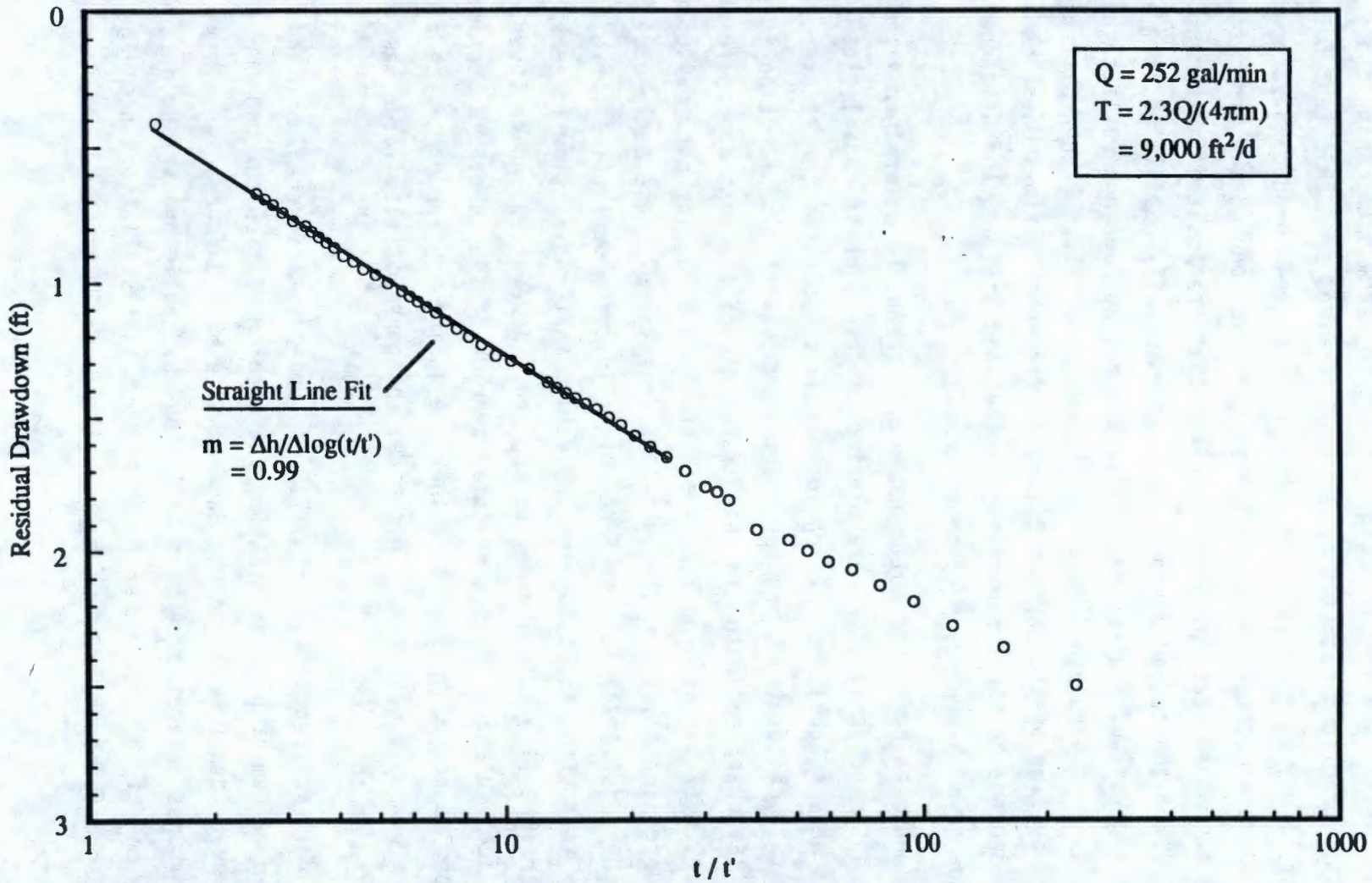


FIGURE 17. Semilog Straight-Line Analysis of Recovery Data for Well 699-26-15

entire open section of the well casing. Although the data can be analyzed, meaningful hydraulic properties cannot be determined from this test because the sand fill may have resulted in a head loss between producing zones and the pumped piezometer screen. This head loss may have reduced the proportion of flow from permeable sections of the aquifer that are located farther up the well, away from the pumped piezometer. Transmissivity calculated from a transient analysis of the recovery data, therefore, does not reflect the permeability of the pumped interval or of the sand fill. Rather, it reflects a weighted average of the permeabilities of different inflow zones, and the weighting depends on the permeability of the sand fill and the distance of the inflow zone from the pumped piezometer screen.

Although meaningful hydraulic properties cannot be determined from this test, the data and derivative were plotted to determine if radial flow conditions were established. A log-log diagnostic plot of the recovery data and derivative calculated using the Agarwal equivalent time function is shown in Figure 18. Data collected in the first 5 min of the test appear to be dominated by well-bore storage, as indicated by the log-log plot having a slope of approximately one. Straight-line analysis of these early data conducted by Deju (1974) is therefore not valid. The derivative curve becomes relatively flat after about 20 min, indicating that radial flow is established and the straight-line solution may be applied. However, as noted above, the result of such an analysis is a weighted average of the permeable sections of the well and cannot be applied to either the entire aquifer or to the section open at the pumped piezometer. Therefore, no transmissivity value was calculated from this test.

This well was recompleted in 1977. Two piezometers were installed and separated by a cement plug eliminating the problem of flow through the sand fill. However, other wells on the Hanford Site have been completed with piezometer tubes separated by sand fill. Any hydraulic properties determined by testing one of the piezometer tubes at such an installation should be carefully scrutinized.

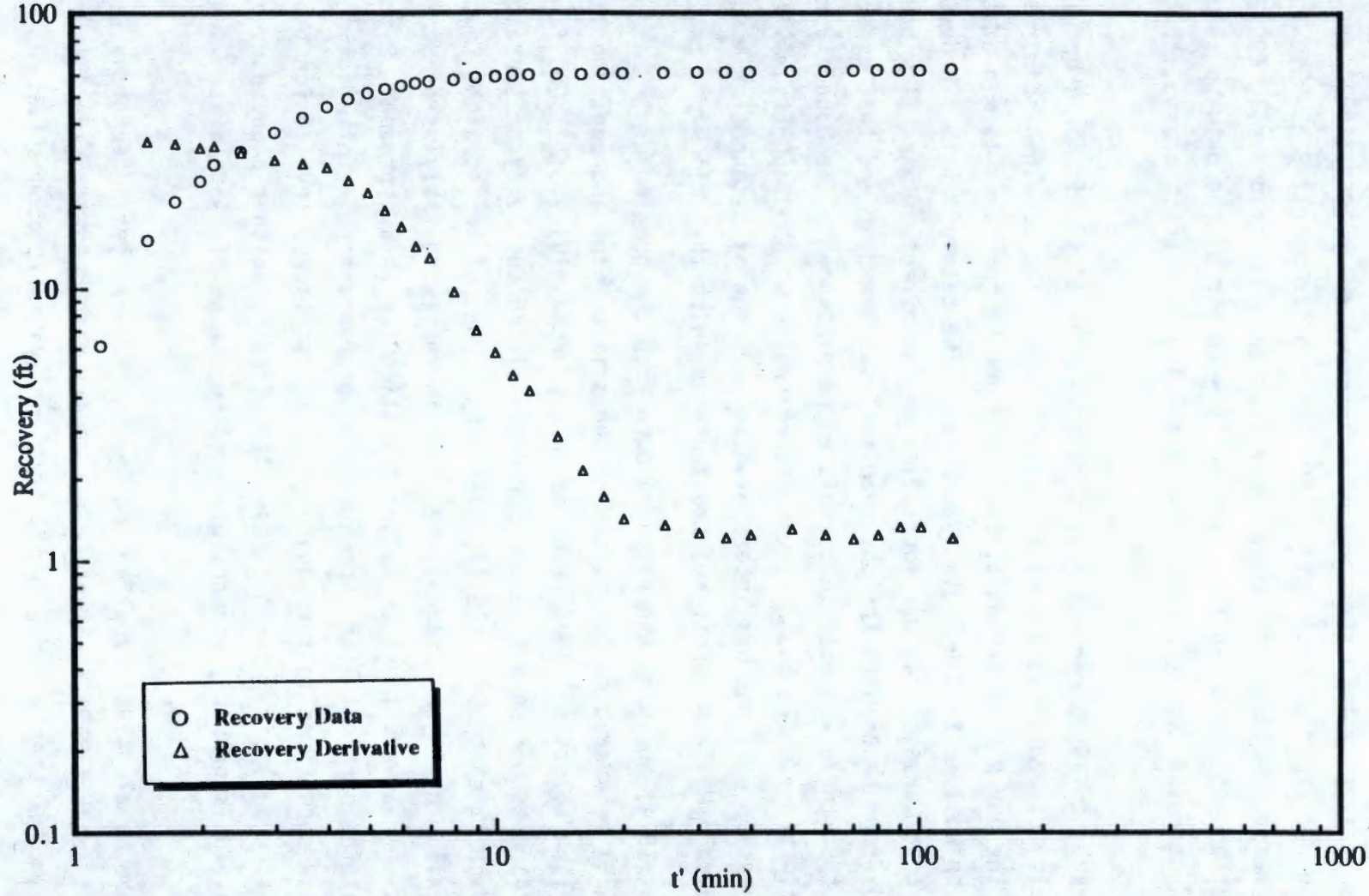


FIGURE 18. Log-Log Diagnostic Plot of the Recovery Data and Derivative for Well 699-28-40

Well 699-31-53B

This constant-rate discharge test was conducted in 1959. Well 699-31-53B was pumped at an average rate of 605 gal/min for nearly 8 h. Drawdown and recovery measurements are also available from an observation well, 699-31-53A, located at a distance of 50 ft. Both wells were perforated between the water table and near the top of a clay unit, resulting in a test interval thickness of 120 ft.

Bierschenk (1959) reports a transmissivity of 14,400 $ft^2/d$, hydraulic conductivity of 120 ft/d, and storativity of 0.06. He obtained this result by matching the early recovery data, collected during the first 15 min at the observation well, with the Theis type-curve. The data after 15 min deviated from the type curve. This was identified as the effect of a no-flow boundary and the difference between the observed residual drawdown and that expected from the type curve was used to calculate the distance to the boundary using image well theory. The boundary was determined to be about 50 ft away from the observation well and was interpreted as the edge of a channel filled with glaciofluvial (Hanford formation) sediments in which the well was located.

Deju (1974) analyzed the recovery data from the pumping well (699-31-53B) by averaging two slopes on the semilog plot and applying the straight-line solution. This resulted in a transmissivity of 21,000 $ft^2/d$. Deju (1974) does not report values for hydraulic conductivity or storativity. The approach taken by Deju (1974), averaging slopes of two straight segments on the semilog plot, was commonly observed in reviewing analyses of Hanford Site tests. However, there is no justification for this approach. Either one or both of the straight-line segments does not represent infinite-acting radial flow conditions in the aquifer and is, therefore, invalid for the straight-line analysis. In this case, the effect of either a boundary or delayed yield is probably responsible for the change of slope of the semilog plot.

Graham et al. (1981) applied the Theis (1935) analysis technique and the Cooper and Jacob (1946) straight-line recovery method to estimate values of 14,000 $ft^2/d$ for transmissivity, 120 ft/d for hydraulic conductivity, and 0.06

for coefficient of storage. Graham et al. (1981) do not state which data set was used for the analysis and do not show plots and analyses.

Figure 19 shows a composite diagnostic plot of the drawdown data in both pumping well B and observation well A. An apparent well loss of 3.8 ft was subtracted from the pumping well drawdown data. Corrections for aquifer dewatering had no significant effect because the aquifer thickness is much greater than the drawdown. The derivative response for the observation well shows some stabilization for the last eight data points. However, it is still trending upward, indicating a changing slope on the semilog plot. This change may be caused by the transition from elastic response to delayed yield expected for an unconfined aquifer. Radial flow conditions are apparently not reached for the elastic response part of the curve prior to influence of the transition to delayed yield. If a transmissivity of 12,000 $ft^2/d$ and a storativity of 0.1, corresponding to the delayed-yield portion of the response, are assumed, then $t/r^2$ must be greater than 0.3 for the criterion $u < 0.01$ to be met. As shown in Figure 19, pumping was terminated before this point was reached. Neither the drawdown nor the recovery data from the observation well data are, therefore, considered valid for straight-line analysis.

A match of the observation well drawdown data with the Theis curve was attempted. The curve match shown in Figure 20 results in a transmissivity of 10,000 $ft^2/d$ and storativity of 0.2. The match is poor and the results are considered a qualitative estimate of the minimum value for transmissivity because the data fall below the type curve. A better match to the data could be achieved, but would result in an unrealistically high value of storativity. The data appear to be approaching the match curve at late time.

The early drawdown data at the pumped well (before about 50 min) appear to be affected by flow-rate variation (Figure 19). The water level in the pumped well increased for a period during the early part of the test. The late-time data show a decreasing derivative that could indicate a constant-head boundary, vertical leakage, or a decrease in flow rate. Because of these complications, only the intermediate-time drawdown data from the pumping well, collected after the flow-rate variation and before the apparent boundary effect, were considered suitable for straight-line analysis. This includes the data from 50 to 110 min after pumping began. The semilog straight-line

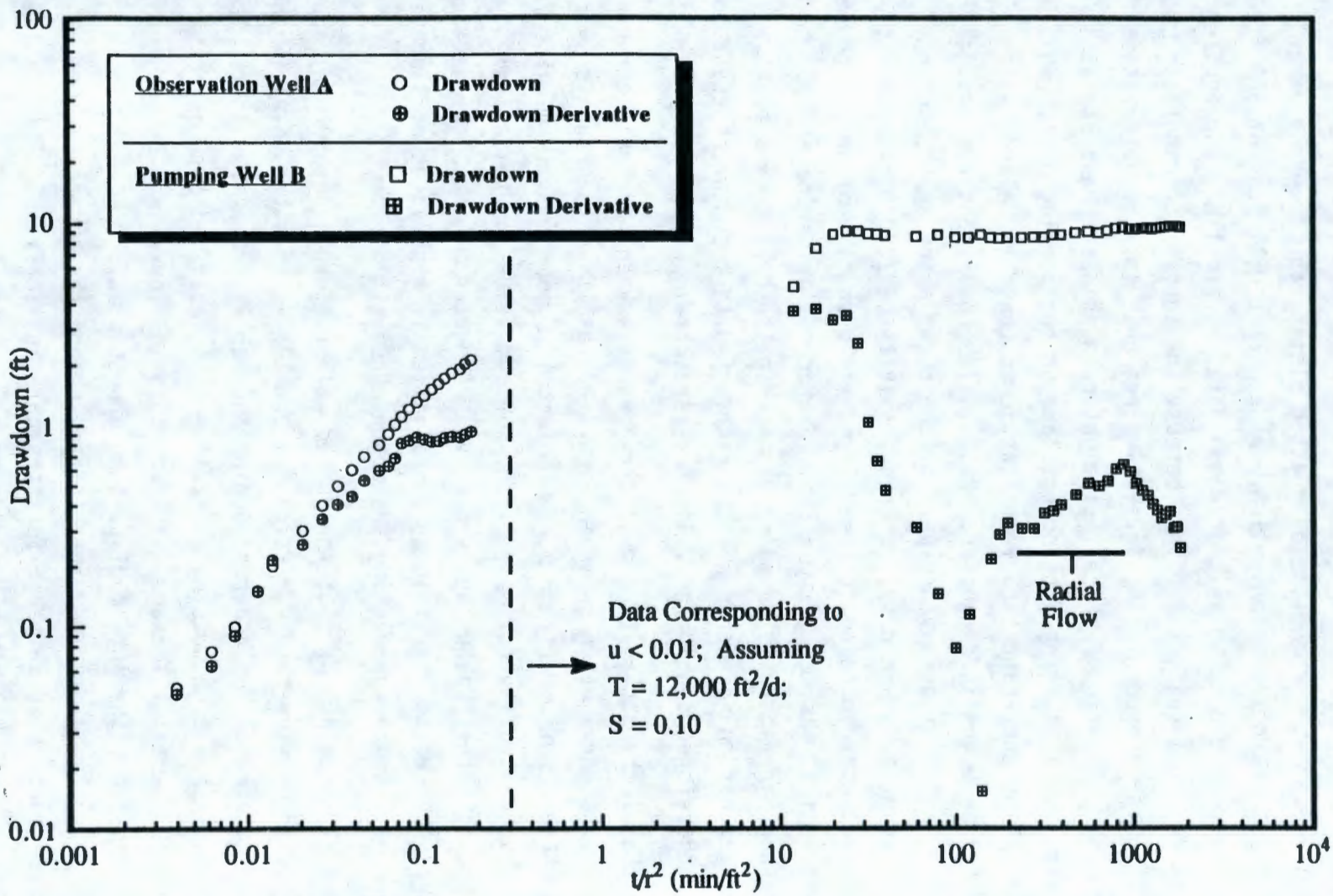


FIGURE 19. Composite Diagnostic Plot of the Drawdown Data and Derivative for Observation Well 699-31-53A and Pumping Well 699-31-53B

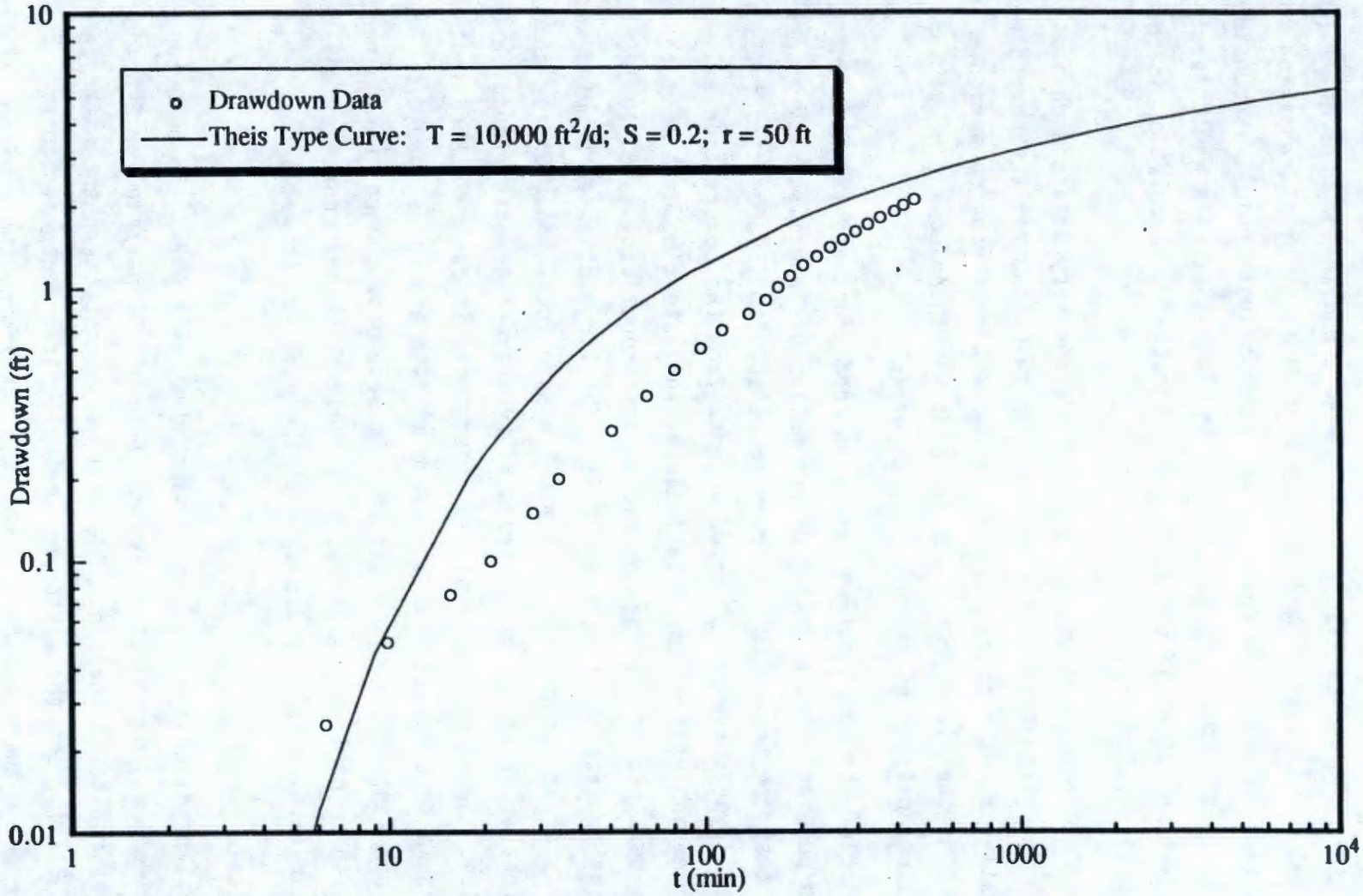


FIGURE 20. Theis Curve Match with Drawdown Data for Observation Well 699-31-53A

analysis of these data is shown in Figure 21 and yields a transmissivity of 13,000 $ft^2/d$. These data also show an upward trend in the derivative (Figure 19) that may be caused by flow-rate variations or by a transition to delayed yield response. Therefore, the transmissivity result is considered approximate. Fitting a straight line to the late-time data would result in a transmissivity of about 15,000 $ft^2/d$. No storativity calculation is possible for the pumping well data.

Figure 22 shows a diagnostic plot of the recovery data and derivative, calculated using the Agarwal equivalent time function, for the pumped well. The derivative shows a steady decline throughout the recovery period. This indicates that the slope of the semilog plot was changing and no valid straight-line analysis of these data was possible.

Because of the complicating formation conditions and the apparent changes in pumping rate, no exact determination of transmissivity is possible from this test. A transmissivity range of 10,000 to 15,000 $ft^2/d$ is estimated based on the type curve fit of drawdown data from the observation well and the straight-line analysis of the intermediate- and late-time data from the pumped well. The best estimate range for hydraulic conductivity is 83 to 125 ft/d based on the aquifer thickness of 120 ft. The large diameter pumping well and availability of an observation well make this an ideal location for conducting a test to characterize the high permeability channel deposits found on the Hanford Site. Based on the results of this test, it can be stated that pumping should be conducted for a minimum of 24 h and pains should be taken to achieve a constant pumping rate and to eliminate disturbances during recovery. Because of the high transmissivity, it is desirable to account for any trends in the water-level data, particularly at the observation well.

Well 699-33-56

A constant-discharge test was conducted at well 699-33-56 on October 25, 1958. The well was pumped at an average rate of 205 gal/min for 8 h and recovery was monitored for 8 h. The well was open between the water table, at a depth of 317 ft, and the bottom of the well, at a depth of 440 ft. A clay unit is present between 405 ft and 440 ft. Therefore, the aquifer thickness was considered to be 88 ft. Bierschenk (1959) calculated a transmissivity of

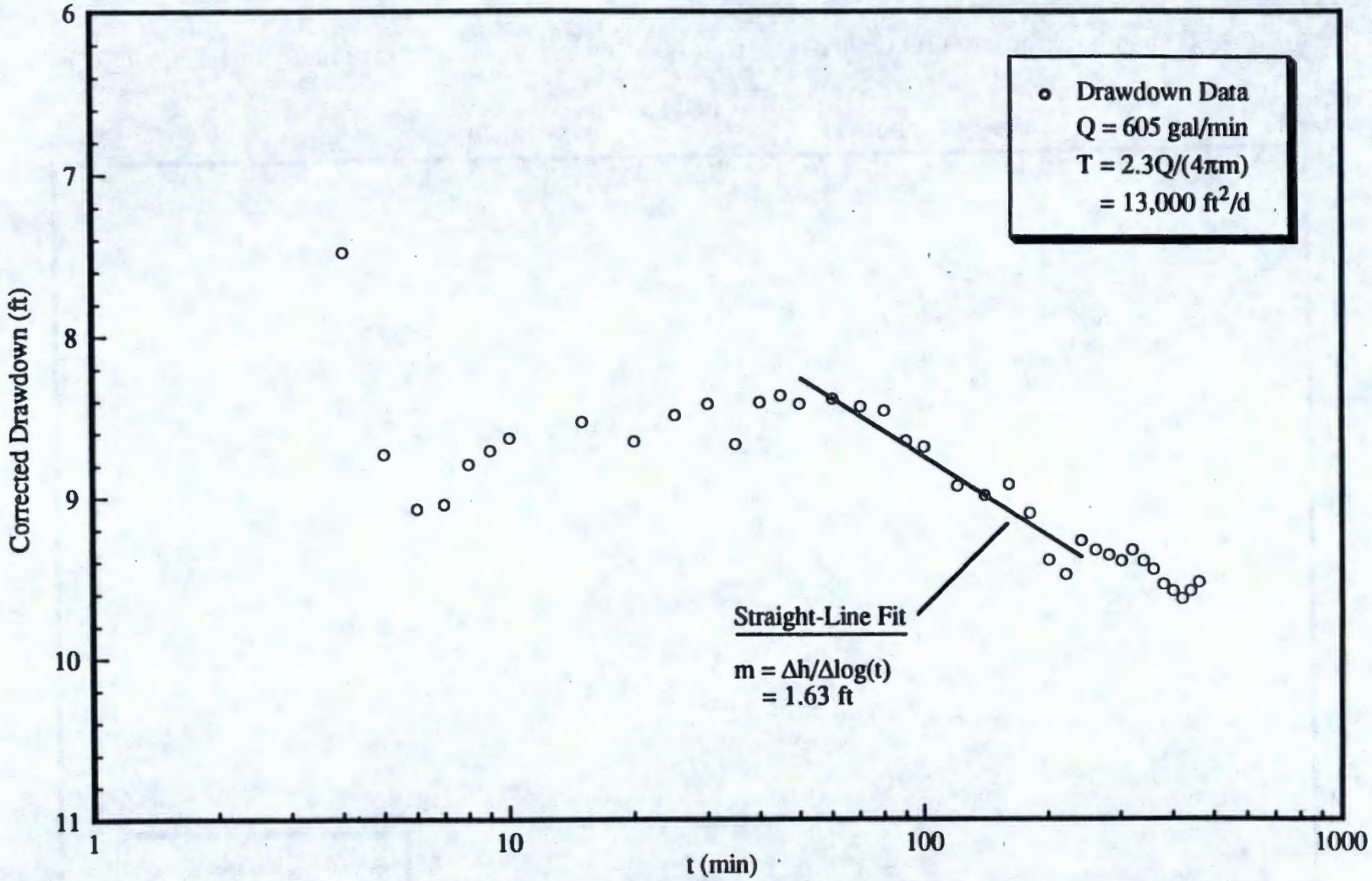


FIGURE 21. Semilog Straight-Line Analysis of Drawdown Data for the Pumping Well 699-31-53B

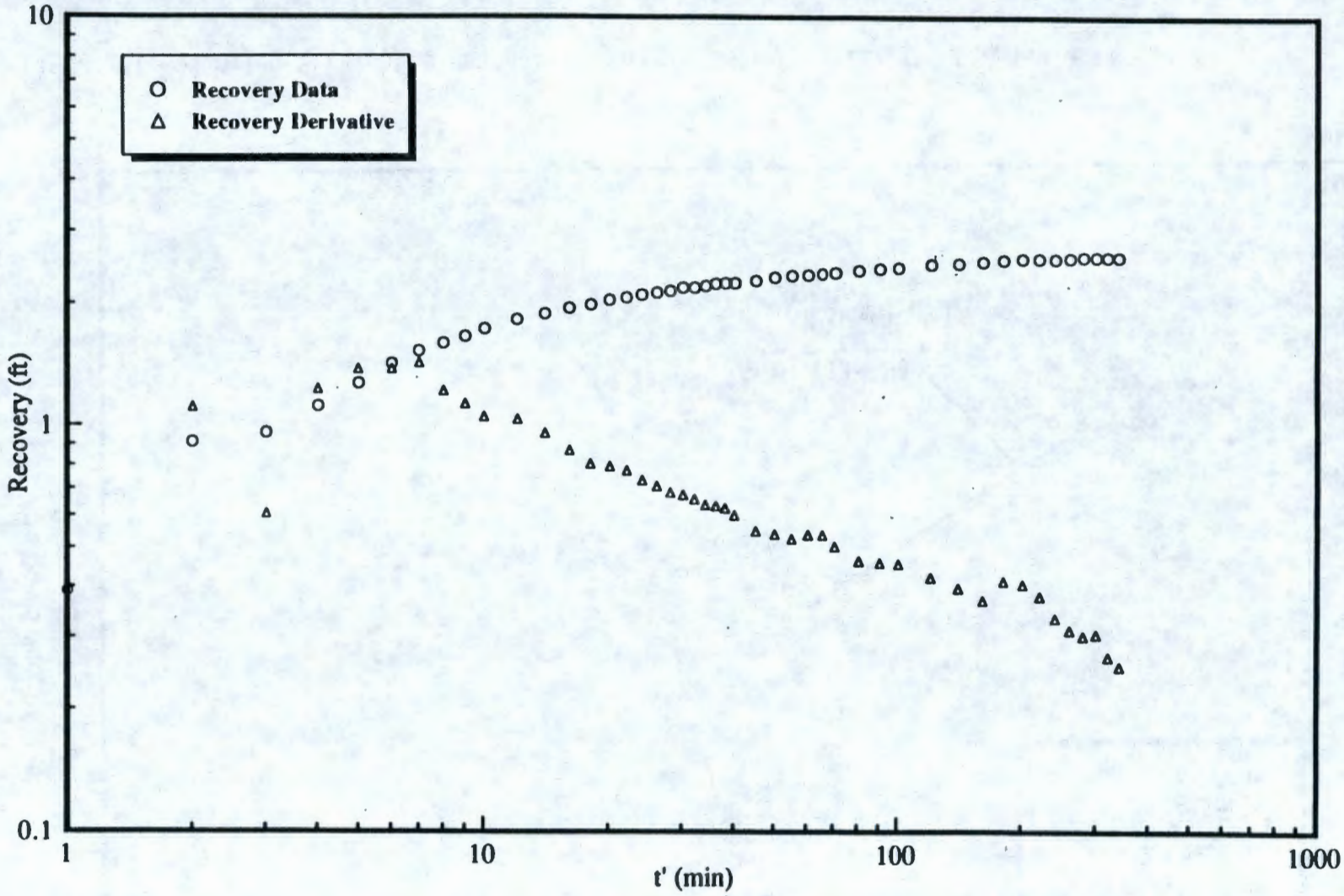


FIGURE 22. Log-Log Diagnostic Plot of the Recovery Data and Derivative for Well 699-31-53B

20,700 $ft^2/d$ from this test. Deju (1974) disregarded the drawdown data and used only the recovery data to estimate a transmissivity value of 22,000 $ft^2/d$. Deju (1974) calculated a value for hydraulic conductivity of 250 ft/d for the upper 88 ft of the test interval. Graham et al. (1981) also used the recovery data and applied the Theis (1935) and Cooper and Jacob (1946) techniques to estimate values for transmissivity and hydraulic conductivity of 21,000 $ft^2/d$ and 230 ft/d, respectively.

A log-log diagnostic plot of the drawdown data and derivative (Figure 23) shows a possible delayed yield response, indicated by a valley in the derivative beginning at about 20 min. Early-time data (before 20 min) is affected by the transition to the delayed-yield portion of the curve and is not suitable for straight-line analysis. The diagnostic plot also shows that radial flow conditions are not achieved before pumping is terminated. Therefore, the late-time drawdown data may not be analyzed by the semilog straight-line technique. The recovery data (not shown) appear to be affected by backflow from the pump column. The water level in the well increases during the first 3 min of recovery to within 0.14 ft of the pre-test level. It then decreases over the next 5 min to 0.61 ft below the pre-test level and then begins a slow increase. Because of this perturbation, no attempt was made to reanalyze the recovery data.

Because none of the data from this test were appropriate for straight-line analysis and the recovery data appear to be affected by injection of water from the pump column, the only estimate of transmissivity is a limiting value based on type-curve matching of the drawdown data. Two type-curves are shown in Figure 23. Values for storativity of 0.0001 and 0.1 were assumed in generating these curves and correspond to reasonable values for the elastic response and the delayed yield response of the aquifer, respectively. These assumed values may be incorrect. However, because this portion of the type curve is relatively flat, assuming an elastic storativity an order of magnitude higher or lower than 0.0001, or assuming a specific yield value between 0.01 and 0.2, would not change the transmissivity value determined from the curve match by more than a factor of 2. The drawdown and derivative are characteristic of transition from elastic response to delayed yield response

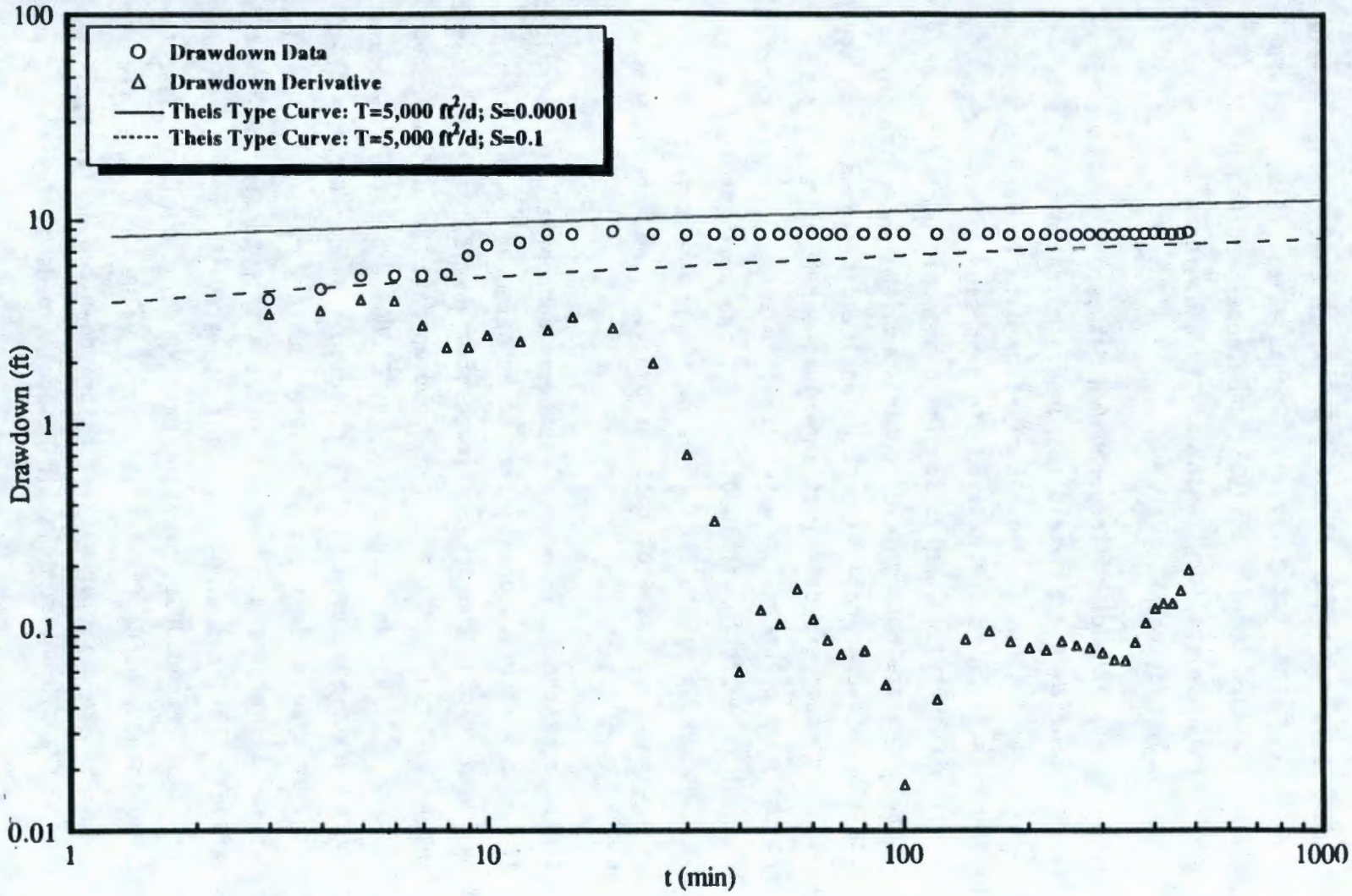


FIGURE 23. Log-Log Diagnostic Plot and Theis Curve Bracketing of the Drawdown Data for Well 699-33-56

of an unconfined aquifer. The data were therefore fit between the two type curves. The resulting transmissivity value was 5000 $ft^2/d$.

The type-curve method is not as reliable as semilog straight-line methods for the pumping well because assumptions that the well is a line sink with no storage and that head losses at the well are negligible are not met. The transmissivity result of type-curve matching for this test is considered a minimum value because well loss may have caused additional drawdown at the well during the test. The transmissivity estimate of 5000 $ft^2/d$ is, therefore, considered a minimum value. The corresponding minimum value of equivalent hydraulic conductivity is 57 ft/d based on an aquifer thickness of 88 ft. From the results of this test, it appears that a pumping duration of 3 to 6 days and a comparable recovery period is needed to accurately determine the transmissivity at this well. Care should be taken to ensure a steady pumping rate and that the recovery data are not affected by backflow from the pump column.

Well 699-35-9

Well 699-35-9 is perforated between the depths of 110 ft and 135 ft. The water-table depth was 113 ft in 1990 (Newcomer et al. 1991) and the aquifer extends to the top of a clay unit at 164 ft. Therefore, the current total aquifer thickness is about 51 ft and the well penetrates the upper 22 ft of the aquifer.

Records of four constant-rate pumping tests of this well are available. These tests were conducted in 1958, 1969, 1977, and 1983. Results of the 1958 test are reported in Bierschenk (1959). A transmissivity of 11,000 $ft^2/d$ was calculated from the recovery data. The 1969 test was analyzed by Kipp and Mudd (1973) and Deju (1974). For this test, pumping was conducted for 4 h at a discharge rate averaging 64 gal/min. A change of slope occurred on the semilog plot of drawdown data from this test. Deju (1974) used straight-line analysis of the earlier-time data to calculate a transmissivity of 2250 $ft^2/d$ and hydraulic conductivity of 45 ft/d. He suggested that the change in slope possibly represented a recharge boundary. Using type-curve fitting analysis, Kipp and Mudd (1973) reported transmissivity values ranging from 1500 $ft^2/d$ to 37,000 $ft^2/d$. They also reported a storativity range, though this estimate

was not considered reliable for the single-well test. They noted in their test summary table that the well may be completely penetrating. This was presumably based on the shape of the drawdown curve and might be caused by relatively low vertical permeability in the apparently thicker aquifer.

Results of the two later tests, conducted in 1977 and 1983, have apparently not been reported in the published literature. The 1977 test was reanalyzed for this report. Pumping was conducted for 8 h at an average rate of 104 gal/min, about double the rate of the other tests. Recovery was also monitored for 8 h. The duration of pumping for the 1983 test was 24 h. This test was not selected for reanalysis, in spite of the long duration, because both the drawdown and recovery measurements are noisy and this noise has a severe impact on calculation of the derivative curve.

The combined effects of partial penetration, aquifer anisotropy, delayed yield, and head losses at the pumping well make it very difficult to determine a meaningful transmissivity value from this test. Partial penetration at a pumping well creates a vertical flow component and results in a decreased drawdown compared to that predicted from the Theis equation. According to Weeks (1969) the drawdown deviation is constant after a time given by

$$t = bS/2K_z$$

where $S$ = storativity
$b$ = aquifer thickness
$K_z$ = vertical hydraulic conductivity

Assuming a storativity of 0.1 for the delayed-yield response, an aquifer thickness of 50 ft, and a vertical hydraulic conductivity equal to 45 ft/d (the K calculated by Deju), t is equal to 80 min. After this time, straight-line analysis should result in a valid transmissivity, although the calculated storativity would be incorrect. However, t may be greater than 80 min if the vertical hydraulic conductivity is lower than the assumed value. Delayed-yield is expected to cause a flattening of the early-time drawdown curve expected for the elastic aquifer response and then a delayed-yield drawdown response at a later time. Head losses at the well may cause an additional component of drawdown during the pumping phase.

A diagnostic log-log plot of the drawdown data from the 1977 test is shown in Figure 24. This shows that the drawdown was relatively constant after about 20 min of pumping and even decreased after about 30 min. This behavior may have been caused by a decrease in the discharge rate. A significant well-loss component is likely in the total drawdown and the increase in water level may also have resulted from development of the well and a reduction in the well-loss component. Because of these complications, no analysis of the drawdown data was attempted.

Recovery data are not affected as greatly by well losses or fluctuations in discharge rate during the pumping period. Therefore, the recovery data were relied upon for test analysis. Figure 25 shows a log-log diagnostic plot of the recovery data. The derivative was calculated based on Agarwal's (1980) equivalent time function for recovery data. The derivative shows a steady decline for about the first 140 min of recovery and then begins to increase. The derivative after 140 min may reflect either a stabilization caused by radial flow conditions, or the increasing derivative expected at the beginning of the delayed-yield response. The test was not conducted for a long enough period to determine the correct interpretation. A straight-line analysis of the recovery data after 140 min was conducted as shown in Figure 26. This resulted in a calculated transmissivity of 12,400 $ft^2/d$ and this value is considered the best estimate possible from this test. The corresponding equivalent hydraulic conductivity, based on an aquifer thickness of 50 ft is 248 ft/d. These estimates may be high if the analyzed portion of the recovery curve corresponds to the transition of the delayed-yield response. The total observed drawdown during pumping also indicates that a lower transmissivity is possible. However, the well head-loss component of drawdown is unknown. The calculated transmissivity of 12,400 $ft^2/d$ is, therefore, regarded as a maximum limit value.

Well 699-42-40C

A multi-well test was conducted at this well site, located near B Pond, on January 18, 1982. Well C was the pumping well and water-level data are also available for observation wells A and B located 24 and 25 ft, respectively, from the pumped well. The pretest depth to water was approximately 123 ft. Well A was completed at a depth of 139 ft to 171 ft and well B was

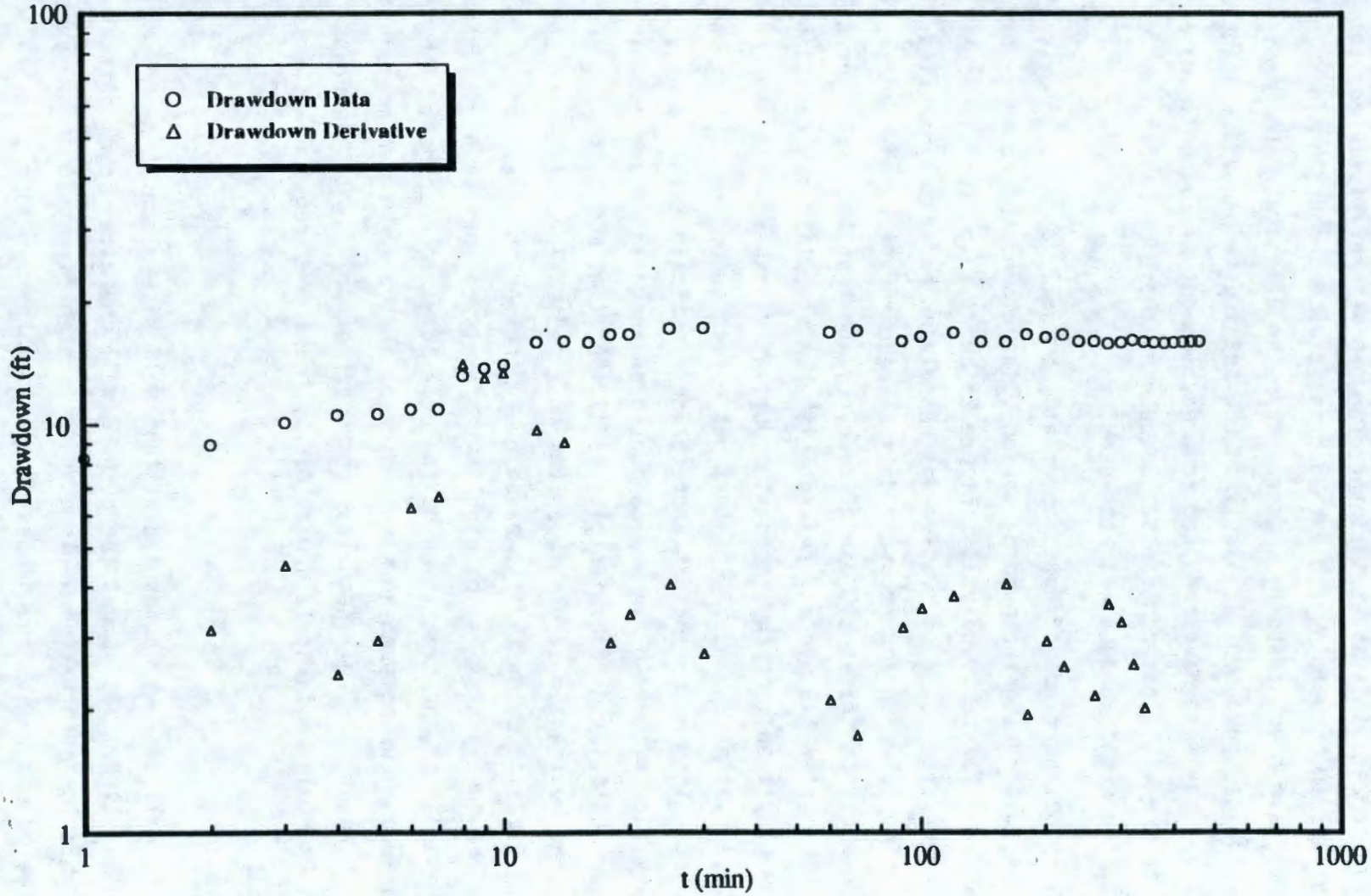


FIGURE 24. Log-Log Diagnostic Plot of the Drawdown Data and Derivative for Well 699-35-9

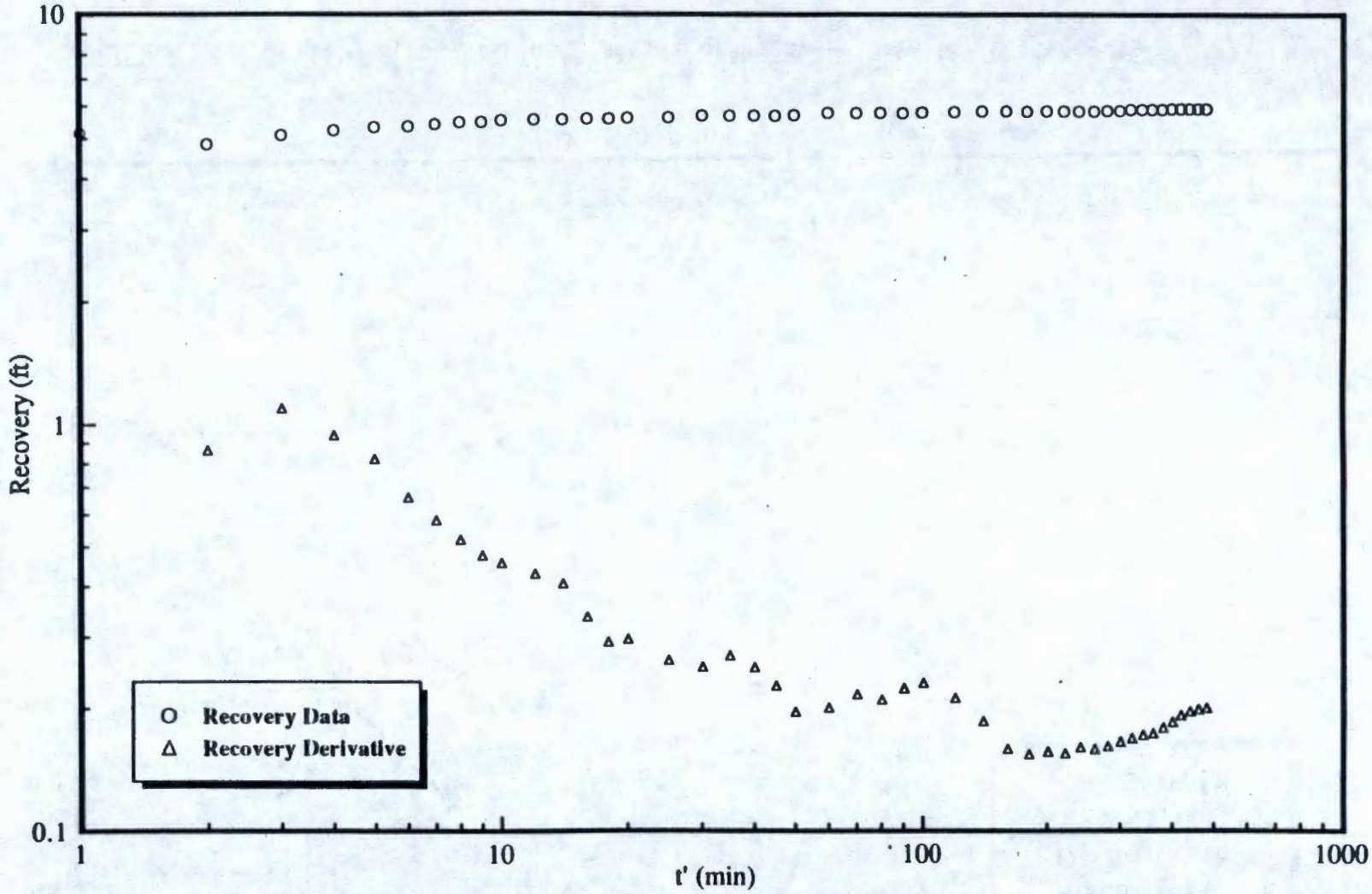


FIGURE 25. Log-Log Diagnostic Plot of the Recovery Data and Derivative for Well 699-35-9

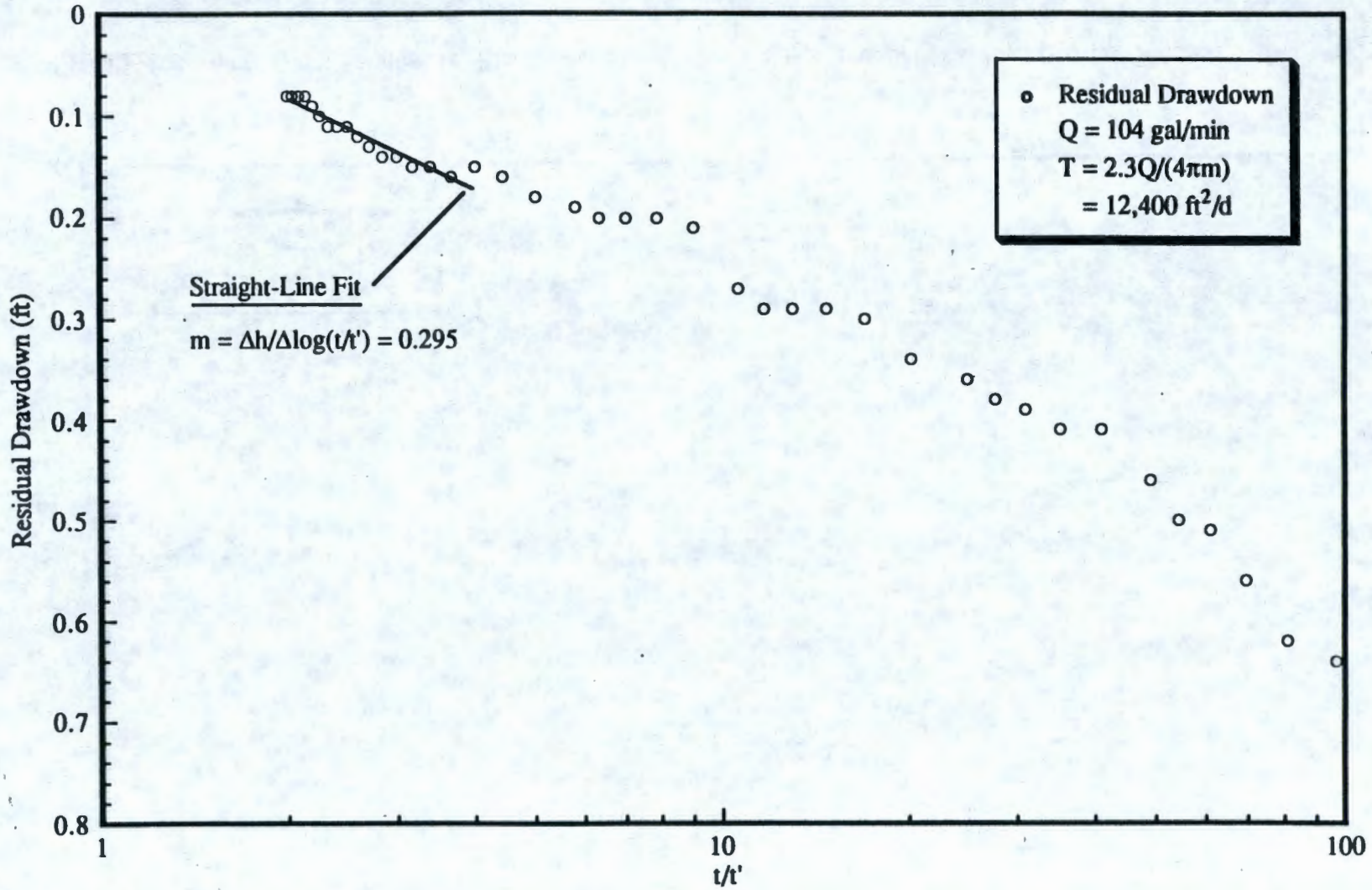


FIGURE 26. Semilog Straight-Line Analysis of Recovery Data for Well 699-35-9

completed at a depth of 130 ft to 150 ft. Well C was open to an adjacent interval at the time of the test. However, the well was later deepened into the basalt aquifer and no record was found of the exact depth interval penetrated by the pumping well. For the reanalysis it was assumed that the pumping well completely penetrated the aquifer. Pumping was conducted for just under 6 h at a flow rate of approximately 21 gal/min.

The Cooper and Jacob (1946) straight-line solution was applied to the drawdown data for both observation wells by Graham et al. (1984). Transmissivity values of 310 $ft^2/d$ and 360 $ft^2/d$ were calculated for data from wells A and B, respectively. Calculated values of storativity were 0.017 and 0.009.

A composite log-log plot of the drawdown data from both observation wells is shown in Figure 27. The derivatives are also plotted and show that straight-line semilog analysis is not valid for this data. Only the last two data points show a possible stabilized derivative. Based on the average transmissivity and storativity calculated by Graham et al. (1984), it may be calculated that the time corresponding to $u < 0.01$ is $t > 800$ min for well A and $t > 870$ min for well B. The observation well data do not meet this criteria for straight-line analysis. For reanalysis of the test data, the composite log-log plot was fit to the Theis (1935) type curve as shown in Figure 27. The resulting value of transmissivity was 300 $ft^2/d$ and the storativity was 0.02. The data fit was relatively poor and the greatest emphasis was placed on fitting the late-time data to the expected drawdown curve. The greater drawdown at well B may be caused by partial penetration of the pumping well. As mentioned, the completion depth of the pumping well is unknown and it may have been in the upper part of the aquifer, adjacent to well B.

Well 699-55-50

Several aquifer pumping tests have been conducted at the 699-55-50 site using various test design configurations. The site consists of four wells, A, B, C, and D, completed within the unconfined aquifer. The test selected for reanalysis was conducted in October 1956 and was one of the first pumping tests on the Hanford site (Biershcenk 1957). Well B was the pumping (stress) well and observation well data were collected from well A at a radial distance

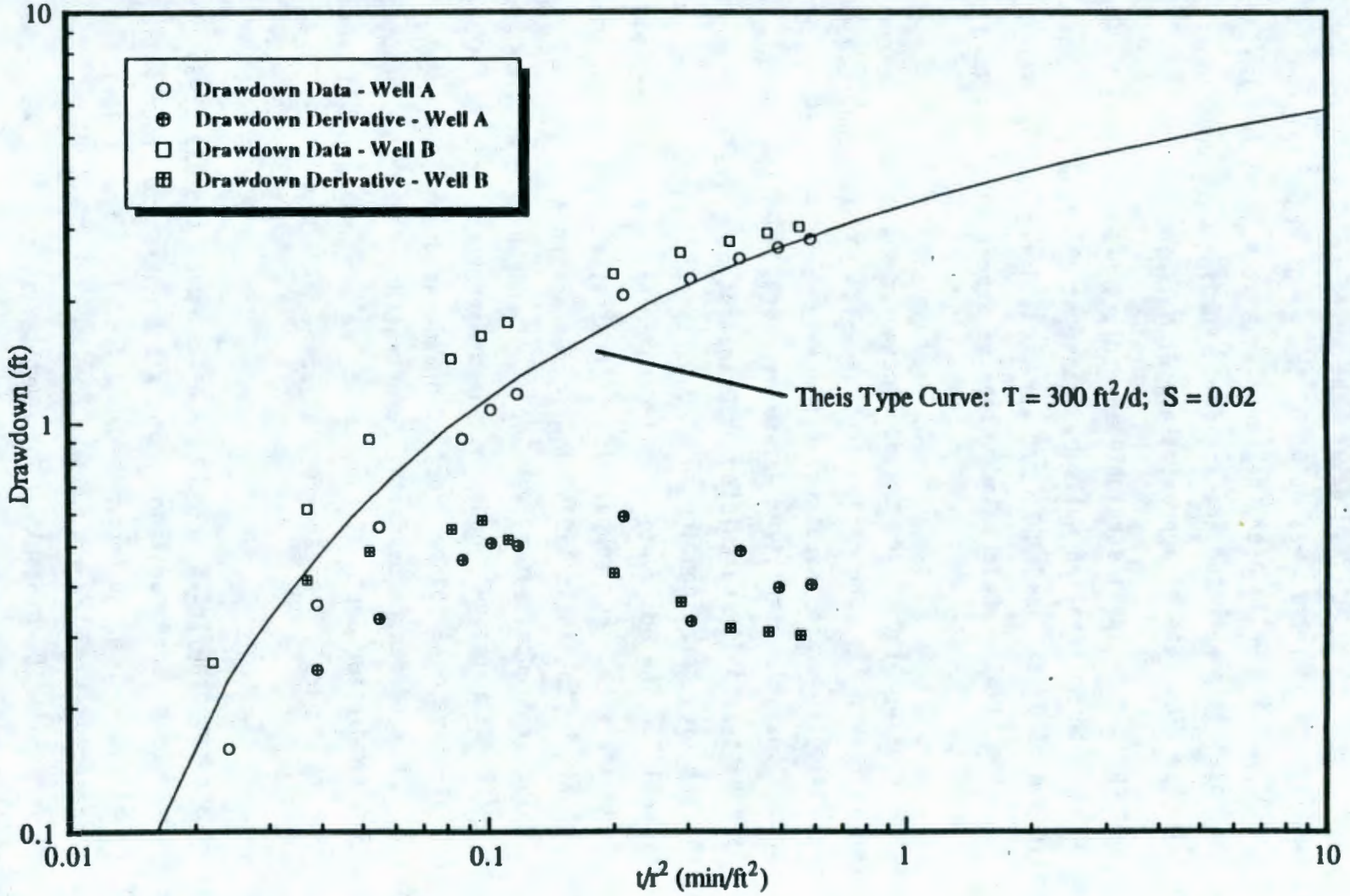


FIGURE 27. Composite Log-Log Diagnostic Plot and Theis Curve Match of the Drawdown Data for Wells 699-42-40A and 699-42-40B

of 25 ft, well C at a radial distance of 61.4 ft, and well D at a radial distance of 157 ft. At the time of the test, the pumping well and observation wells A and D completely penetrated the aquifer. The bottom of the aquifer was at 85 ft and the static depth to water prior to the test ranged from 45 to 47 ft. Therefore, the aquifer thickness was about 40 ft. The open depth interval for observation well C was 35 to 59 ft.

Pumping began at 9:00 a.m. on October 1, 1956 and continued for 48 h. The flow rate during pumping averaged 697 gal/min. Although the pump was off for a short period at about 8 h into the test, the flow rate varied by less than 5% over the remainder of the pumping period. Recovery data were recorded for 48 h after stopping the pump.

The original analyses (Bierschenk 1957) matched the composite recovery data from the observation wells with the Theis type curve. The early-time data deviated from the curve, as expected, because of the effects of delayed yield. The resulting transmissivity was 400,000 $ft^2/d$ and storativity was 0.20. Straight-line semilog analyses of the late-time recovery data from wells A, C, and D were also conducted and yielded transmissivity values between 400,000 and 414,000 $ft^2/d$. The storativity values determined by this method ranged from 0.19 to 0.21.

The results of Bierschenk's (1957) analyses for the different observation wells agree very well for this test. To check the validity of the assumption of radial infinite-acting flow, a composite diagnostic plot (Figure 28) of the observation well responses and the derivative was prepared. The response predicted by the Theis equation for transmissivity of 400,000 $ft^2/d$ and storativity of 0.2 is also shown on the plot. The derivative of well A shows a stabilization after time corresponding to $t/r^2 = 0.03$, and a depressed derivative at earlier time corresponding to the transition from elastic aquifer response to delayed yield. The recovery data from well C falls below that of well A and the two responses appear to be converging. This may reflect the partial penetration of well C. The derivative for well C also shows the delayed-yield effect. The results of the original analysis are believed to be valid.

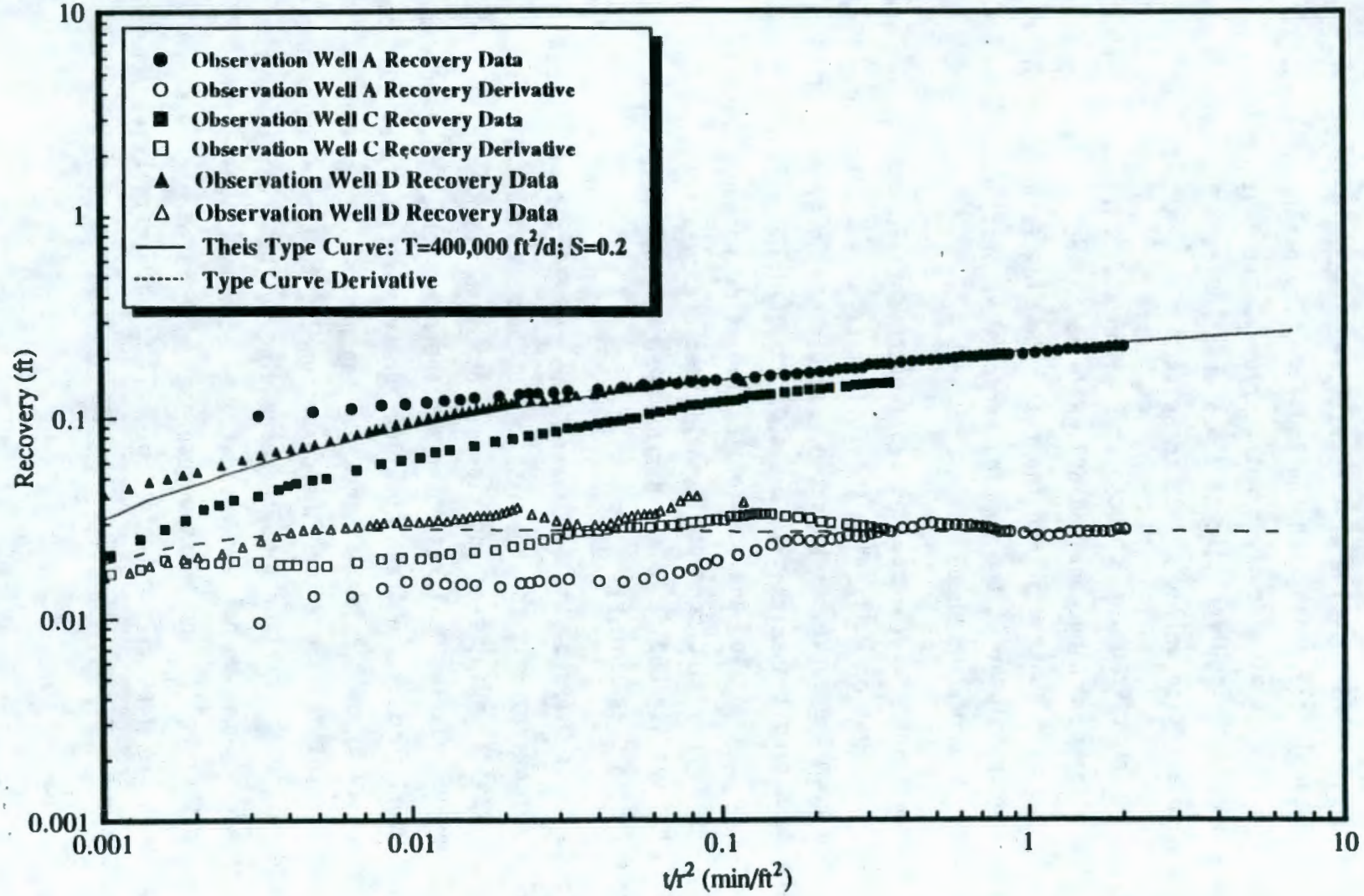


FIGURE 28. Composite Log-Log Diagnostic Plot and Theis Curve Match of the Observation Well Drawdown Data at the 699-55-50 Cluster Site

Reanalysis Summary

Results of the pumping test reanalyses are summarized in Table 3. The reanalysis result agrees with the original analysis result for half of the tests examined. Reanalysis indicated that only limiting values of transmissivity could be determined for wells 699-33-56 and 699-35-9. The revised transmissivity estimate for well 699-31-53B is 50 to 25% lower than the original result. Results from one of the wells (699-28-40) did not represent the aquifer.

Different tests vary in many respects including the original purpose of the tests, accuracy and precision of the test equipment, test duration, well

TABLE 3. Results of Aquifer Test Reanalyses

| WELL (699) | ORIGINAL ANALYSIS T ($ft^2/d$) | ORIGINAL ANALYSIS S | REANALYSIS T ($ft^2/d$) | REANALYSIS S | COMMENTS |
|---|---|---|---|---|---|
| -17-47 | 5,300 (D) | - | 5,100 | - | |
| -26-15 | 8,880 (D) | - | 9,000 | - | |
| -28-40 | 5 (D) | - | - | - | Data not representative of the aquifer |
| -31-53B | 21,000 (D) | - | 10,000-15,000 | - | Result for pumping well |
| -33-56 | 20,700 (B) | - | > 5,000 | - | Minimum limiting value |
| -35-9 | 2,250 (D) | - | < 12,400 | - | Maximum limiting value |
| -42-40C | 310 (G)<br>360 | .009017 | 300 | .02 | Observation well |
| -55-50 | 400,000 (B) | .20 | 400,000 | .20 | Observation well |

(D) = Deju (1974).

(B) = Bierschenk (1957).

(G) = Graham et al. (1981).

completion, frequency of data recording, presence of boundaries, and perhaps most importantly, the magnitude of the transmissivity of the interval tested. High transmissivity intervals on the Hanford Site must be pumped at several hundred gallons per minute to create analyzable drawdown. Low transmissivity intervals must generally be pumped for a longer period for semilog analysis methods to be valid. This is especially true for unconfined aquifer tests where the transition from elastic aquifer response to delayed yield affects the results. Dewatering of the unconfined aquifer section being tested may also introduce uncertainty or even invalidate the results.

The most frequent mistake in analyzing pumping tests was the misapplication of semilog straight-line methods. Semilog methods may only be properly applied where infinite-acting radial flow has been established and where the test time is great enough for the semilog approximation to be valid. One common mistake was to apply the straight-line technique to data that are affected by transition to delayed-yield response. This generally results in a high transmissivity estimate because the flattened part of the drawdown curve is being analyzed. Many Hanford Site wells partially penetrate the aquifer. Partial penetration at the pumping well may cause a deviation from the unexpected response depending on 1) the completion depth of observation wells, 2) distance to the observation well, and 3) the vertical anisotropy of the aquifer. For single-well tests, the drawdown will be less than that expected for a fully penetrating well. However, the slope of the semilog straight line will approach that of a full penetrating well for "long" pumping times. Use of log-log diagnostic plots including the derivative of the water-level change are useful in identifying the correct data for straight-line analysis.

Because of the differences in individual tests, it is difficult to come to any general conclusion regarding the reliability of available hydraulic property measurements for the Hanford Site. The majority of reported test results are considered to provide correct estimates of test interval hydraulic properties, but each test is affected by an uncertainty that is usually unreported and difficult to quantify. Uncertainty is also introduced when an attempt is made to generalize an individual test result to a larger area of the aquifer. A large data set is required to statistically represent the unconfined aquifer at Hanford because of the heterogeneity of the flow system.

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