DETERMINATION OF FRACTURED AQUIFER CHARACTERISTICS FROM EVALUATION OF PUMP TESTS OF WELLS IN THE CRYSTALLINE ROCKS OF THE BLUE RIDGE ALLOCTHON

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(ABSTRACT)

The Precambrian age rocks of the Blue Ridge thrust sheet near Roanoke, Virginia, comprise an igneous and metamorphic assemblage with the predominance of porosity and permeability of the formations attributed to secondary factors. Aquifer characteristics of transmissivity, storage coefficient, hydraulic conductivity and fracture permeability are determined from evaluation of pump tests conducted on ground water supply wells developed in this fractured aquifer.

Evaluation of pump test data indicates that aquifer response is similar to a double porosity medium in some instances. Comparison of pump tests at locations close to, and further removed from, the leading edge of the Blue Ridge Thrust Fault indicate little variability in fracture permeability. The data suggest that deep circulation of ground water in the Blue Ridge allocthon may be more likely than previously thought.

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INTRODUCTION

The majority of ground water storage and movement in consolidated aquifers occurs in features with secondary porosity and permeability, such as joints, bedding and cleavage planes, fault breccia zones, fractures and solution cavities. The extent to which a crystalline rock aquifer will store and transmit ground water is greatly influenced by the nature and characteristics of the features which provide porosity and permeability. Fracture length, width, spacing, orientation and interconnection will affect the hydrologic characteristics of the rock mass as a whole, while individual well yields will reflect the number and extent of the fractures that the wellbore intersects.

The Precambrian age rocks of the Blue Ridge thrust sheet near Roanoke, Virginia, comprise an igneous and metamorphic assemblage with the predominance of the porosity and permeability of the formation attributed to secondary factors. That these units can serve as a reliable aquifer is due to the extensive fracture system developed in the Blue Ridge thrust sheet. Pumping tests conducted on water supply wells provides information on the characteristics of the aquifer system which, in turn, can provide data on the potential effects of circulating ground water in more extensive studies regarding regional geological phenomena. The extent to which circulating ground water will influence geologic phenomena in crystalline rocks is greatly dependent upon secondary (fracture), instead of primary (intergranular), porosity and permeability.

In the past fifteen years, the author has successfully used fracture trace analysis to determine water well locations for domestic, industrial and public water supply systems. This experience has demonstrated that both the quantity and reliability of water well supplies is dependent upon the borehole intersecting fractures within the bedrock. Other researchers (Parizek, 1976; Siddiqui and Parizek, 1971) have also demonstrated the correlation between well yield and fracture trace/lineament positions and intersections.

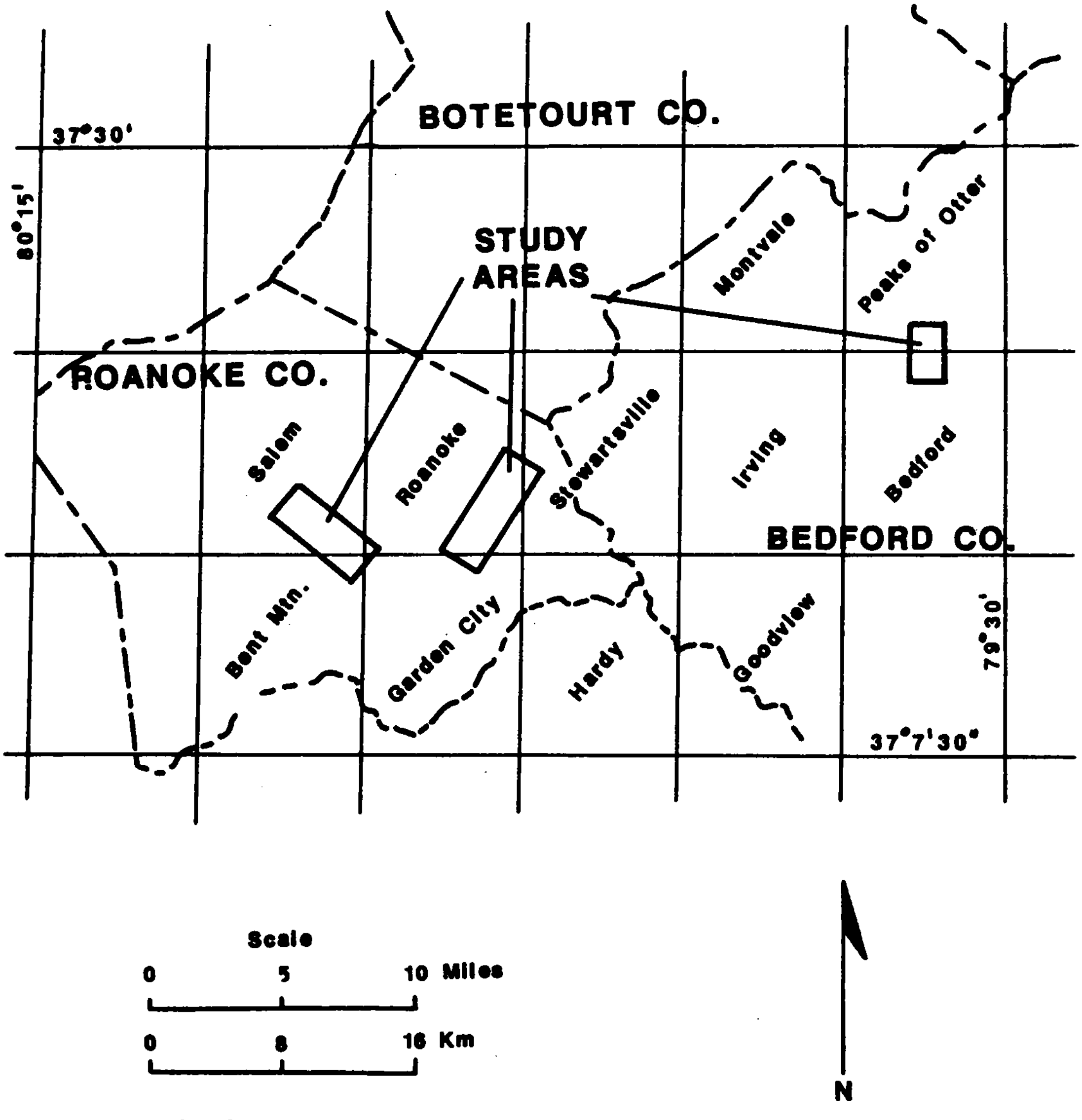
The purpose of this investigation is to determine crystalline rock aquifer characteristics, such as transmissivity, storage coefficient, hydraulic conductivity and fracture permeability, from evaluation of pump tests conducted on ground water supply wells and to identify the fracture system(s) associated with these wells. Identification of the nature (ie., confined versus unconfined) of the fractured aquifer in the study area is possible through review of the drilling logs for the wells and evaluation of production well pump test data. The surficial expression of fracture systems in the vicinity of the wells evaluated in this study were mapped by interpretation of LANDSAT photography, aerial photographs and topographic quadrangle maps. Data on the subsurface orientation of the fracture traces (eg., well temperature logs, seismic surveys, rock cores, etc.), other than that provided by the drillers' logs, were not available.

The equations that describe transient ground water flow in both porous and fractured media are applied in the evaluation of the pump test data. Further, the hydrogeologic setting and the pump test procedure must be considered as part of the evaluation to assess the applicability of the evaluation results to the thrust sheet as a whole.

STUDY AREAS

Pump tests from public water supply wells in two different areas were evaluated as part of this study. The area with the greatest number of pump tests includes a zone approximately 3 miles wide and 26 miles in length along the trace of the Blue Ridge Thrust Fault in Roanoke County, Virginia. Another area which provided pump test data is the site of the City of Bedford Well Field located near Kelso Mills in Bedford County. These areas were selected for evaluation because of extensive ground water development in crystalline rocks to meet the needs of public water supply systems and the availability of pump test data. All or part of these areas have been subjected to detailed geologic mapping and hydrogeologic evaluations conducted by several investigators from Virginia Polytechnic Institute and State University, the Virginia Division of Mineral Resources, the Virginia State Water Control Board and private individuals or firms. The limits of the study areas, an index of the U.S.G.S. Topographic Quadrangle maps and previous investigations in the vicinity of these areas are shown in Figure 1.

The pump tests required by the Virginia Department of Health to demonstrate the reliability of public water supply wells were evaluated to determine the characteristics of the fractured aquifer in the Roanoke area. Additionally, the results of an aquifer test from the City of Bedford Well Field in the Kelso Mills area of Bedford County, Virginia (approximately 25 miles east of the primary study area) are also included in the evaluation to provide further



Previous Investigations:

Roanoke County--Amato, 1968, 1974; Bartholomew, 1982; Breeding and Dawson, 1976; Hazlett, 1976; Waller, 1976.

Bedford County--Hamilton, 1964.

Figure 1

Study Areas Location Map and Previous Investigations information on the hydrogeological characteristics of these fractured rocks. The pump tests in the Roanoke area provide information on aquifer characteristics near the edge of the Blue Ridge master decollement, while the City of Bedford Well Field aquifer test provides hydrogeological information from within the thrust sheet itself. The depth of the wells evaluated vary from approximately 200 feet to over 700 feet and therefore, the data obtained is more applicable to shallower portions of the thrust sheet. However, conclusions concerning the applicability of these data to the entire thickness of the thrust sheet as a whole are possible by comparison of the study areas to similar terranes studied by other researchers.

GROUND WATER FLOW EQUATIONS

The general equation describing ground water flow was developed by Henry Darcy in 1856 from observations made during experiments with water flow through sand filters. This is an empirical equation, based on experimental data, and has the general form of (Freeze & Cherry, 1979):

$$Q = -KiA \qquad (1)$$

where,

Q = volumetric flow rate $[L^3/T]$
K = hydraulic conductivity $[L/T]$
i = hydraulic gradient [dimensionless]
A = cross sectional area $[L^2]$

Equation (1) describes ground water flow under steady state conditions in a porous media. The minus sign in equation (1) indicates that flow is in the direction of decreasing hydraulic gradient. Equation (1) is essential in ground water budget analyses, but cannot be applied directly to the evaluation of well pump tests that typically require evaluation of transient ground water flow conditions. The equations describing transient conditions were developed from analogous equations describing heat conduction in solids.

Transient Flow without Vertical Movement

The equation describing transient flow in an aquifer in response to a pumping well was first introduced by C. V. Theis, with the assistance of C. I. Lubin, in 1935 (Lohman, 1972). The decline in head in response to pumping (drawdown, (s)) is of the form:

$$s = \frac{Q}{4\pi T}\int_{r^2S/4Tt}^{\infty}\left(\frac{e^{-u}}{u}\right)du \qquad [L] \qquad (2)$$

where,

s = drawdown [L]
Q = constant discharge rate from well [L^3/T]
T = Transmissivity [L^2/T]
r = distance between pumping and observation wells [L]
S = storage coefficient [dimensionless]
t = time since discharge began [T], and
u = variable of integration

Solution of equation (2) involves several assumptions for an ideal aquifer which generally are not met for real aquifers. These assumptions, as stated by Theis (1935), are: (1) the aquifer is homogeneous and isotropic; (2) the water body has infinite areal extent (ie., its boundaries are beyond the effects of the pumping well in the time considered); (3) the discharging well penetrates the entire thickness of the aquifer; (4) the well is of infinitesimal diameter (of no real significance after a few minutes); and, (5) the water removed from storage is instantaneously discharged with a decline in head.

Equation (1) cannot be integrated directly, but its value can be approximated by the following infinite series:

$$s = \frac{Q}{4\pi T}\left[-0.577216 - \ln u + u - \frac{u^2}{2\cdot 2!} + \frac{u^3}{3\cdot 3!} - \ldots\right] \quad [L] \qquad (3)$$

where,

$$u = \frac{r^2 S}{4Tt} \quad [\text{dimensionless}] \qquad (4)$$

From inspection, it is evident that u is the variable of integration in the Theis equation presented previously. The value of the series presented above (ie., equation 2) is usually expressed as W(u), stated as "the well function of u." Values of W(u) and u have been tabulated by different workers (see Ferris, Knowles, Brown, and Stallman, 1962), and for known values of u and W(u), the value of transmissivity (T) of the aquifer may be determined from:

$$T = \frac{Q}{4\pi s} W(u) \qquad [L^2/T] \tag{5}$$

and the storage coefficient (S) may be determined from:

$$S = \frac{4Ttu}{r^2} \tag{6}$$

The curve matching technique of solving these equations developed by C. V. Theis (Wenzel, 1942) incorporates plotting of selected values of W(u) and u on logarithmic graph paper and overlaying this type curve on a plot of s versus r^2/t from the observation well which are also on logarithmic graph paper. Match point values of W(u), u, s and r^2/t are determined from the best fit match of the plots and the above equations are solved using these match point values. This method provides a relatively simple and quick solution for determination of aquifer characteristics, but is not always amenable to solution with the data available from production well pump test drawdown values.

Transient Flow with Vertical Movement

The curve matching technique developed by Theis was applicable for an ideal aquifer which met the confines delineated in the qualifying assumptions stated above. These assumptions do not allow for water to be derived from the confining beds overlying the aquifer and consequently, a leaky confined aquifer cannot be evaluated with strictly the Theis equation. Hantush (1960) made an important modification to the Theis method which accounts for water taken from storage in overlying semipervious confining beds. These equations are:

$$T = \frac{Q}{4\pi s} H(u,B) \qquad [L^2/T] \qquad (7)$$

where,

$$H(u,B) = \int_u^\infty \frac{e^{-y}}{y} \operatorname{erfc}\left(\frac{B/\sqrt{u}}{\sqrt{y(y-u)}}\right) dy \qquad [\text{dimensionless}] \qquad (8)$$

$u = \frac{r^2S}{4Tt}$ [dimensionless] as in the Theis equation, and

$$B = \frac{r}{4b}\left(\sqrt{\frac{K'Ss'}{KSs}} + \sqrt{\frac{K''Ss''}{KSs}}\right) \qquad [\text{dimensionless}] \qquad (9)$$

where,

K = hydraulic conductivity of the main aquifer,

K', K" = hydraulic conductivities of the semipervious confining beds,
S = bSs Storage coefficients of the main aquifer
S'= b'Ss' and of the semipervious confining beds,
S"= b"Ss" respectively; and,
Ss, Ss', Ss" = specific storage of the main aquifer and the different confining beds (b, b',b")

The significance of equations (7), (8), and (9) lies in the fact that they address the solutions for the drawdown distributions for all confined aquifers, whether they are leaky or not. As can be seen from inspection, as the hydraulic conductivities of the confining beds approach zero, or are zero (ie., a perfect confined aquifer), B becomes zero, and equation (7) becomes that of Theis (equation (5)). Therefore, use of the Theis curve matching technique with plots of H(u,B) versus 1/u and different values of B, will allow evaluation of confined aquifers, whether or not water is derived from the confining beds. Consequently, evaluation of well pump tests, where drawdown in an observation well at some distance (r) from the pumping well has been recorded, will not only permit calculation of transmissivity and storage coefficient, but will also provide insight as to the degree of "leakage" from the confining beds.

Straight Line Solutions

Cooper and Jacob (1946) showed that if the value of u is less than or equal to about 0.01, then all but the first two terms in equation (3) above may be neglected. Consequently, if data plots of s versus log t, or s versus log 1/r2, or s versus log t/r2 are made on semilogarithmic paper, solutions for transmissivity and storage coefficient may be determined as follows:

$$T = \frac{2.3Q}{4\pi\Delta s/\Delta \log t} \quad [L^2/T] \qquad (10)$$

and,

$$S = 2.25\, T\left(\frac{t}{r^2}\right)_o \quad [\text{dimensionless}] \qquad (11)$$

where,

T = Transmissivity $[L^2/T]$
Q = discharge rate from pumping well $[L^3/T]$
$\Delta s/\Delta \log t$ = drawdown over one log cycle of time $[L]$
r = distance from pumping well to observation point $[L]$
$\left(\frac{t}{r^2}\right)_o$ = zero drawdown intercept

It should be noted that when plots of s versus log $1/r^2$, or s versus log t/r^2 are employed, modifications to equations (10) and (11) are necessary. Lohman (1972) provides a detailed discussion on the use of time-drawdown and distance-drawdown plots for determination of aquifer characteristics.

As discussed by Lohman (1972), considerable judgement must be exercised when this straight-line evaluation method is used. As review of equation (4) indicates, if r, S and T are constants, and $u \leq 0.01$, then only the data points used for determination of T and S which are collected after time (t) which fulfills this requirement are valid. Consequently, the data points collected during the later stages of a pump test will provide the information necessary for more accurate determination of aquifer characteristics. Also, it should be noted that for drawdown data from production wells only, it is not possible to determine the storage coefficient, since the effective radius of the production well, and drawdown due to well losses, are not generally known (Walton, 1987).

The use of the straight-line method developed by Cooper and Jacob (1946) for evaluation of pumping wells must be recognized as providing an *estimate* of aquifer transmissivity, to the extent that the real aquifer approaches the assumptions stated by Theis, that the duration of the pump test is sufficiently long to negate the effects of well losses and that the accuracy of the data collected reflects the actual drawdown in the discharging well. However, the assumptions utilized by Theis, as stated previously, are not usually met for real aquifers and consequently, modifications to the governing equations are necessary to provide a more accurate determination of aquifer characteristics. This is especially true for the evaluation of fractured aquifers.

Fractured Aquifers

Over the past twenty years considerable interest has been directed towards evaluation of fractured reservoirs or fractured aquifers. Much of this interest has been the result of efforts to maximize production from fractured petroleum reservoirs, although the equations governing fluid flow are applicable to both petroleum and water, provided that the effects of viscosity, compressibility and pressure are taken into account. As discussed by Streltsova-Adams (1978), two distinct fractured aquifer or fractured reservoir systems can be present: (1) a formation with two coexisting porosities and permeabilities (double porosity medium); and, (2) a formation in which both fluid storage and permeability are fracture controlled (purely fractured medium).

Double Porosity Medium: The double porosity medium model, in which the blocks of the rock mass have a relatively high porosity, but low permeability and the fractures in the formation exhibit relatively low porosity, but high permeability, has been used to explain the drawdown response of a fractured aquifer as a reequalization of pressure differentials between the blocks and fissures, with flow from the blocks to the fissures (Strelstova-Adams, 1978; Pollard, 1959). For the purely fractured medium model, in which both porosity and permeability are derived from the fractures in the rock mass, the drawdown response will be similar to that of a homogeneous medium, provided that the fractures are numerous enough and randomly distributed. As the degree of fracturing increases and the blocks of the rock mass become smaller and smaller, the aquifer becomes increasingly similar to that of a homogeneous porous medium (Parsons, 1966).

The generalized differential equations for fluid flow in a double porosity medium is analogous to heat conduction in a two component heterogeneous medium, as described by Rubinstein (1948), and is as follows:

$$k_1 \Delta s_1 = Ss_1 \frac{\partial s_1}{\partial t} + \alpha (s_1 - s_2) \qquad (12)$$

and,

$$k_2 \Delta s_2 = Ss_2 \frac{\partial s_2}{\partial t} + \alpha (s_2 - s_1) \qquad (13)$$

where,

k_1, k_2 - permeabilities of the fissures and porous blocks, respectively [L/T]
s_1, s_2 - drawdown response in the fissures and porous blocks, respectively [L/T]
Ss_1, Ss_2 - storage coefficient in the fissures and porous blocks, respectively [dimensioness]
t - time [T]
Δ - the Laplace operator
α - characteristic of fractual rock [dimensioness]

As discussed by Streltsova-Adams (1978), the first term on the right hand side of equation (12) expresses the change in volume of fluid due to compressibility of the fissures and can be disregarded to due to the low porosity of the fissures. The left hand side of equation (13) is the volume change of the fluid due to flow passing through the sides of the blocks and may also be disregarded as being small (due to the low permeability of the block) when compared to the volume change due to expansion of the fluid. With these simplifying assumptions, equations (12) and (13) may be reduced to the following:

$$k_1 \Delta s_1 = \alpha(s_1 - s_2) \qquad (14)$$

and,

$$Ss_2 \frac{\partial s_2}{\partial t} = \alpha(s_1 - s_2) \qquad (15)$$

By eliminating s_2 (drawdown in the porous block) from the above equations, the equation for fluid flow in the fissure is:

$$k_1 \Delta s_1 = Ss_2 \frac{\partial s_1}{\partial t} - n_1 \; Ss_2 \frac{\partial s_1}{\partial t} \qquad (16)$$

where,

$$n_1 = k_1/\alpha.$$

The above equations have been utilized by Boulton and Streltsova (1975; 1977a; 1977b) to develop type curves for drawdown functions for different values of n_1 and S. Some of these type curves are presented in Appendix II. A more detailed discussion of the derivation of these type curves can be found in the forgoing references.

Purely Fractured Medium: For a fractured reservoir, fluid flow in a single fracture is assumed to be equal to the flow between two parallel smooth plates and can be described as follows (Parsons, 1966):

$$v = \frac{W^2}{12u} \frac{dp}{dL} \qquad (17)$$

and,

$$q - \frac{hW^3}{12u} \frac{dp}{dL} \quad (18)$$

where,

v - average velocity in the fracture [L/T]
W - fracture width [L]
u - viscosity
q - volumetric flow rate [L^3/T]
$\frac{dp}{dL}$ - pressure gradient

For a highly fractured aquifer, or portion of an aquifer, the response to pumping can be considered to be that of a homogeneous, anisotropic porous medium, while pumping from an isolated fracture can be evaluated by equations (17) and (18) (Parsons, 1966). However, the use of equations (17) and (18) is limited, unless data is available on the fracture widths, either by direct inspection (eg., outcrops or rock cores), geophysical borehole logs, downhole television or some other means whereby widths for the fracture(s) can be determined.

The characteristics of a fractured aquifer will approach those of an equivalent homogeneous porous medium as the degree of fracturing intensifies, so long as both the porosity and permeability of the formation are fracture controlled, and the fracture system is continuous and interconnected at a given scale (Nelson, 1985). In this hydrogeologic setting, the use of the Theis curve matching technique becomes increasingly appropriate and will provide accurate determinations of transmissivity and storage coefficient. If the fracture systems have a regular spacing, with the same orientation and width, then the equivalent aquifer would be a homogeneous, anisotropic porous medium (Parsons, 1966).

Evaluation of a two dimensional, homogeneous, anisotropic medium assumes that there are two axes, at right angles to one another, which are the maximum and minimum permeability axes. Fluid flow, in the direction of the pressure gradient, is a combination of the flow along these maximum and minimum permeability axes (usually assigned to the x and y axes, respectively). The flow along each axis is described by the following equations (Parsons, 1966):

$$v_x = -\frac{k_x \partial p}{u \partial x} \qquad [L/T] \qquad (19)$$

and,

$$v_y = -\frac{k_y \partial p}{u \partial y} \qquad [L/T] \qquad (20)$$

where,

v_x = velocity in the x direction [L/T]
v_y = velocity in the y direction [L/T]
k_x = permeability in the x direction [L/T]
k_y = permeability in the y direction [L/T]
u = fluid viscosity
$\frac{\partial p}{\partial x}$ = pressure change in the x direction
$\frac{\partial p}{\partial y}$ = pressure change in the y direction

Use of equations (19) and (20) to determine the anisotropic flow characteristics of a fractured aquifer is generally more realistic, since information on specific fracture widths and orientations is not available and thus, use of equations (17) and (18) is not feasible. However, to use equations (19) and (20), drawdown information from at least two different observation wells (preferably at right angles to one another) is desirable, although not mandatory. In a homogeneous, anisotropic aquifer, use of maximum and minimum permeability axes leads to the development of the hydraulic conductivity ellipse for evaluation of pumping tests.

HYDROGEOLOGIC FRAMEWORK

The hydrogeology of an area encompasses such factors as the lithology of the formations present, geologic structure, climate and surface hydrology. The hydrogeologic factors considered in this investigation were the generalized geology of the study areas, and the relative locations of the Blue Ridge Thrust Fault, fracture traces/lineaments and water wells. To assess the applicability of the aquifer characteristics determined from the pump test evaluations, an understanding of the fracture systems and the geology of the study areas is necessary.

Fracture Systems

The predominance of ground water occurrence and flow in the crystalline rocks of the Blue Ridge Allocthon near Roanoke, Virginia is along features with secondary porosity and permeability (Breeding and Dawson, 1976). The term secondary refers to features which developed in the rock fabric after initial formation or placement of the rock mass. The features which provide this secondary porosity and permeability are predominantly the fractures and joints in the bedrock, although other features such as cleavage or bedding planes will also contribute porosity and permeability to the formation.

The scales of fracturing in a rock mass have been identified as (1) submicroscopic, (2) microscopic and (3) macroscopic which involve, respectively: (1) rupture of the cohesive forces as the basic structural units of the rock undergo relative displacement; (2)

fractures present at the level of constituent grains and grain boundaries (includes rock type, texture, fabric and stress inhomogeneities); and, (3) fractures visible to the unaided eye, as in rock cores, outcrop, topographic features and aerial photographs (Friedman, 1975). Of primary interest in this study is the macroscopic fracturing of the bedrock in the Blue Ridge Allocthon in the study area.

Fracture systems in large rock masses are a worldwide occurrence and act as reservoirs and conductors of fluid resources, whether the fluid is ground water, petroleum or gas (Streltsova-Adams, 1978). Fracture systems identified in large rock masses have been generally subdivided by Stearns and Friedman (1972) and Friedman (1975) into three major classes: (1) regional orthogonal fractures; (2) fractures associated with folding and faulting; and, (3) fractures associated with desiccation, temperature changes and mass wasting. No satisfactory explanation for the development of regional orthogonal fracture systems has emerged, but several empirical observations can be made (Stearns and Friedman, 1972): (1) these fractures are continuous over long distances (ie., up to several miles) as a narrow band or single break as can be seen on aerial photographs or satellite images; (2) vertical continuity is dependent upon the nature of the rock mass in which they are developed; (3) vertical development is not generally terminated within a bed, but occurs at lithological changes where the stress transmission characteristics of the units change (eg., vertical continuity through sandstone or interbedded sandstone and shale beds, with termination at the contact with a significant shale unit); and, (4) the orientations of the regional orthogonal fracture systems are extremely consistent.

Fractures associated with folding and faulting are genetically and geometrically related to those features (Friedman, 1975). Fractures associated with faulting are usually produced by the same stress state that caused the fault, while fractures associated with folds do not exhibit this relationship since several different stress states can be developed during the folding history of a particular volume of rock (Stearns and Friedman, 1972). While mapping of fracture systems associated with faults has been performed, generalizations concerning the zone width of genetically fault-related fractures and fracture density distributions have not been possible (Friedman, 1975). Stearns (1973) concluded that the fracture zone width is greatest adjacent to wrench faults, as opposed to thrust and normal faults, but that the width is also related to rock type and orientation of the rock unit's planar anisotrop relative to the fault plane.

Fractures associated with desiccation, temperature changes and mass wasting are generally smaller in size and extent and will reflect diverse and inconsistent orientations. Development of these fractures is more dependent upon late stage physical and chemical factors which have affected the rock mass, instead of the regional characteristics and structural history of the area.

Fracture systems in the study area were identified utilizing LANDSAT photography, aerial photographs and interpretation of topographic features on 7.5 minute U.S.G.S.Topographic Quadrangles. Fracture trace maps in the vicinity of the public water supply wells evaluated in this are presented in Appendix I. It should be noted that linear features which are mapped as fractures traces will also include linearity caused by bedding or cleavage planes, gneissosity, joints, faults, and differential weathering, as well as fracturing of the bedrock (Lattman and Matzke, 1961). These maps indicate pertinent geologic contacts, the trace of the Blue Ridge Thrust Fault, well locations and fracture traces. Topographic features, such as straight valleys or stream segments, saddles in ridges and other consistent physical features that are linear in nature were mapped as fracture traces, in accordance with methods described by Lattman (1958).

Since fracture traces and lineaments are recognizable for distances of up to several miles as straight lines without appreciable changes in direction, these fractures must be vertical or nearly vertical in their orientation (Trainer and Ellison, 1967). As with other geologic phenomena which possess a physical orientation, the surface expression of a fracture will become more discontinuous as the dip of the fracture becomes more horizontal. Consequently, alignment of shorter fracture trace segments may be indicative of shear zones which have been interrupted by erosion. These shear zones may only be identifiable from review of drilling logs and may not have a surface manifestation which is recognizable from topographic features. This situation appears to be present for some of the more productive wells evaluated in this study, because the number of water production zones identified on the driller's logs for the wells are greater than the number of fracture traces identified from aerial photograph and topographic map interpretation. However, as discussed by Lattman and Matzke (1961), fracture traces and lineaments may also represent zones of joint concentration. Consequently, the different production zones identified on the drillers' logs may be different joints that are associated with one common fracture trace or lineament.

Where possible, regional orthogonal fractures identified on the LANDSAT photograph that fall within the area of interest have been indicated on the maps presented in Appendix I. These fractures, which exhibit a consistent orientation for tens of miles, are actually lineaments and may help establish master drainage basins (Gold, Parizek, and Alexander, 1973). For clarification, fracture traces are considered to be less than one mile in length, while lineaments are greater than one mile in length (Lattman, 1958).

Geology of the Primary Study Area

The primary study area is transected in a northeast to southwest direction by the Blue Ridge Thrust Fault which is a low angle (ie., less than 20°, Woodward, 1932) reverse fault, with Precambrian age metamorphic rocks, identified as the Blue Ridge Complex, thrust over Cambrian age carbonates and clastics of the Shady Dolomite and

Rome Formation, respectively. Geologic investigations of the eastern United States indicate that the Blue Ridge Mountains are allocthonous and form an anticlinorium.

In the eastern part of the study area, Blue Ridge Complex rocks (ie., cataclasite, massive granulite gneiss, porphyroblastic granulite gneiss and layered granulite gneiss) are in fault contact with the shales of the Rome formation (Bartholomew, 1981). In the southern portion of the study area, the Blue Ridge Complex rocks are in fault contact with the clastics of the Cambrian age Chilhowie group and the carbonates of the Cambrian age Shady dolomite (Woodward, 1932). However, west of Twelve O'clock Knob in Salem, Virginia, the Blue Ridge Thrust Sheet is represented by the Poor Mountain Fault along which the clastics of the Lower Cambrian Unicoi Formation have been thrust over the Cambrian age Rome formation, and the Fries Fault which marks the contact between the Chilhowie clastics and the Blue Ridge Complex rocks (Amato, 1968; 1974).

The Blue Ridge Thrust Fault

The sinuous trace of the Poor Mountain Fault west of Salem, Virginia, indicates that it has a relatively low angle of five (5) to ten (10) degrees southeastward (Amato, 1974). In the eastern portion of the study area, the trace is less sinuous, thereby suggesting a steeper dip of the fault plane. Several wells which are incorporated in this study provide some information on the dip of the fault plane. Specifically, the location of the Craig Avenue #2 well in the Town of Vinton, Virginia, was determined so that the well would intersect the fault. This well is located approximately 450 feet east of the mapped trace of the fault, at about the same elevation, and is 412 feet deep. The fact that this well does not encounter the fault may indicate that the dip of the fault plane at that location is greater than 42 degrees. However, another structural control (eg., a strike normal fault with downthrow to the east) could also be responsible for the well not intersecting the fault. Two other wells do intersect the fault plane and the depths of intersection, in conjunction with the relative elevations of these wells and the fault trace, indicate a dip of the fault plane of 11 degrees (Hidden Valley No. 9) and 8 degrees (Garden City). The relative positions of the trace of the Blue Ridge Thrust Fault, fracture traces/lineaments and production wells are indicated on the fracture trace maps presented in Appendix I.

Geology of the Secondary Study Area

The City of Bedford Well Field, located in the Kelso Mills area of Bedford County, is developed in the Marshall Gneiss which is described as a quartz-feldspar gneiss and bitotite-bearing feldspathic gneiss and schist (Hamilton, 1964). The nearest mapped fault to the well field is the Peaks of Otter Fault which is a high angle reverse fault, located over 4.5 miles to the northwest of the well field. Consequently, the ground water in the vicinity of the well field will be contained in the joints, cleavage and gneissity planes and fractures present in the Marshall Formation.

Hamilton (1964) mapped joint patterns in the Marshall Formation and determined that two maxima were present with orientations of N78°W, 52°SW and N4°W, 72°NE, with other joint trends of N43°W, 87°SW, N18°E, 80°SE, N27°E, 39°NW, N65°E,75°NW and N68°E, 71°SE. Many of these joint patterns, especially the two maxima, are closely aligned with the fracture trace map of the well field presented in Appendix VI. Therefore, it is apparent that the fractures and joints previously identified contain and transmit ground water extracted by the well field.

PUMP TEST METHOD

The pump tests evaluated as part of this investigation were conducted on public water supply wells developed in the crystalline rocks of the Blue Ridge Allocthon. These tests were intended to be constant discharge tests, of a minimum 48-hour duration, as required by the Virginia Department of Health to demonstrate the reliability of the well. Typically, observation wells were not available and only drawdown measurements in the production well, usually determined by air line pressure gauge readings, were collected. A schematic of this technique is included at the beginning of Appendix III. The major drawback with use of the air line method is that the air line must be charged each time a reading is taken to insure accuracy of the measurement and this may become difficult to achieve in a well with a continuously declining water level since the pressure in the air line will also be declining as does the water level.

The discharge rate during earlier stages of some of the tests varied occasionally as a yield was sought that would to stabilize drawdown in the production well; however, these tests were not designed to be constant drawdown or step pump tests. Pump tests were conducted at a flow rate so that drawdown in the production well would stabilize prior to conclusion of the test. Since the primary reason for the test was to establish well reliability and not to determine aquifer characteristics, many well tests were conducted at production rates that were less than what could probably be derived from the well. For most of the tests, drawdown in the production well did stabilize prior to conclusion of the test.

Rock cores were not available to provide information on the primary porosity and permeability of the formations intersected by the wells evaluated in this study. Therefore, intergranular (primary) porosity and permeability of the rock mass in the study areas was assumed to be minimal or non-existent either because these were absent in the original rock fabric (eg., granites) or had been eliminated due to solution or precipitation phenomena during metamorphisism. Consequently, the fractured aquifer present in the study area was considered to be one in which both the porosity and permeability were fracture controlled. As discussed later, review of the pump test drawdown data indicates aquifer responses which are indicative of both double porosity and homogeneous porous media.

The aquifer is referred to as a fractured aquifer because the majority of the ground water in the study area is present in fractures in the rock mass and well production is affected by the number and extent of fractures intersecting the well bore (Streltsova-Adams, 1978). The ability of this aquifer to store and transmit ground water is dependent upon two physical characteristics of the rock mass: (1) effective porosity, which is the percentage or volume of the rock mass that is available for storage of the ground water; and, (2) permeability of the rock mass, which is the ease with which the ground water is transmitted through the interconnected openings (ie., fractures) in the bedrock.

A total of twenty-two well pump tests were evaluated as part of this investigation, although only seventeen tests provided data that were considered valid for determination of aquifer characteristics. Two of the pump tests were conducted on wells which penetrate the Blue Ridge Thrust Fault itself (ie., Hidden Valley #9 and Garden Park), while the remaining tests were on wells which were developed in one or more fractures. The two wells which penetrated the fault zone were not located at the intersection of fracture traces, nor are fractures or water zones indicated on the drilling logs for these wells prior to intersecting the fault zone. Consequently, the results of these pump tests are felt to be more indicative of the fault zone itself.

Typically, fracture porosity is less than that of an analogous porous media, although fracture permeability can be several orders of magnitude greater than that of a porous rock mass (Streltsova-Adams, 1978). Baker (1955) indicates that fractures with widths of 0.01 inch and 0.05 inch can be equivalent to unfissured formations, with uniform permeabilities of 100 and 1000 millidarcys, of 45.4 feet and 568 feet, respectively. Additionally, as the density of the fracturing increases, the response of the fractured aquifer to pumping more closely approaches that of a porous medium, since the size of the non-porous blocks become smaller and smaller. Also, as fracturing increases and bedrock weathering becomes greater, a weathered zone around the fractures may effectively produce an environment that closely resembles a porous medium since much of the intergranular cement has been decomposed, thereby producing a "secondary" intergranular porosity and permeability.

PUMP TEST EVALUATION

Since the majority of the drawdown information was collected in production wells, the Straight Line Method discussed previously was utilized for evaluation of the pump test data. However, the curve matching technique, utilizing the Hantush Modified Method of evaluation, was used for analyzing the drawdown information in the Craig Avenue #1 well (see Appendix V) and for two of the observation wells incorporated in the City of Bedford Well Field Aquifer Test (see Appendix VI).

Straight Line Method

The pump test results were initially evaluated by the author with a microcomputer program developed by Walton (1987) which uses a least squares method to fit a straight line to a semilogarithmic plot of the drawdown data. After determination of these initial transmissivity values, the drawdown data was manually plotted on semilogarithmic graph paper and a straight line superimposed on the data. In construction of this line, drawdown values from later periods of the pump test were used as much as possible, since drawdown data collected from latter stages of the test will be more likely to satisfy the condition of $u \leq 0.01$, as discussed previously.

Tabulation of the pump test data for the wells evaluated is presented in Appendix III and plots of s versus log t are presented in Appendix IV. Production well information (ie.,well name, well number depth, yield, and water production zones) are summarized in Table 1. It should be noted that all pump test data, with the

TABLE 1

SUMMARY OF WATER WELL CONSTRUCTION INFORMATION, YIELD AND WATER PRODUCING ZONES

WELL NAME	WELL NO.	DEPTH (FT)	DIAMETER (FT)	YIELD (GPM)	WATER PRODUCING ZONES (DEPTH)
Hidden Valley #9	W-16	348	0.67	209	190-240
Garden Park	W-14	479	0.50	91	165-215
Craig Avenue #1	W-17	625	0.67	260	30-35; 320-335
Craig Avenue #2	W-1	412	0.67	405	35-37; 145-165; 365-368
Town of Vinton	W-10	705	0.67	50	42; 60; 188; 402-406; 575-576
Town of Vinton #2	W-4	345	0.50	800	15; 60; 128; 190; 225; 280; 305; 328
Town of Vinton #3	W-3	405	0.50	424	115-116; 215-216
Town of Vinton #5	W-2	360	0.67	1000	85-87; 90-95; 110-111; 127-130; 145-148; 150-151; 308-309; 330-331
Brookwood #1	W-20	325	0.67	18	None identified on log
Brookwood #3	W-19	225	0.67	12	180-190
William Byrd #2	W-18	445	0.67	165	230; 265; 330; 355
William Byrd #3	W-21	485	0.67	143	70-71; 195-196; 455-485
Bridlewood #1	W-9	405	0.67	35	100; 145; 350
Arlington Forest	W-13	236	0.50	42.5	72-90; 160-163
Starky Well #4	W-7	447	0.83	415	120-122; 156; 196; 217; 235
Grisso Well	W-6	500	0.67	223	76; 163; 315
Homewood #2	W-5	385	0.67	94	175; 245; 355
Homewood #3	W-11	420	0.67	170	30; 410-420
Long Ridge #1	W-8	465	0.67	49	140-145; 200-202; 445-450
Long Ridge #2	W-12	605	0.50	54	454-455; 505
Hidden Valley #3	W-15	503	0.67	44	286-287
Bedford #2	W-22	450	0.67	149	315-330; 340-350; 390-400
Bedford #5	W-23	450	0.67	85	55-60; 220-225; 330-333
Bedford #6	W-24	310	0.67	48	165-170; 179-180; 190-195
Bedford #7	W-25	400	0.67	191	29-32; 105-160; 198-240
Bedford #8	W-26	400	0.67	74	32-60; 60-85; 90-163

exception ofdrawdown data collected in the Craig Avenue #1 well during pumping of the Craig Avenue #2 well and some data collected during the testing of the City of Bedford Well Field, are from the production wells only, with water levels being collected either by direct measurement or calculated from pressure gauge readings of an air line installed in the production well prior to the pump test.

Interpretation

The production well drawdown graphs presented in Appendix IV can be grouped into three categories: (1) Type I--plots where the data exhibits different slopes and breaks in slope, with several segments that are flat-lying; (2) Type II--plots where the data points fall onto two or more parallel straight line segments with intermediate, transitional data values between the line segments; and, (3) Type III--plots where the data exhibit a slope that is abruptly terminated in a segment with no slope (ie., flat lying). These graphs represent drawdown in the production well and do not reflect the changes in water level that occur in the aquifer that would be evident from drawdown levels measured in observation wells at some distance from the production well.

For many of the graphs, there are flat segments which reflect no change in drawdown values over considerable lengths of time. As mentioned previously, the primary purpose of those production well tests was to establish the reliability of the well for a specified production rate. Consequently, one purpose of the test was to stabilize drawdown in the production well prior to conclusion of the test and to maintain that pumping rate for an extended period of time. Therefore, the values of aquifer transmissivities determined from these tests are probably lower than those determined from a more rigorous test. However, some of the drawdown graphs presented in Appendix IV are similar to other graphs on fractured reservoirs discussed in the literature (see Sreltsova-Adams, 1978, pp. 363-367 and Appendix II). The relationship between drawdown and the logarithmic value of time (s versus log t) will be a straight line when the condition $u \leq 0.01$ is satisfied. For production wells, the "u test" is satisfied almost immediately, although data from longer time intervals is preferred to overcome problems with well losses.

<u>Type I</u>: These plots are characterized by several flat-lying line segments and breaks in slope of the plotted data. The flat-lying line segments indicate no drawdown in the production well, while the stepwise plots indicate successive increases in the drawdown in the well. This distribution of drawdown values can be the result of improper airline pressurization, errors in the collecting the gauge readings, inadequate precision of the gauge or the observer so that water level fluctuations were not indicated, or indicative of the water level changes in the production well when the cone of depression intersects different boundaries. For example, drawdown in the production well may stabilize until such time that the cone of depression intersects a no flow boundary, at which time drawdown in the production well will resume again. If the drawdown measurements were collected in an observation well, the drawdown slope would be constant

(but not flat) until the no flow boundary was encountered, at which time an increase in slope would occur. The steepness of the slope of the drawdown plot is dependent upon the aquifer characteristics. The slope of the drawdown plot will increase if a no flow boundary is encountered and will lessen if a recharge boundary is intersected by the cone of depression. Some of the plots that exhibit a no slope line segment at the end of the pump test are interpreted to indicate that the cone of depression had not intersected an aquifer boundary prior to termination of the test.

Many of the Type I plots cannot be evaluated, due to the variety of potential problems that may have effected the drawdown values measured in the well. To be considered reliable, a minimum of three data points had to fall on the same line segment. The plots for production wells W-2, W-3, W-9, W-14, W-16 and W-17 are considered to be reliable since the final point on each step of the drawdown plot fall on the same straight line, or a minimum of three data points fall on the same line segment. For the other plots, the data does not exhibit this relationship and thus, are considered suspect.

Type II: These plots are characterized by the drawdown data falling on predominantly two, parallel or approximately parallel line segments and is characteristic of a double porosity medium (Streltsova-Adams, 1978). The two parallel line segments, with transitional data between the segments, represent the drawdown response as one porosity/permeability component initially supplies water to the well, followed by the second porosity/permeability component supplying water to the well, after initial dewatering of the aquifer occurs. The parallel line segments occur because the drawdown response is measuring water levels in the fractures and this response remains the same (ie., parallel line segments) both before and after the second porosity/permeability component supplies water to the well.

The essential hypothesis, as discussed by Streltsova-Adams (1978), incorporates both matrix and fracture porosity and permeability to account for the nature of the drawdown plots. In this model, it is assumed that the porosity of the block is high, but permeability is low, while the porosity of the fractures is low, but permeability is high (see previous discussion on the double porosity medium). Consequently, the initial drawdown reflects water movement along the fractures until initial depletion of the fracture system is approached. Thereafter, a relatively rapid increase in the drawdown is experienced, until such time that the water held in the porous blocks can be released to the fracture system, and thereby flow to the production well.

The major thrust of the double porosity medium concentrates on porous blocks and fractures, but the rationale is equally applicable to a fractured aquifer where two sets of fractures are present that have different porosities and permeabilities. As discussed previously, this latter situation is assumed to be the case in the study areas, since primary (intergranular) porosity and permeability were probably eliminated during the geologic history of the area, or were never present in the original rock fabric.

The Type II plots presented in Appendix IV are very consistent in the overall configuration, although some of the plots exhibit data points that do not conform with what would be indicated from the above discussion. The plot for production well W-7 is one which exhibits some variability and may not be suitable for further interpretation. The plot for well W-6 seems to indicate a double-double porosity model, since there are two sets of parallel or subparallel line segments which some of the data fall on, although problems with data collection may account for this distribution. The remainder of the Type II plots are consistent in indicating a double porosity medium.

Type III: The Type III plots exhibit drawdown slopes which are continuous with time and do not stabilize, or abruptly terminate with a flat lying segment. Interpretation of these drawdown trends indicates difficulties in collection of the water levels in the production well, or an aquifer which is strictly fracture controlled, with low ground water supply potential. Due to the variability of the data, the Type III plots were not amenable for evaluation and could not be used for determination of aquifer characteristics. Additionally, the drawdown graph in well W-17 (Craig Avenue #1), during pumping of W-2 (Craig Avenue #2), falls in this category and could not be used because the "u-test" was not satisfied.

Hantush Modified Method

Drawdown levels were monitored in the Craig Avenue #1 well (W-17) during the pump test for the Craig Avenue #2 well (W-2), with a weight driven, Stevens recorder and float assembly in the well. Ground water levels monitoring occurred in the Craig Avenue #1 well before and after the pump test to provide data on ground water level fluctuations. The drawdown graph from this well (see Appendix V) was evaluated using the Hantush Modified Method of the Theis curve matching technique which resulted in an aquifer transmissivity of 1375 ft^2/day and a storage coefficient of 7.975×10^{-4}.

The results of the City of Bedford Well Field Aquifer Test which the author conducted during August, 1981, are summarized in Appendix VI. This aquifer analysis incorporated a 48 hour simultaneous pump test of five productions wells, in conjunction with continuous water level measurements in three privately owned water wells. The City of Bedford Well Field is in the Kelso Mills area of Bedford County and is underlain by igneous and metamorphic rocks identified as the Blue Ridge Complex. Therefore, the hydrogeologic setting of this fractured aquifer is similar to the primary study area in Roanoke County, Virginia.

The advantage with the City of Bedford Well Field test was that two observation wells (located on apparently conjugate fracture traces) were available for data collection. Drawdown data from these wells indicate a preferred transmissivity of 361 ft^2/day, with a minor transmissivity of 303 ft^2/day. The storage coefficient in the preferred direction was determined to be 4.58×10^{-5}, while in the minor direction, the storage coefficient was 2.53×10^{-5}. The average aquifer transmissivity, as determined from straight line plots of s_w/Q versus log t/r_w^2 for the production wells is 126 ft^2/day.

Discussion of Pump Test Results

Well construction information is summarized in Table 1, which indicates well number, name, depth, diameter, yield and water producing (fracture) zones. The water (fracture) zones for each well were determined by inspection of water well completion reports for each well and are determined by the driller during construction of the well. Many of the zones are indicated as a single depth on the drillers' logs, although other logs indicate an actual zone from which ground water was apparently entering the well. When only a specified depth was indicated on the log, a water producing zone one foot thick was assumed, although only the specified depth in presented in Table 1. Review of the maps presented in Appendix I will reveal the number and orientations of fracture traces identified from interpretation of topographic features, aerial photographs and LANDSAT photography. Comparison of the number of water producing zones with the number of fracture traces reveals that more water producing zones are noted than fracture traces. As discussed previously, this could be explained by fracture zones that are more nearly horizontal than vertical and thus, would exhibit a more discontinuous surface express.

The pump test results are summarized in Table 2 and indicate a range of transmissivities form 11 ft^2/day to 3956 ft^2/day. This wide range of values is attributed to variations in the aquifer, the number of fractures intersected by the well, the rate and duration of the pump test and the accuracy of the drawdown values collected. A tabulation of number of mapped fracture traces and water producing (fracture) zones is also presented in Table 2. Review of this data indicates that as the number and significance of the fractures increases, so does the value of transmissivity determined from the pump test. The relationship between transmissivity also holds true for the number of water (fracture) zones noted by the driller relationship verifies that the majority of ground water occurrence and movement in the crystalline rocks of the Blue Ridge allocthon is in fractures. Therefore, the yield of wells developed in this fractured aquifer is related to the number and extent of fractures intersected by the well, which agrees with the findings of other research conducted in consolidated aquifers (Parizek, 1976; Siddiqui and Parizek, 1971).

Estimates of Fracture Permeability

Transmissivity is defined as the hydraulic conductivity per unit aquifer thickness multiplied by the thickness of the aquifer (Lohman, 1972), or:

$$T = \bar{K}b \qquad [L^2/T] \qquad (21)$$

where,

T = transmissivity $[L^2/T]$
$\bar{K}$ = average hydraulic conductivity $[L/T]$, and
b = aquifer thickness $[L]$

To estimate the "thickness" of the fractured aquifer contributing water to the well, the maximum depth to water in the well (see Appendix III) was compared to the depth intervals of the water producing zones delineated on the drilling logs (see Table 1). The water producing

TABLE 2

SUMMARY OF TRANSMISSIVITIES, FRACTURES AND PRODUCTION ZONES

WELL NO.	WELL NAME	T (FT^2/DAY)	FRACTURES	PRODUCTION ZONES (DEPTH, FT.)
W-1	Craig Avenue #2	1684	2-major	145-165; 365-368
W-2	Town of Vinton #5	3956	2-major	85-87; 90-95; 110-111; 127-130; 145-148; 150-151; 308-309; 330-331
W-3	Town of Vinton #3	1265	3-major	115-116; 215-216
W-5	Homewood #2	48	1-minor	355-356
W-7	Starky Well #4	250	2-major	196; 217; 235
W-8	Long Ridge #1	35	1-major	445-450
W-9	Bridlewood #1	11	1-minor	350
W-11	Homewood #3	162	2-major	410-420
W-14	Garden Park	247	None	Fault Zone: 190-240
W-15	Hidden Valley #3	80		
W-16	Hidden Valley #9	224	None	Fault Zone: 165-215
W-17	Craig Avenue #1	1189	2-major	320-335
W-18	William Byrd #2	179	1-major	230; 265; 330; 355
W-20	Brookwood #1	91	1-minor	None identified on log
W-21	William Byrd #3	237	1-major	455-485
W-22	Bedford #2	600	2-major	315-330; 340-350; 390-400
W-23	Bedord #5	550	2-major	220-225; 330-333
W-24	Bedford #6	100	2-major	165-170; 179-180; 190-195
W-25	Bedford #7	750	3-major	105-160; 198-240
W-26	Bedford #8	80	1-major	32-60; 60-85; 85-90; 90-163

NOTES:

1. Number of fractures determined from fracture trace analysis.

2. Major fractures are greater than one mile in length.

3. Minor fractures are less than one mile in length.

4. Production zones are those water bearing zones identified by the driller that were not dewatered during production tests.

5. Values of transmissivity for the City of Bedford well are lower since well interference indicated greater drawdown than what would occur if the wells were pumped individually.

zones that were lower than the maximum depth to water in the well were assumed to be supplying ground water to the well during the latter stages of the pump tests. The aggregate thickness of the water producing zones, as determined above, was assumed to be the aquifer thickness which was used to calculate the hydraulic conductivity of the aquifer, as determined from the pump tests. The values of transmissivity, aquifer thickness and hydraulic conductivity are summarized in Table 3. As review of this table indicates, fracture hydraulic conductivity ranges from 4.5 ft/day to 632.5 ft/day. These values are within the ranges presented by Freeze and Cherry (1979, p. 29) and are indicative of a good fractured igneous and metamorphic rock aquifer.

Comparison of the transmissivity values from the Craig Avenue #1 observation well during the Craig Avenue #2 pump test (determined by the Hantush Modified Method) to the transmissivity estimate from analysis of the Craig Avenue #2 production well pump test (determined by the Straight Line Method), reveals that the Straight Line Method provides a value that is slightly lower than that determined with the observation well, although both values are extremely close. If the production well pump tests were conducted for a longer period of time, the drawdown data collected in these wells may allow a more accurate estimation of the aquifer transmissivity. However, the data collected do provide a good estimate of the fractured aquifer characteristics, until such time that more sophisticated well and aquifer tests are possible.

TABLE 3

SUMMARY OF TRANSMISSIVITIES, HYDRAULIC CONDUCTIVITIES AND INTRINSIC PERMEABILITIES

WELL NO.	WELL NAME	T (FT^2/DAY)	b (ft.)	K (ft./day)	k (cm^2)
W-1	Craig Avenue #2	1684	23	73.2	2.63E-07
W-2	Town of Vinton #5	3956	17	237.7	8.38E-07
W-3	Town of Vinton #3	1265	2	632.5	2.28E-06
W-5	Homewood #2	48	1	48	1.72E-07
W-7	Starky Well #4	250	3	83.3	3.00E-07
W-8	Long Ridge #1	35	5	7	2.52E-08
W-9	Bridlewood #1	11	1	11	3.96E-08
W-11	Homewood #3	162	10	16.2	5.83E-08
W-14	Garden Park	247	50	4.94	1.78E-08
W-15	Hidden Valley #3	80		---	---
W-16	Hidden Valley #9	224	50	4.5	1.62E-08
W-17	Craig Avenue #1	1189	15	79.3	2.85E-07
W-18	William Byrd #2	179	4	44.8	1.61E-07
W-20	Brookwood #1	91	N/A	---	---
W-21	William Byrd #3	237	30	7.9	2.84E-08
W-22	Bedford #2	600	35	17.1	6.15E-08
W-23	Bedord #5	550	13	42.3	1.52E-07
W-24	Bedford #6	100	11	9.1	3.28E-08
W-25	Bedford #7	750	100	7.5	2.70E-08
W-26	Bedford #8	80	111	0.7	2.52E-09

NOTES:

1. T - Tranmissivity (ft^2/day).
2. b - aquifer thickness (aggregate thickness of fracture zones not dewatered during pump test) (ft).
3. K - Hydraulic Conductivity (ft/day).
4. k - Intrinsic permeability (cm^2).
5. --- - Not determined.

Scrutiny of the well test results, the water (fracture) zones supplying the wells and the fracture trace analysis, indicates a good correlation between number of fractures intersected and well yield or aquifer transmissivity. In general, this correlation indicates transmissivities of less than 100 ft^2/day if the well intersects one minor or one major fracture, and transmissivities of greater than 100 ft^2/day if two or more major fractures are encountered by the wellbore. The Blue Ridge Thrust Fault zone itself has an average transmissivity of 236 ft^2/day, as determined from the W-14 and W-16 pump tests. Also, significant fractures (i.e., regional orthognal fractures) which would be more likely to extend to the fault zone have transmissivities of 1189 ft^2/day (Craig Avenue #1) to 3956 ft^2/day (Town of Vinton #5). As review of Table 3 indicates, the hydraulic conductivity values, as determined from the production well pump tests, range from 4.5 ft/day to 632.5 ft/day.

To evaluate the steady state flow conditions in the Blue Ridge allocthon at depth, a value for fracture permeability must be determined. As discussed by Lohman (1972), the hydraulic conductivity is a property of the medium and the natural ground water, while intrinsic permeability is a property of the medium only. Consequently, the estimates of hydraulic conductivity presented in Table 3 have been adjusted to reflect the intrinsic permeability of the fractures in accordance with the method presented by Freeze & Cherry (1979, p.29). Values for intrinsic permeability range from 1.62×10^{-8} cm^2 to 2.28×10^{-6} cm^2, with a value of 1.7×10^{-8} cm^2 indicated for the Blue Ridge

Thrust Fault zone. The values of intrinsic permeability for the portion of the Blue Ridge thrust sheet in Bedford County have been determined to be approximately 2.21 x 10^{-8} cm^2, which is in the range of values determined for the thrust sheet in the primary study area.

The transmissivity of the fault zone and fractures at depth in the allocthon cannot be determined directly from the pump tests data evaluated in this study. The sole of the thrust fault in South Carolina has been established at a depth of approximately 3 kilometers and fractures containing ground water have been inferred at depths up to 20 kilometers (Costain, Bollinger and Speer, 1987). The porosity and permeability of fractures is more easily affected by compressive forces, either due to increased depth of burial or fluid depletion, than the matrix of the rock which contains the fractures (Nelson, 1985). However, as discussed in the section on the double porosity medium, compressibility of the fractures is considered negligible since fracture porosity is generally low. Consequently, movement of ground water in the fractures and fault zone in the Blue Ridge allocthon is considered viable, although the actual rate of flow, or other flow related characteristics (i.e., hydraulic conductivity, transmissivity and storage coefficient) may be lower than what has been determined from the pump tests considered in this study.

Analysis of fluid inclusions in fracture zone samples at depths of 8,500 feet to 12,000 feet indicate the development of fracture porosity and permeability accompanying tectonism (Currie and Nwachukwu, 1974). Mineralogical evidence collected in similar terranes in Maine indicate fluid movement through the rock mass under metamorphic conditions of 380-325°C and 3.5 kbar (Costain, Bollinger and Speer, 1987), which are conditions that are in excess of those anticipated at the depth of the sole of the Blue Ridge Thrust Fault. Therefore, it is likely that the values of intrinsic permeability for the fault zone and the more significant fractures identified in this study, would be applicable for evaluation of ground water flow conditions at the base of allocthon, although the actual value of intrinsic permeability may be slightly lower. Since the porosity of fractures is low and the volume reduction of the water due to fracture compressibility is negligible compared to the volume of water released from storage (Streltsova-Adams, 1978), values of intrinsic permeability determined from evaluation of the pump tests may be quite applicable to the thrust sheet as a whole. Aquifer characteristics determined from the City of Bedford Well Field aquifer test are within the range of values determined from the leading edge of the thrust sheet. While the values of transmissivity, hydraulic conductivity and intrinsic permeability are different between the primarily and secondary study areas, these values are within one order of magnitude and therefore, may be applicable to the entire thrust sheet.

SUMMARY

The production well pump test data evaluated in this study provide good estimates of transmissivity and storage coefficient for the crystalline rocks of the Blue Ridge allocthon. The drawdown data from the pump tests (see Appendix IV) were grouped into three categories. Two of these categories are indicative of double porosity, and homogeneous, anisotropic media. Additionally, a definite relationship exists between well yield and the number and extent of fracture the well intersects. Values for fracture hydraulic conductivity and intrinsic permeability have been determined and the close range of values is indicative of data which should be similar to the conditions that would be encountered at depth within the allocthon. The propagation of fractures with depth and the transmissive character of the Blue Ridge Thrust Fault zone, in conjunction with abundant ground water resources in the Blue Ridge allocthon, indicate that deep ground water circulation may be more likely than has been previously thought.

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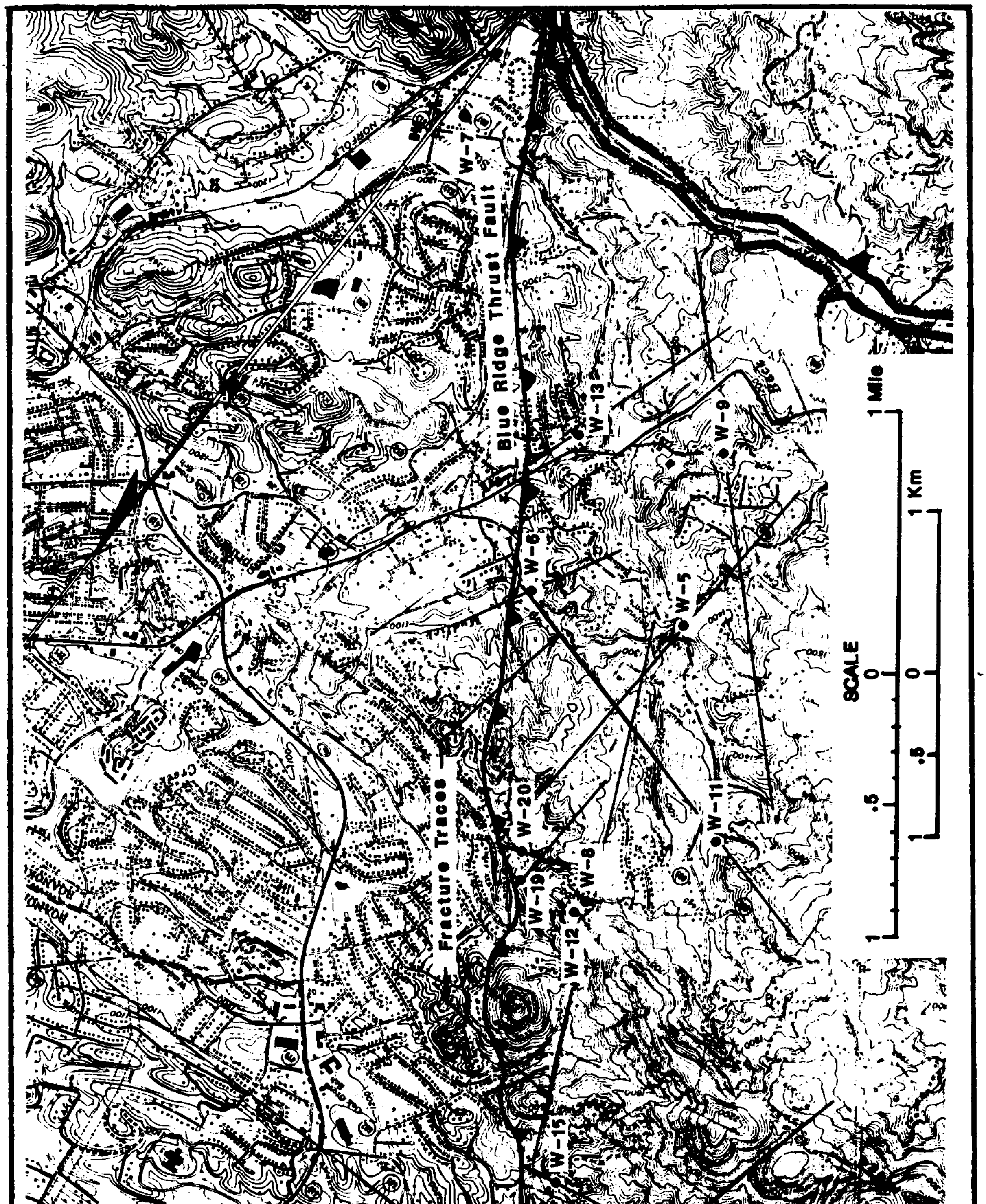
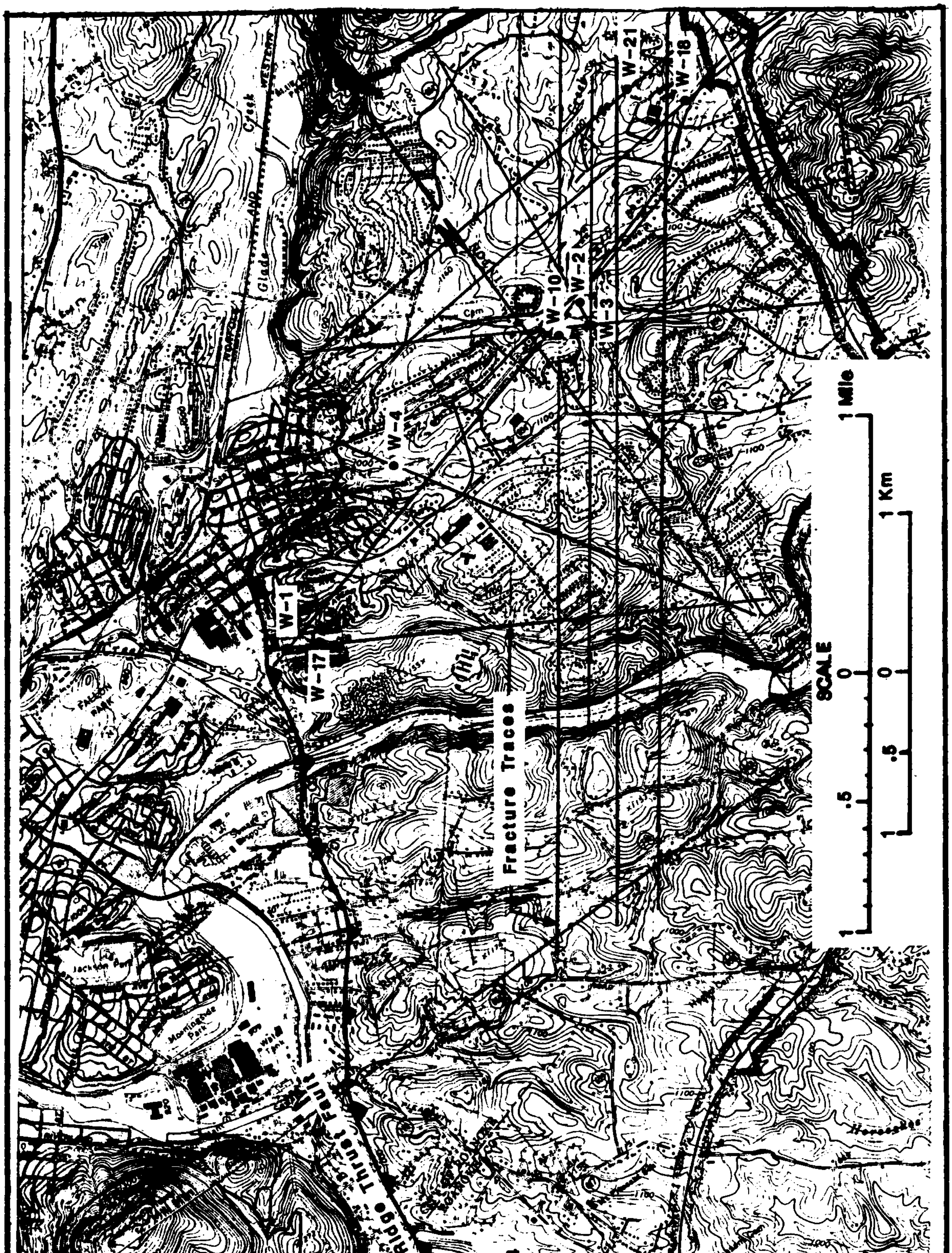
APPENDIX I

WELL LOCATION MAPS
(Western Study Area)
(Eastern Study Area)

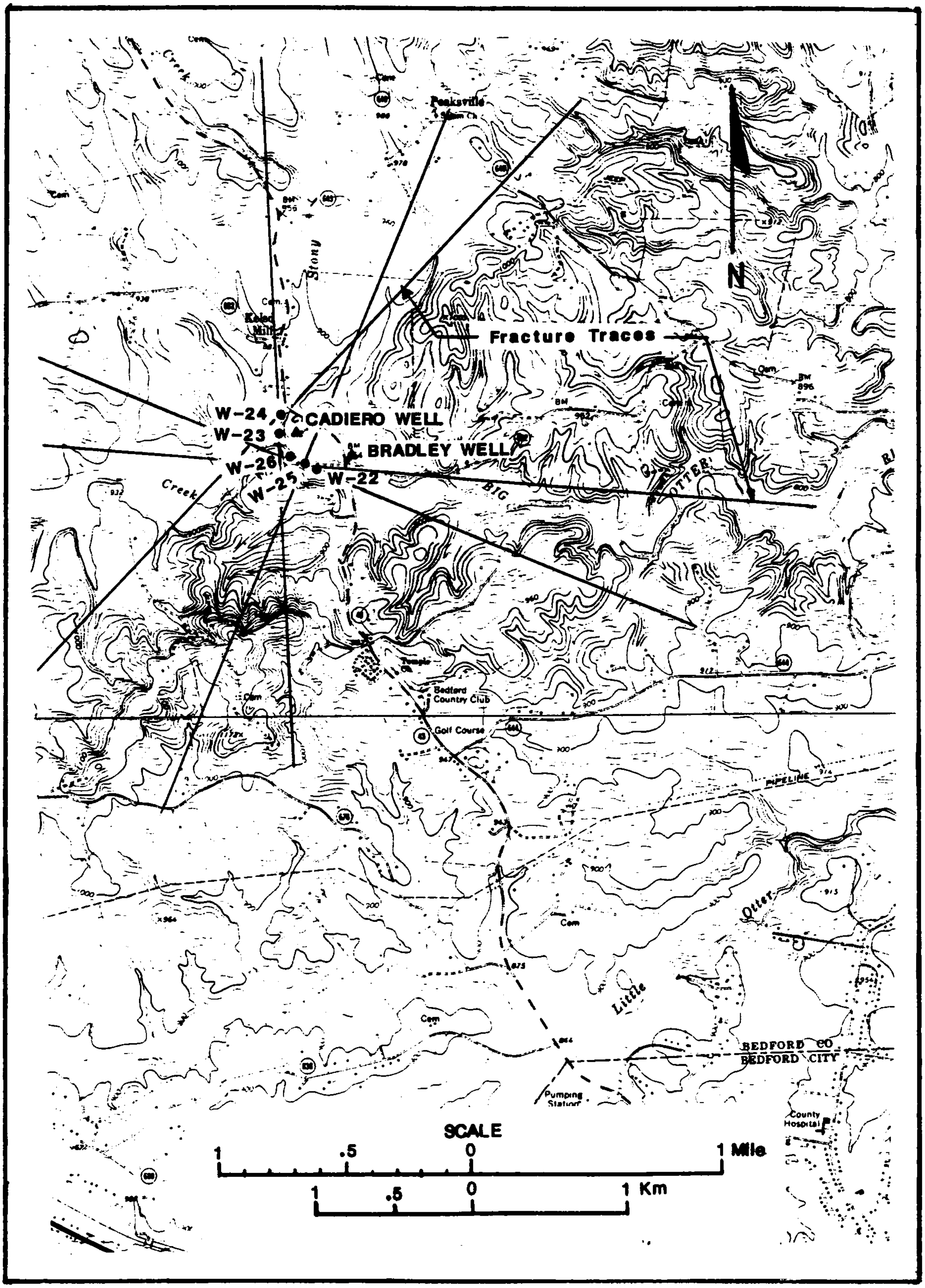
Western Study Area


Blue Ridge Thrust Fault
Fracture Traces
W-7
W-13
W-9
W-6
W-5
W-20
W-11
W-19
W-8
W-12
W-15
W-16
SCALE
1
.5
0
1 Mile
1
.5
0
1 Km

Eastern Study Area

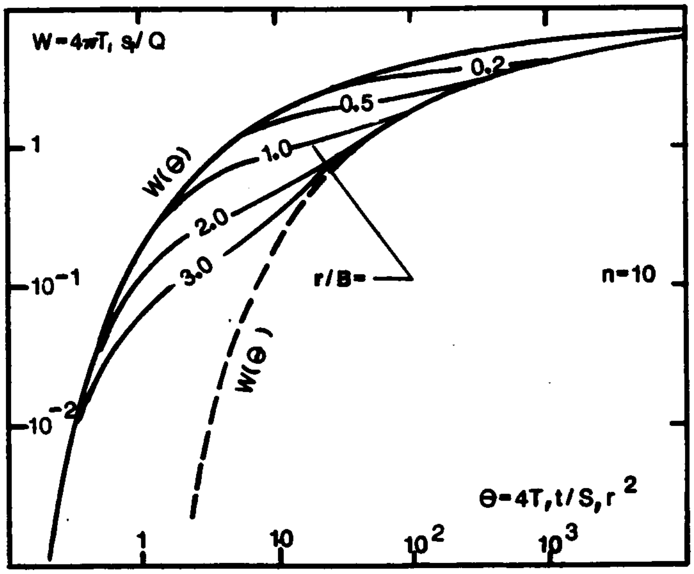

W-1
W-17
W-4
W-10
W-2
W-3
W-21
W-18
W-14
Fracture Traces
Blue Ridge Thrust Fault
Glade Creek
Falcon Park
Jackson Park
Morningside Park
SCALE
1 .5 0 1 Mile
1 .5 0 1 Km

Secondary Study Area

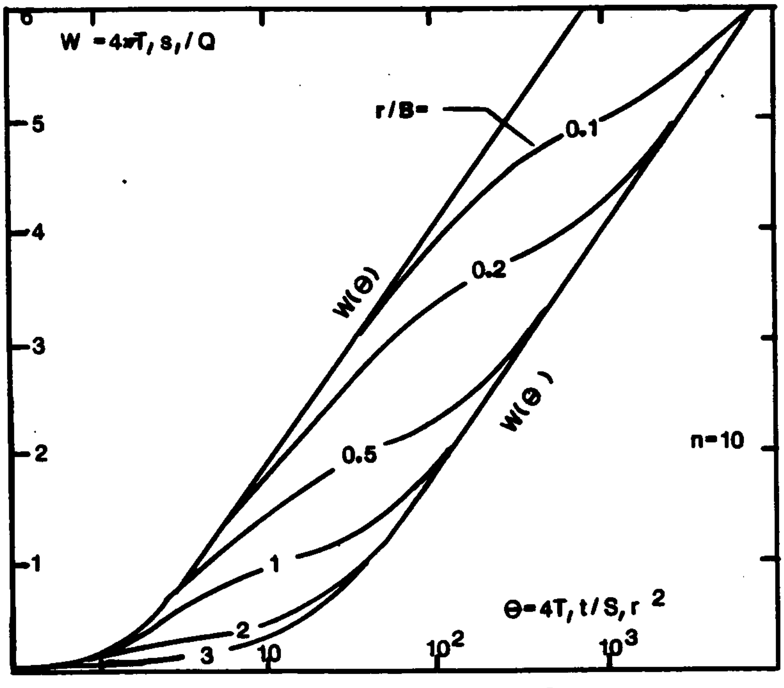

Peaksville
Creek
Stony
Kelso Mill
Cem
N
Fracture Traces
W-24
W-23
W-26
W-25
W-22
CADIERO WELL
BRADLEY WELL
Creek
BIG
OTTER
Temple
Bedford Country Club
Golf Course
PIPELINE
Otter
Little
BEDFORD CO.
BEDFORD CITY
Pumping Station
County Hospital
SCALE
1
.5
0
1 Mile
1
.5
0
1 Km

APPENDIX II

DOUBLE POROSITY DRAWDOWN TYPE CURVES



FULL LOGARITHMIC COORDINATES



SEMILOGARITHMIC COORDINATES

SOURCE: Streltsova-Adams (1978), page 379

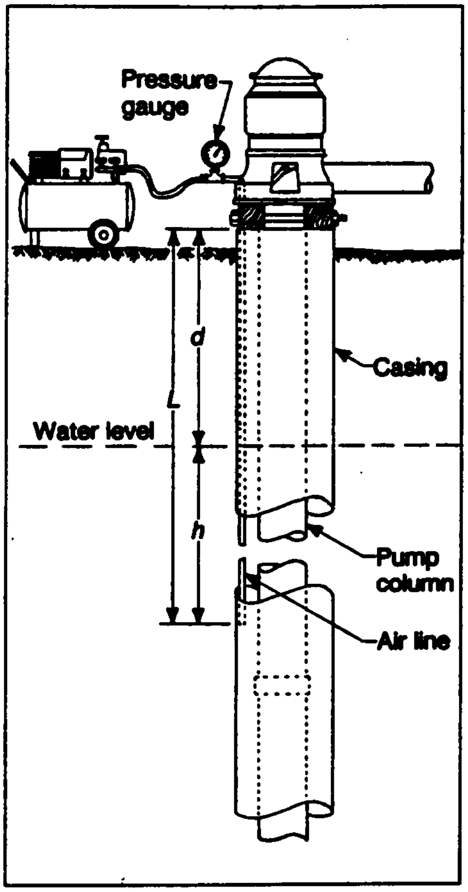
APPENDIX III

AIR LINE WATER LEVEL MEASUREMENT METHOD

DRAWDOWN DATA

Air Line Water Level Measurement Method

AIR LINE WATER LEVEL MEASUREMENT METHOD



Depth to Water: $d = L - h$

where,

d = depth to water (ft.)
L = length of air line (ft.)
h = feet of water above bottom of air line (ft.)
= gauge reading (psi) X 2.31

Source: Driscoll (1986), p. 551.

Drawdown Data

IDENTIFICATION NUMBER: W-1
WELL NAME: CRAIG AVENUE #2
WELL YIELD: 84,649 FT3/DAY
WELL DEPTH (FT.): 412
SWL (FT.): 0.00
AIRLINE LENGTH (FT.): 224.00
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	8.46E+04	100	1.18E-03	3.09E-02
6.94E-03	8.46E+04	107	1.26E-03	6.19E-02
1.04E-02	8.46E+04	108	1.28E-03	9.28E-02
1.39E-02	8.46E+04	108.5	1.28E-03	1.24E-01
1.74E-02	8.46E+04	108.6	1.28E-03	1.55E-01
2.08E-02	8.46E+04	108.75	1.28E-03	1.86E-01
2.43E-02	8.46E+04	109	1.29E-03	2.17E-01
2.78E-02	8.46E+04	109	1.29E-03	2.48E-01
3.12E-02	8.46E+04	109.5	1.29E-03	2.78E-01
3.47E-02	8.46E+04	109.6	1.29E-03	3.09E-01
3.82E-02	8.46E+04	109.9	1.30E-03	3.40E-01
4.17E-02	8.18E+04	110	1.35E-03	3.71E-01
8.33E-02	8.18E+04	110.5	1.35E-03	7.43E-01
1.25E-01	8.18E+04	111	1.36E-03	1.11E+00
1.67E-01	7.70E+04	111.9	1.45E-03	1.49E+00
2.08E-01	7.70E+04	112.8	1.47E-03	1.86E+00
2.50E-01	7.70E+04	113.4	1.47E-03	2.23E+00
2.92E-01	7.70E+04	114	1.48E-03	2.60E+00
3.33E-01	7.70E+04	114.7	1.49E-03	2.97E+00
3.75E-01	7.70E+04	115.5	1.50E-03	3.34E+00
4.17E-01	7.70E+04	116.3	1.51E-03	3.71E+00
4.58E-01	7.70E+04	117.1	1.52E-03	4.08E+00
5.00E-01	7.70E+04	118	1.53E-03	4.46E+00
5.42E-01	7.70E+04	118.7	1.54E-03	4.83E+00
5.83E-01	7.70E+04	119.6	1.55E-03	5.20E+00
6.25E-01	7.70E+04	120.3	1.56E-03	5.57E+00
6.67E-01	7.70E+04	121	1.57E-03	5.94E+00
7.08E-01	7.70E+04	121.7	1.58E-03	6.31E+00
7.50E-01	7.70E+04	121.9	1.58E-03	6.68E+00
7.92E-01	7.70E+04	122	1.59E-03	7.05E+00
8.33E-01	7.70E+04	122.4	1.59E-03	7.43E+00
8.75E-01	7.70E+04	122.6	1.59E-03	7.80E+00
9.17E-01	7.70E+04	122.75	1.60E-03	8.17E+00
9.58E-01	7.70E+04	123	1.60E-03	8.54E+00
1.00E+00	7.70E+04	123.4	1.60E-03	8.91E+00

IDENTIFICATION NUMBER: W-2
WELL NAME: Town of Vinton #5
WELL YIELD : 192,384 FT3/DAY
WELL DEPTH (FT.): 360
SWL (FT.): 21.00
AIRLINE LENGTH (FT.): 189.00
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	2.12E+05	29.40	1.39E-04	3.09E-02
6.94E-03	1.92E+05	34.02	1.77E-04	6.19E-02
1.04E-02	1.92E+05	34.02	1.77E-04	9.28E-02
1.39E-02	1.92E+05	34.02	1.77E-04	1.24E-01
1.74E-02	1.92E+05	34.02	1.77E-04	1.55E-01
2.08E-02	1.92E+05	34.02	1.77E-04	1.86E-01
2.43E-02	1.92E+05	36.33	1.89E-04	2.17E-01
2.78E-02	1.92E+05	36.33	1.89E-04	2.48E-01
3.12E-02	1.92E+05	36.33	1.89E-04	2.78E-01
3.47E-02	1.92E+05	36.33	1.89E-04	3.09E-01
3.82E-02	1.92E+05	36.33	1.89E-04	3.40E-01
4.17E-02	1.92E+05	38.64	2.01E-04	3.71E-01
5.21E-02	1.92E+05	38.64	2.01E-04	4.64E-01
6.25E-02	1.92E+05	38.64	2.01E-04	5.57E-01
7.29E-02	1.92E+05	40.95	2.13E-04	6.50E-01
9.37E-02	1.92E+05	40.95	2.13E-04	8.35E-01
2.40E-01	1.92E+05	43.26	2.25E-04	2.13E+00
4.17E-01	1.92E+05	45.57	2.37E-04	3.71E+00
3.33E-01	7.70E+04	114.70	1.49E-03	2.97E+00
3.75E-01	7.70E+04	115.50	1.50E-03	3.34E+00
4.17E-01	7.70E+04	116.30	1.51E-03	3.71E+00
4.58E-01	7.70E+04	117.10	1.52E-03	4.08E+00
5.00E-01	7.70E+04	118.00	1.53E-03	4.46E+00
5.42E-01	7.70E+04	118.70	1.54E-03	4.83E+00
5.83E-01	7.70E+04	119.60	1.55E-03	5.20E+00
6.25E-01	7.70E+04	120.30	1.56E-03	5.57E+00
6.67E-01	7.70E+04	121.00	1.57E-03	5.94E+00
7.08E-01	7.70E+04	121.70	1.58E-03	6.31E+00
7.50E-01	7.70E+04	121.90	1.58E-03	6.68E+00
7.92E-01	7.70E+04	122.00	1.59E-03	7.05E+00
8.33E-01	7.70E+04	122.40	1.59E-03	7.43E+00
8.75E-01	7.70E+04	122.60	1.59E-03	7.80E+00
9.17E-01	7.70E+04	122.75	1.60E-03	8.17E+00
9.58E-01	7.70E+04	123.00	1.60E-03	8.54E+00
1.00E+00	7.70E+04	123.40	1.60E-03	8.91E+00

IDENTIFICATION NUMBER: W-3
WELL NAME: TOWN OF VINTON #3
WELL YIELD: 81,571 FT3/DAY
WELL DEPTH (FT.): 405.00
SWL (FT.): 16.00
AIRLINE LENGTH (FT.): 210.00
WELL DIAMETER (FT.): 0.50

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	48096.06	43.85	9.12E-04	5.56E-02
6.94E-03	48096.06	46.16	9.60E-04	1.11E-01
1.04E-02	57715.28	50.78	8.80E-04	1.67E-01
1.39E-02	57715.28	50.78	8.80E-04	2.22E-01
1.74E-02	81763.31	50.78	6.21E-04	2.78E-01
2.08E-02	81763.31	64.64	7.91E-04	3.33E-01
2.43E-02	81763.31	64.64	7.91E-04	3.89E-01
2.78E-02	81763.31	64.64	7.91E-04	4.44E-01
3.12E-02	81763.31	64.64	7.91E-04	5.00E-01
3.47E-02	81763.31	64.64	7.91E-04	5.56E-01
3.82E-02	81763.31	64.64	7.91E-04	6.11E-01
4.17E-02	81763.31	64.64	7.91E-04	6.67E-01
2.50E-01	81763.31	64.64	7.91E-04	4.00E+00
3.33E-01	81763.31	69.26	8.47E-04	5.33E+00
7.92E-01	81763.31	73.88	9.04E-04	1.27E+01
2.00E+00	81763.31	78.50	9.60E-04	3.20E+01

IDENTIFICATION NUMBER: W-4
WELL NAME: TOWN OF VINTON #2
WELL YIELD: 153,907 FT3/DAY
WELL DEPTH (FT.): 345,00
SWL (FT.): 2.00
AIRLINE LENGTH (FT.): 208.00
WELL DIAMETER (FT.): 0.50

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
1.04E-02	1.54E+05	44.30	2.88E-04	1.67E-01
2.08E-02	1.54E+05	67.40	4.38E-04	3.33E-01
3.12E-02	1.54E+05	90.50	5.88E-04	5.00E-01
4.17E-02	1.54E+05	90.50	5.88E-04	6.67E-01
8.33E-02	1.54E+05	102.05	6.63E-04	1.33E+00
1.25E-01	1.54E+05	102.05	6.63E-04	2.00E+00
1.67E-01	1.54E+05	102.05	6.63E-04	2.67E+00
2.08E-01	1.54E+05	102.05	6.63E-04	3.33E+00
2.50E-01	1.54E+05	102.05	6.63E-04	4.00E+00
2.92E-01	1.54E+05	102.05	6.63E-04	4.67E+00
3.33E-01	1.54E+05	102.05	6.63E-04	5.33E+00

IDENTIFICATION NUMBER: W-5
WELL NAME: HOMEWOOD #2
WELL YIELD: 18,084 FT3/DAY
WELL DEPTH (FT.): 385.00
SWL (FT.): 13.00
AIRLINE LENGTH (FT.): 357.00
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	1.79E+04	101.45	5.67E-03	3.09E-02
6.94E-03	1.79E+04	126.86	7.09E-03	6.19E-02
1.04E-02	1.79E+04	138.41	7.74E-03	9.28E-02
1.39E-02	1.79E+04	145.34	8.12E-03	1.24E-01
1.74E-02	1.79E+04	149.96	8.38E-03	1.55E-01
2.08E-02	1.79E+04	156.89	8.77E-03	1.86E-01
2.43E-02	1.89E+04	168.44	8.93E-03	2.17E-01
2.78E-02	1.89E+04	177.68	9.42E-03	2.48E-01
3.12E-02	1.89E+04	182.30	9.67E-03	2.78E-01
3.47E-02	1.89E+04	184.61	9.79E-03	3.09E-01
3.82E-02	1.89E+04	189.23	1.00E-02	3.40E-01
4.17E-02	1.89E+04	191.54	1.02E-02	3.71E-01
8.33E-02	1.89E+04	210.02	1.11E-02	7.43E-01
1.25E-01	1.89E+04	223.88	1.19E-02	1.11E+00
1.67E-01	1.89E+04	235.43	1.25E-02	1.49E+00
2.08E-01	1.89E+04	242.36	1.29E-02	1.86E+00
2.50E-01	1.89E+04	251.60	1.33E-02	2.23E+00
3.75E-01	1.89E+04	256.22	1.36E-02	3.34E+00
4.17E-01	1.89E+04	258.53	1.37E-02	3.71E+00
4.58E-01	1.89E+04	286.25	1.52E-02	4.08E+00
5.83E-01	1.89E+04	293.18	1.56E-02	5.20E+00
6.67E-01	1.89E+04	297.80	1.58E-02	5.94E+00
7.50E-01	1.89E+04	302.42	1.60E-02	6.68E+00
9.17E-01	1.89E+04	307.04	1.63E-02	8.17E+00
9.58E-01	1.89E+04	311.66	1.65E-02	8.54E+00
1.21E+00	1.77E+04	316.28	1.79E-02	1.08E+01
1.38E+00	1.73E+04	320.90	1.85E-02	1.23E+01
1.46E+00	1.73E+04	325.52	1.88E-02	1.30E+01
1.58E+00	1.73E+04	330.14	1.91E-02	1.41E+01
1.62E+00	1.73E+04	327.83	1.89E-02	1.45E+01
1.71E+00	1.73E+04	332.45	1.92E-02	1.52E+01
2.00E+00	1.73E+04	330.14	1.91E-02	1.78E+01

IDENTIFICATION NUMBER: W-6
WELL NAME: ROANOKE CO. PSA, GRISSO WELL
WELL YIELD: 42,902 FT3/DAY
WELL DEPTH (FT.): 500
SWL (FT.): 56.00
AIRLINE LENGTH (FT.): 315
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	4.42E+04	11.83	2.67E-04	3.09E-02
6.94E-03	4.42E+04	11.83	2.67E-04	6.19E-02
1.04E-02	4.42E+04	11.83	2.67E-04	9.28E-02
1.39E-02	4.42E+04	11.83	2.67E-04	1.24E-01
1.74E-02	4.42E+04	14.14	3.20E-04	1.55E-01
2.08E-02	4.42E+04	14.14	3.20E-04	1.86E-01
2.43E-02	4.42E+04	16.45	3.72E-04	2.17E-01
2.78E-02	4.42E+04	16.45	3.72E-04	2.48E-01
3.12E-02	4.42E+04	21.07	4.76E-04	2.78E-01
3.47E-02	4.42E+04	21.07	4.76E-04	3.09E-01
3.82E-02	4.42E+04	28.00	6.33E-04	3.40E-01
4.17E-02	4.42E+04	39.55	8.94E-04	3.71E-01
8.33E-02	4.42E+04	41.86	9.46E-04	7.43E-01
1.25E-01	4.42E+04	51.10	1.15E-03	1.11E+00
1.67E-01	4.42E+04	62.65	1.42E-03	1.49E+00
2.08E-01	4.42E+04	74.20	1.68E-03	1.86E+00
2.92E-01	4.42E+04	76.51	1.73E-03	2.60E+00
3.33E-01	4.42E+04	85.75	1.94E-03	2.97E+00
3.75E-01	4.42E+04	90.37	2.04E-03	3.34E+00
4.17E-01	4.42E+04	101.92	2.30E-03	3.71E+00
7.50E-01	4.33E+04	108.85	2.51E-03	6.68E+00
7.92E-01	4.23E+04	111.16	2.63E-03	7.05E+00
8.33E-01	4.23E+04	120.40	2.84E-03	7.43E+00
8.75E-01	4.23E+04	125.02	2.95E-03	7.80E+00
9.17E-01	4.23E+04	134.26	3.17E-03	8.17E+00
9.58E-01	4.23E+04	143.50	3.39E-03	8.54E+00
1.00E+00	4.23E+04	148.12	3.50E-03	8.91E+00
1.17E+00	4.23E+04	155.05	3.66E-03	1.04E+01
1.54E+00	4.23E+04	161.98	3.83E-03	1.37E+01
2.00E+00	4.23E+04	166.60	3.94E-03	1.78E+01

IDENTIFICATION NUMBER: W-7
WELL NAME: STARKY WELL #4
WELL YIELD: 79,839 FT3/DAY
WELL DEPTH (FT.): 447.00
SWL (FT.): 68.00
AIRLINE LENGTH (FT.): 200.00
WELL DIAMETER (FT.): 0.83

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
2.08E-02	5.77E+04	34.98	6.06E-04	1.21E-01
3.12E-02	7.70E+04	58.08	7.55E-04	1.81E-01
4.17E-02	7.70E+04	62.70	8.15E-04	2.42E-01
8.33E-02	7.70E+04	67.32	8.75E-04	4.84E-01
1.25E-01	7.70E+04	85.80	1.11E-03	7.26E-01
1.67E-01	7.70E+04	85.80	1.11E-03	9.68E-01
2.08E-01	8.18E+04	90.42	1.11E-03	1.21E+00
2.50E-01	8.66E+04	97.35	1.12E-03	1.45E+00
2.92E-01	8.66E+04	101.97	1.18E-03	1.69E+00
3.33E-01	8.66E+04	104.28	1.20E-03	1.94E+00
3.75E-01	8.66E+04	108.90	1.26E-03	2.18E+00
4.17E-01	8.66E+04	108.90	1.26E-03	2.42E+00
4.58E-01	8.66E+04	108.90	1.26E-03	2.66E+00
5.00E-01	8.66E+04	113.52	1.31E-03	2.90E+00
5.42E-01	8.66E+04	115.83	1.34E-03	3.15E+00
5.83E-01	8.66E+04	118.14	1.36E-03	3.39E+00
6.25E-01	8.66E+04	120.45	1.39E-03	3.63E+00
6.67E-01	8.66E+04	108.90	1.26E-03	3.87E+00
7.08E-01	8.66E+04	108.90	1.26E-03	4.11E+00
7.50E-01	8.66E+04	108.90	1.26E-03	4.35E+00
7.92E-01	8.66E+04	108.90	1.26E-03	4.60E+00
8.33E-01	8.66E+04	108.90	1.26E-03	4.84E+00
8.75E-01	8.66E+04	108.90	1.26E-03	5.08E+00
9.17E-01	8.66E+04	113.52	1.31E-03	5.32E+00
9.58E-01	8.66E+04	113.52	1.31E-03	5.56E+00
1.00E+00	8.18E+04	115.83	1.42E-03	5.81E+00
1.04E+00	8.18E+04	115.83	1.42E-03	6.05E+00
1.08E+00	8.18E+04	115.83	1.42E-03	6.29E+00
1.12E+00	8.18E+04	115.83	1.42E-03	6.53E+00
1.17E+00	8.18E+04	115.83	1.42E-03	6.77E+00
1.21E+00	7.70E+04	120.45	1.57E-03	7.02E+00
1.25E+00	7.70E+04	120.45	1.57E-03	7.26E+00
1.29E+00	7.70E+04	120.45	1.57E-03	7.50E+00
1.33E+00	7.70E+04	120.45	1.57E-03	7.74E+00
1.38E+00	7.70E+04	122.76	1.60E-03	7.98E+00
1.42E+00	7.70E+04	122.76	1.60E-03	8.23E+00
1.46E+00	7.70E+04	122.76	1.60E-03	8.47E+00
1.50E+00	7.70E+04	122.76	1.60E-03	8.71E+00
1.54E+00	7.70E+04	127.38	1.66E-03	8.95E+00
1.58E+00	7.70E+04	127.38	1.66E-03	9.19E+00

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1.62E+00 7.70E+04   127.38 1.66E-03 9.44E+00
1.67E+00 7.70E+04   127.38 1.66E-03 9.68E+00
1.71E+00 7.70E+04   127.38 1.66E-03 9.92E+00
1.75E+00 7.70E+04   127.38 1.66E-03 1.02E+01
1.79E+00 7.70E+04   127.38 1.66E-03 1.04E+01
1.83E+00 7.70E+04   127.38 1.66E-03 1.06E+01
1.87E+00 7.70E+04   127.38 1.66E-03 1.09E+01
1.92E+00 7.70E+04   127.38 1.66E-03 1.11E+01
1.96E+00 7.70E+04   127.38 1.66E-03 1.14E+01
2.00E+00 7.70E+04   127.38 1.66E-03 1.16E+01
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IDENTIFICATION NUMBER:  W-8
WELL NAME:  LONG RIDGE #1
WELL YIELD:  9,427 FT3/DAY
WELL DEPTH (FT.):  465
SWL (FT.):  300
AIRLINE LENGTH (FT.):  420
WELL DIAMETER (FT.):  0.67


TIME (d)  Q (cf/d)    Sw       Sw/Q      T/Rw^2
3.47E-03 1.12E+04    -0.12 *********3.09E-02
6.94E-03 1.10E+04     4.50 4.10E-04 6.19E-02
1.04E-02 1.10E+04     9.12 8.32E-04 9.28E-02
1.39E-02 1.08E+04    18.36 1.70E-03 1.24E-01
1.74E-02 1.08E+04    22.98 2.13E-03 1.55E-01
2.08E-02 1.06E+04    27.60 2.61E-03 1.86E-01
2.43E-02 1.06E+04    32.22 3.05E-03 2.17E-01
2.78E-02 1.04E+04    36.84 3.55E-03 2.48E-01
3.12E-02 1.04E+04    41.46 3.99E-03 2.78E-01
3.47E-02 1.02E+04    43.77 4.29E-03 3.09E-01
3.82E-02 1.02E+04    46.08 4.52E-03 3.40E-01
4.17E-02 1.00E+04    50.70 5.07E-03 3.71E-01
8.33E-02 1.00E+04    50.70 5.07E-03 7.43E-01
1.25E-01 9.81E+03    59.94 6.11E-03 1.11E+00
1.67E-01 9.81E+03    62.25 6.34E-03 1.49E+00
2.08E-01 9.81E+03    64.56 6.58E-03 1.86E+00
2.50E-01 9.62E+03    66.87 6.95E-03 2.23E+00
2.92E-01 9.62E+03    69.18 7.19E-03 2.60E+00
3.33E-01 9.62E+03    71.49 7.43E-03 2.97E+00
3.75E-01 9.62E+03    73.80 7.67E-03 3.34E+00
4.17E-01 9.62E+03    76.11 7.91E-03 3.71E+00
4.58E-01 9.43E+03    78.42 8.32E-03 4.08E+00
5.00E-01 9.43E+03    80.73 8.56E-03 4.46E+00
5.42E-01 9.43E+03    83.04 8.81E-03 4.83E+00
5.83E-01 9.43E+03    85.35 9.05E-03 5.20E+00
6.25E-01 9.43E+03    87.66 9.30E-03 5.57E+00
6.67E-01 9.23E+03    87.66 9.49E-03 5.94E+00
7.08E-01 9.23E+03    89.97 9.74E-03 6.31E+00
7.50E-01 9.23E+03    89.97 9.74E-03 6.68E+00
7.92E-01 9.23E+03    92.28 9.99E-03 7.05E+00
8.33E-01 9.23E+03    92.28 9.99E-03 7.43E+00
8.75E-01 9.23E+03    92.28 9.99E-03 7.80E+00
9.17E-01 9.23E+03    94.59 1.02E-02 8.17E+00
9.58E-01 9.23E+03    96.90 1.05E-02 8.54E+00
1.00E+00 9.23E+03    99.21 1.07E-02 8.91E+00
1.04E+00 9.23E+03    99.21 1.07E-02 9.28E+00
1.08E+00 9.23E+03    99.21 1.07E-02 9.65E+00
1.12E+00 9.23E+03    99.21 1.07E-02 1.00E+01
1.17E+00 9.23E+03    99.21 1.07E-02 1.04E+01
1.21E+00 9.23E+03    99.21 1.07E-02 1.08E+01
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1.25E+00	9.23E+03	99.21	1.07E-02	1.11E+01
1.29E+00	9.23E+03	99.21	1.07E-02	1.15E+01
1.33E+00	9.23E+03	99.21	1.07E-02	1.19E+01
1.38E+00	9.23E+03	99.21	1.07E-02	1.23E+01
1.42E+00	9.23E+03	99.21	1.07E-02	1.26E+01
1.46E+00	9.23E+03	99.21	1.07E-02	1.30E+01
1.50E+00	9.23E+03	99.21	1.07E-02	1.34E+01
1.54E+00	9.23E+03	99.21	1.07E-02	1.37E+01
1.58E+00	9.23E+03	99.21	1.07E-02	1.41E+01
1.62E+00	9.23E+03	99.21	1.07E-02	1.45E+01
1.67E+00	9.23E+03	99.21	1.07E-02	1.49E+01
1.71E+00	9.23E+03	99.21	1.07E-02	1.52E+01
1.75E+00	9.23E+03	99.21	1.07E-02	1.56E+01
1.79E+00	9.23E+03	99.21	1.07E-02	1.60E+01
1.83E+00	9.23E+03	99.21	1.07E-02	1.63E+01
1.87E+00	9.23E+03	99.21	1.07E-02	1.67E+01
1.92E+00	9.23E+03	99.21	1.07E-02	1.71E+01
1.96E+00	9.23E+03	99.21	1.07E-02	1.75E+01
2.00E+00	9.23E+03	99.21	1.07E-02	1.78E+01

IDENTIFICATION NUMBER: W-9
WELL NAME: BRIDLEWOOD WELL #1
WELL YIELD: 6,733 FT3/DAY
WELL DEPTH (FT.): 405
SWL (FT.): 36
AIRLINE LENGTH (FT.): 336
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	1.06E+04	15.87	1.50E-03	3.09E-02
6.94E-03	1.06E+04	34.35	3.25E-03	6.19E-02
1.04E-02	1.06E+04	71.31	6.74E-03	9.28E-02
1.39E-02	1.06E+04	85.17	8.05E-03	1.24E-01
1.74E-02	1.06E+04	99.03	9.36E-03	1.55E-01
2.08E-02	1.00E+04	112.89	1.13E-02	1.86E-01
2.43E-02	9.81E+03	126.75	1.29E-02	2.17E-01
2.78E-02	9.62E+03	133.68	1.39E-02	2.48E-01
3.12E-02	9.62E+03	138.30	1.44E-02	2.78E-01
3.47E-02	9.62E+03	156.78	1.63E-02	3.09E-01
3.82E-02	9.62E+03	170.64	1.77E-02	3.40E-01
4.17E-02	6.73E+03	184.50	2.74E-02	3.71E-01
8.33E-02	6.73E+03	184.50	2.74E-02	7.43E-01
1.25E-01	6.73E+03	196.05	2.91E-02	1.11E+00
1.67E-01	6.73E+03	272.28	4.04E-02	1.49E+00
2.08E-01	6.73E+03	276.90	4.11E-02	1.86E+00
2.50E-01	6.73E+03	276.90	4.11E-02	2.23E+00
2.92E-01	6.73E+03	276.90	4.11E-02	2.60E+00
3.33E-01	6.73E+03	276.90	4.11E-02	2.97E+00
3.75E-01	6.73E+03	276.90	4.11E-02	3.34E+00
4.17E-01	6.73E+03	276.90	4.11E-02	3.71E+00
4.58E-01	6.73E+03	276.90	4.11E-02	4.08E+00
5.00E-01	6.73E+03	276.90	4.11E-02	4.46E+00
5.42E-01	6.73E+03	276.90	4.11E-02	4.83E+00
5.83E-01	6.73E+03	276.90	4.11E-02	5.20E+00
6.25E-01	6.73E+03	276.90	4.11E-02	5.57E+00
6.67E-01	6.73E+03	276.90	4.11E-02	5.94E+00
7.08E-01	6.73E+03	276.90	4.11E-02	6.31E+00
7.50E-01	6.73E+03	276.90	4.11E-02	6.68E+00
7.92E-01	6.73E+03	276.90	4.11E-02	7.05E+00
8.33E-01	6.73E+03	276.90	4.11E-02	7.43E+00
8.75E-01	6.73E+03	276.90	4.11E-02	7.80E+00
9.17E-01	6.73E+03	276.90	4.11E-02	8.17E+00
9.58E-01	6.73E+03	276.90	4.11E-02	8.54E+00
1.00E+00	6.73E+03	276.90	4.11E-02	8.91E+00
1.04E+00	6.73E+03	276.90	4.11E-02	9.28E+00
1.08E+00	6.73E+03	276.90	4.11E-02	9.65E+00
1.12E+00	6.73E+03	276.90	4.11E-02	1.00E+01
1.17E+00	6.73E+03	276.90	4.11E-02	1.04E+01
1.21E+00	6.73E+03	276.90	4.11E-02	1.08E+01

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1.25E+00 6.73E+03   276.90 4.11E-02 1.11E+01
1.29E+00 6.73E+03   276.90 4.11E-02 1.15E+01
1.33E+00 6.73E+03   276.90 4.11E-02 1.19E+01
1.38E+00 6.73E+03   276.90 4.11E-02 1.23E+01
1.42E+00 6.73E+03   276.90 4.11E-02 1.26E+01
1.71E+00 6.73E+03   276.90 4.11E-02 1.52E+01
1.75E+00 6.73E+03   276.90 4.11E-02 1.56E+01
1.79E+00 6.73E+03   276.90 4.11E-02 1.60E+01
1.82E+00 6.73E+03   276.90 4.11E-02 1.62E+01
1.86E+00 6.73E+03   276.90 4.11E-02 1.66E+01
1.94E+00 6.73E+03   276.90 4.11E-02 1.73E+01
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IDENTIFICATION NUMBER: W-10
WELL NAME: TOWN OF VINTON
WELL YIELD: 9,619 FT3/DAY
WELL DEPTH (FT.): 705
SWL (FT.): 17
AIRLINE LENGTH (FT.): 400
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	1.35E+04	128.9	9.57E-03	3.09E-02
6.94E-03	1.35E+04	198.2	1.47E-02	6.19E-02
1.04E-02	1.33E+04	225.92	1.70E-02	9.28E-02
1.39E-02	1.29E+04	244.4	1.90E-02	1.24E-01
1.74E-02	1.21E+04	239.78	1.98E-02	1.55E-01
2.08E-02	1.15E+04	258.26	2.24E-02	1.86E-01
2.43E-02	1.12E+04	276.74	2.48E-02	2.17E-01
2.78E-02	1.12E+04	295.22	2.65E-02	2.48E-01
3.12E-02	1.06E+04	313.7	2.96E-02	2.78E-01
3.47E-02	1.04E+04	318.32	3.06E-02	3.09E-01
3.82E-02	1.04E+04	322.94	3.11E-02	3.40E-01
4.17E-02	1.04E+04	332.18	3.20E-02	3.71E-01
8.33E-02	9.62E+03	341.42	3.55E-02	7.43E-01
2.00E+00	9.62E+03	341.42	3.55E-02	1.78E+01

IDENTIFICATION NUMBER: W-11
WELL NAME: HOMEWOOD WELL #3
WELL YIELD: 32,705 FT3/DAY
WELL DEPTH (FT.): 420
SWL (FT.): 50
AIRLINE LENGTH (FT.): 399
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	2.89E+04	71.80	2.49E-03	3.09E-02
6.94E-03	2.89E+04	164.20	5.69E-03	6.19E-02
1.04E-02	2.89E+04	187.30	6.49E-03	9.28E-02
1.39E-02	2.89E+04	189.61	6.57E-03	1.24E-01
1.74E-02	2.89E+04	194.23	6.73E-03	1.55E-01
2.08E-02	2.89E+04	198.85	6.89E-03	1.86E-01
2.43E-02	2.89E+04	198.85	6.89E-03	2.17E-01
2.78E-02	2.89E+04	198.85	6.89E-03	2.48E-01
3.12E-02	2.89E+04	198.85	6.89E-03	2.78E-01
3.47E-02	2.89E+04	198.85	6.89E-03	3.09E-01
3.82E-02	2.89E+04	198.85	6.89E-03	3.40E-01
4.17E-02	2.89E+04	198.85	6.89E-03	3.71E-01
1.67E-01	3.27E+04	198.85	6.08E-03	1.49E+00
2.92E-01	3.27E+04	210.40	6.43E-03	2.60E+00
6.67E-01	3.27E+04	221.95	6.79E-03	5.94E+00
9.58E-01	3.27E+04	231.19	7.07E-03	8.54E+00
1.67E+00	3.27E+04	233.50	7.14E-03	1.49E+01
2.00E+00	3.27E+04	240.43	7.35E-03	1.78E+01

IDENTIFICATION NUMBER: W-12
WELL NAME: LONG RIDGE #2
WELL YIELD: 10,581 FT3/DAY
WELL DEPTH (FT.): 605
SWL (FT.): 330
AIRLINE LENGTH (FT.): 420
WELL DIAMETER (FT.): 0.5

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	1.06E+04	3.00	2.84E-04	5.56E-02
6.94E-03	1.06E+04	3.00	2.84E-04	1.11E-01
1.04E-02	1.06E+04	3.00	2.84E-04	1.67E-01
1.39E-02	1.06E+04	3.00	2.84E-04	2.22E-01
1.74E-02	1.06E+04	3.00	2.84E-04	2.78E-01
2.08E-02	1.06E+04	3.00	2.84E-04	3.33E-01
2.43E-02	1.06E+04	3.00	2.84E-04	3.89E-01
2.78E-02	1.06E+04	3.00	2.84E-04	4.44E-01
3.12E-02	1.06E+04	3.00	2.84E-04	5.00E-01
3.47E-02	1.06E+04	3.00	2.84E-04	5.56E-01
3.82E-02	1.06E+04	3.00	2.84E-04	6.11E-01
4.17E-02	1.06E+04	3.00	2.84E-04	6.67E-01
8.33E-02	1.06E+04	3.00	2.84E-04	1.33E+00
1.25E-01	1.06E+04	3.00	2.84E-04	2.00E+00
1.67E-01	1.06E+04	3.00	2.84E-04	2.67E+00
2.08E-01	1.06E+04	3.00	2.84E-04	3.33E+00
2.50E-01	1.06E+04	3.00	2.84E-04	4.00E+00
2.92E-01	1.06E+04	3.00	2.84E-04	4.67E+00
3.33E-01	1.04E+04	12.00	1.16E-03	5.33E+00
3.75E-01	1.04E+04	12.00	1.16E-03	6.00E+00
4.17E-01	1.04E+04	12.00	1.16E-03	6.67E+00
4.58E-01	1.04E+04	12.00	1.16E-03	7.33E+00
5.00E-01	1.04E+04	12.00	1.16E-03	8.00E+00
5.42E-01	1.04E+04	12.00	1.16E-03	8.67E+00
5.83E-01	1.04E+04	12.00	1.16E-03	9.33E+00
6.25E-01	1.04E+04	12.00	1.16E-03	1.00E+01
6.67E-01	1.04E+04	12.00	1.16E-03	1.07E+01
7.08E-01	1.02E+04	14.00	1.37E-03	1.13E+01
7.50E-01	1.02E+04	14.00	1.37E-03	1.20E+01
7.92E-01	1.02E+04	14.00	1.37E-03	1.27E+01
8.33E-01	1.02E+04	14.00	1.37E-03	1.33E+01
8.75E-01	1.02E+04	14.00	1.37E-03	1.40E+01
9.17E-01	1.02E+04	14.00	1.37E-03	1.47E+01
9.58E-01	1.02E+04	14.00	1.37E-03	1.53E+01
1.00E+00	1.02E+04	14.00	1.37E-03	1.60E+01
1.04E+00	1.02E+04	14.00	1.37E-03	1.67E+01
1.08E+00	1.02E+04	14.00	1.37E-03	1.73E+01
1.12E+00	1.02E+04	14.00	1.37E-03	1.80E+01
1.17E+00	1.00E+04	20.00	2.00E-03	1.87E+01
1.21E+00	1.02E+04	14.00	1.37E-03	1.93E+01

IDENTIFICATION NUMBER: W-13
WELL NAME: ARLINGTON FOREST
WELL YIELD: 8,176 FT3/DAY
WELL DEPTH (FT.): 236
SWL (FT.): 35
AIRLINE LENGTH (FT.): 209
WELL DIAMETER (FT.): 0.5

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
2.08E-02	9.62E+03	30.78	3.20E-03	3.33E-01
4.17E-02	9.62E+03	30.78	3.20E-03	6.67E-01
8.33E-02	8.18E+03	76.98	9.41E-03	1.33E+00
1.25E-01	8.18E+03	81.60	9.98E-03	2.00E+00
1.67E-01	8.18E+03	93.15	1.14E-02	2.67E+00
2.08E-01	8.18E+03	93.15	1.14E-02	3.33E+00
2.50E-01	8.18E+03	93.15	1.14E-02	4.00E+00
2.92E-01	8.18E+03	93.15	1.14E-02	4.67E+00
3.33E-01	8.18E+03	93.15	1.14E-02	5.33E+00
3.75E-01	8.18E+03	93.15	1.14E-02	6.00E+00
4.17E-01	8.18E+03	93.15	1.14E-02	6.67E+00
4.58E-01	8.18E+03	93.15	1.14E-02	7.33E+00
5.00E-01	8.18E+03	93.15	1.14E-02	8.00E+00
5.42E-01	8.18E+03	93.15	1.14E-02	8.67E+00
5.83E-01	8.18E+03	93.15	1.14E-02	9.33E+00
6.25E-01	8.18E+03	93.15	1.14E-02	1.00E+01
6.67E-01	8.18E+03	93.15	1.14E-02	1.07E+01
7.08E-01	8.18E+03	93.15	1.14E-02	1.13E+01
7.50E-01	8.18E+03	93.15	1.14E-02	1.20E+01
7.92E-01	8.18E+03	93.15	1.14E-02	1.27E+01
8.33E-01	8.18E+03	93.15	1.14E-02	1.33E+01
8.75E-01	8.18E+03	93.15	1.14E-02	1.40E+01
9.17E-01	8.18E+03	93.15	1.14E-02	1.47E+01
9.58E-01	8.18E+03	93.15	1.14E-02	1.53E+01
1.00E+00	8.18E+03	93.15	1.14E-02	1.60E+01
1.04E+00	8.18E+03	93.15	1.14E-02	1.67E+01
1.08E+00	8.18E+03	93.15	1.14E-02	1.73E+01
1.12E+00	8.18E+03	93.15	1.14E-02	1.80E+01
1.17E+00	8.18E+03	93.15	1.14E-02	1.87E+01
1.21E+00	8.18E+03	93.15	1.14E-02	1.93E+01
1.25E+00	8.18E+03	93.15	1.14E-02	2.00E+01
1.29E+00	8.18E+03	93.15	1.14E-02	2.07E+01

IDENTIFICATION NUMBER: W-14
WELL NAME: GARDEN PARK
WELL YIELD: 14,429 FT3/DAY
WELL DEPTH (FT.): 479
SWL (FT.): 29
AIRLINE LENGTH (FT.): 273
WELL DIAMETER (FT.): 0.50

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
1.04E-02	5.77E+03	96.16	1.67E-02	1.67E-01
2.08E-02	5.77E+03	96.16	1.67E-02	3.33E-01
3.12E-02	5.77E+03	96.16	1.67E-02	5.00E-01
4.17E-02	5.77E+03	96.16	1.67E-02	6.67E-01
5.21E-02	5.77E+03	96.16	1.67E-02	8.33E-01
6.25E-02	5.77E+03	96.16	1.67E-02	1.00E+00
7.29E-02	5.77E+03	96.16	1.67E-02	1.17E+00
8.33E-02	5.77E+03	96.16	1.67E-02	1.33E+00
9.37E-02	7.70E+03	96.16	1.25E-02	1.50E+00
1.04E-01	7.70E+03	100.78	1.31E-02	1.67E+00
1.15E-01	7.70E+03	100.78	1.31E-02	1.83E+00
1.25E-01	7.70E+03	100.78	1.31E-02	2.00E+00
1.35E-01	7.70E+03	100.78	1.31E-02	2.17E+00
1.46E-01	7.70E+03	100.78	1.31E-02	2.33E+00
1.56E-01	7.70E+03	100.78	1.31E-02	2.50E+00
1.67E-01	7.70E+03	100.78	1.31E-02	2.67E+00
1.77E-01	7.70E+03	100.78	1.31E-02	2.83E+00
1.87E-01	9.62E+03	100.78	1.05E-02	3.00E+00
1.98E-01	9.62E+03	100.78	1.05E-02	3.17E+00
2.08E-01	9.62E+03	100.78	1.05E-02	3.33E+00
2.19E-01	9.62E+03	100.78	1.05E-02	3.50E+00
2.29E-01	9.62E+03	100.78	1.05E-02	3.67E+00
2.40E-01	9.62E+03	100.78	1.05E-02	3.83E+00
2.50E-01	1.44E+04	100.78	6.98E-03	4.00E+00
2.60E-01	1.44E+04	100.78	6.98E-03	4.17E+00
2.71E-01	1.44E+04	100.78	6.98E-03	4.33E+00
2.81E-01	1.44E+04	105.40	7.30E-03	4.50E+00
2.92E-01	1.44E+04	105.40	7.30E-03	4.67E+00
3.02E-01	1.44E+04	105.40	7.30E-03	4.83E+00
3.12E-01	1.44E+04	105.40	7.30E-03	5.00E+00
3.23E-01	1.44E+04	105.40	7.30E-03	5.17E+00
3.33E-01	1.44E+04	105.40	7.30E-03	5.33E+00
3.44E-01	1.44E+04	105.40	7.30E-03	5.50E+00
3.54E-01	1.44E+04	105.40	7.30E-03	5.67E+00
3.65E-01	1.92E+04	105.40	5.48E-03	5.83E+00
3.75E-01	1.92E+04	110.02	5.72E-03	6.00E+00
3.85E-01	1.92E+04	110.02	5.72E-03	6.17E+00
3.96E-01	1.92E+04	110.02	5.72E-03	6.33E+00
4.06E-01	1.92E+04	110.02	5.72E-03	6.50E+00
4.17E-01	1.92E+04	110.02	5.72E-03	6.67E+00

IDENTIFICATION NUMBER: W-15
WELL NAME: HIDDEN VALLEY #3
WELL YIELD: 8,465 FT3/DAY
WELL DEPTH (FT.): 503
SWL (FT.): 120
AIRLINE LENGTH (FT.): 440
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
4.17E-02	1.15E+04	125.96	1.09E-02	3.71E-01
8.33E-02	1.15E+04	132.89	1.15E-02	7.43E-01
1.25E-01	1.15E+04	146.75	1.27E-02	1.11E+00
1.67E-01	1.10E+04	149.06	1.36E-02	1.49E+00
2.08E-01	1.06E+04	151.37	1.43E-02	1.86E+00
2.50E-01	9.81E+03	158.3	1.61E-02	2.23E+00
2.92E-01	9.04E+03	179.09	1.98E-02	2.60E+00
3.33E-01	8.66E+03	190.64	2.20E-02	2.97E+00
3.75E-01	8.66E+03	197.57	2.28E-02	3.34E+00
4.17E-01	8.66E+03	202.19	2.34E-02	3.71E+00
4.58E-01	8.46E+03	204.5	2.42E-02	4.08E+00
5.00E-01	8.46E+03	204.5	2.42E-02	4.46E+00
5.42E-01	8.46E+03	206.81	2.44E-02	4.83E+00
5.83E-01	8.46E+03	209.12	2.47E-02	5.20E+00
6.25E-01	8.46E+03	216.05	2.55E-02	5.57E+00
6.67E-01	8.46E+03	218.36	2.58E-02	5.94E+00
7.08E-01	8.46E+03	220.67	2.61E-02	6.31E+00
7.50E-01	8.46E+03	222.98	2.63E-02	6.68E+00
7.92E-01	8.46E+03	222.98	2.63E-02	7.05E+00
8.33E-01	8.46E+03	222.98	2.63E-02	7.43E+00
8.75E-01	8.46E+03	222.98	2.63E-02	7.80E+00
9.17E-01	8.46E+03	222.98	2.63E-02	8.17E+00
9.58E-01	8.46E+03	222.98	2.63E-02	8.54E+00
1.00E+00	8.46E+03	222.98	2.63E-02	8.91E+00
1.04E+00	8.46E+03	222.98	2.63E-02	9.28E+00

DENTIFICATION NUMBER: W-16
WELL NAME: HIDDEN VALLEY #9
WELL YIELD: 40,400 FT3/DAY
WELL DEPTH (FT.): 348
SWL (FT.): 44
AIRLINE LENGTH (FT.): 178
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	5.77E+04	52.00	9.01E-04	3.09E-02
6.94E-03	4.81E+04	77.00	1.60E-03	6.19E-02
1.04E-02	4.62E+04	103.00	2.23E-03	9.28E-02
1.39E-02	4.62E+04	136.00	2.95E-03	1.24E-01
1.74E-02	4.62E+04	136.00	2.95E-03	1.55E-01
2.08E-02	4.62E+04	136.00	2.95E-03	1.86E-01
2.43E-02	4.62E+04	136.00	2.95E-03	2.17E-01
2.78E-02	4.62E+04	136.00	2.95E-03	2.48E-01
3.12E-02	4.62E+04	136.00	2.95E-03	2.78E-01
3.47E-02	4.62E+04	136.00	2.95E-03	3.09E-01
3.82E-02	4.62E+04	136.00	2.95E-03	3.40E-01
4.17E-02	4.62E+04	136.00	2.95E-03	3.71E-01
5.21E-02	4.62E+04	136.00	2.95E-03	4.64E-01
6.25E-02	4.62E+04	136.00	2.95E-03	5.57E-01
7.29E-02	4.62E+04	136.00	2.95E-03	6.50E-01
8.33E-02	4.62E+04	136.00	2.95E-03	7.43E-01
1.04E-01	4.62E+04	136.00	2.95E-03	9.28E-01
1.25E-01	4.62E+04	136.00	2.95E-03	1.11E+00
1.46E-01	4.62E+04	136.00	2.95E-03	1.30E+00
1.67E-01	4.62E+04	136.00	2.95E-03	1.49E+00
1.87E-01	4.52E+04	136.00	3.01E-03	1.67E+00
2.08E-01	4.52E+04	136.00	3.01E-03	1.86E+00
2.29E-01	4.42E+04	136.00	3.07E-03	2.04E+00
2.50E-01	4.33E+04	136.00	3.14E-03	2.23E+00
2.92E-01	4.33E+04	136.00	3.14E-03	2.60E+00
3.33E-01	4.23E+04	136.00	3.21E-03	2.97E+00
3.75E-01	4.23E+04	136.00	3.21E-03	3.34E+00
4.17E-01	4.23E+04	136.00	3.21E-03	3.71E+00
4.58E-01	4.23E+04	136.00	3.21E-03	4.08E+00
5.00E-01	4.23E+04	136.00	3.21E-03	4.46E+00
5.42E-01	4.23E+04	136.00	3.21E-03	4.83E+00

IDENTIFICATION NUMBER: W-17
WELL NAME: CRAIG AVENUE #1
WELL YIELD: 50,020 FT3/DAY
WELL DEPTH (FT.): 625
SWL (FT.): 12
AIRLINE LENGTH (FT.): 224
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	6.35E+04	154.25	2.43E-03	3.09E-02
6.94E-03	5.39E+04	156.56	2.91E-03	6.19E-02
1.04E-02	5.39E+04	158.87	2.95E-03	9.28E-02
1.39E-02	5.39E+04	161.18	2.99E-03	1.24E-01
1.74E-02	5.39E+04	163.49	3.04E-03	1.55E-01
2.08E-02	5.39E+04	163.49	3.04E-03	1.86E-01
2.43E-02	5.00E+04	165.80	3.31E-03	2.17E-01
2.78E-02	5.00E+04	165.80	3.31E-03	2.48E-01
3.12E-02	5.00E+04	165.80	3.31E-03	2.78E-01
3.47E-02	5.00E+04	165.80	3.31E-03	3.09E-01
3.82E-02	5.00E+04	165.80	3.31E-03	3.40E-01
4.17E-02	5.00E+04	165.80	3.31E-03	3.71E-01
8.33E-02	5.00E+04	165.80	3.31E-03	7.43E-01
1.25E-01	5.00E+04	165.80	3.31E-03	1.11E+00
1.67E-01	5.00E+04	165.80	3.31E-03	1.49E+00
2.08E-01	5.00E+04	165.80	3.31E-03	1.86E+00
2.50E-01	5.00E+04	165.80	3.31E-03	2.23E+00
2.92E-01	5.00E+04	165.80	3.31E-03	2.60E+00
3.33E-01	5.00E+04	165.80	3.31E-03	2.97E+00
3.75E-01	5.00E+04	165.80	3.31E-03	3.34E+00
4.17E-01	5.00E+04	165.80	3.31E-03	3.71E+00
4.58E-01	5.00E+04	165.80	3.31E-03	4.08E+00
5.00E-01	5.00E+04	165.80	3.31E-03	4.46E+00
5.42E-01	5.00E+04	165.80	3.31E-03	4.83E+00
5.83E-01	5.00E+04	165.80	3.31E-03	5.20E+00
6.25E-01	5.00E+04	165.80	3.31E-03	5.57E+00
6.67E-01	5.00E+04	165.80	3.31E-03	5.94E+00
7.08E-01	5.00E+04	165.80	3.31E-03	6.31E+00
7.50E-01	5.00E+04	165.80	3.31E-03	6.68E+00
7.92E-01	5.00E+04	165.80	3.31E-03	7.05E+00
8.33E-01	5.00E+04	165.80	3.31E-03	7.43E+00

IDENTIFICATION NUMBER: W-18
WELL NAME: WILLIAM BYRD #2
WELL YIELD (gpm): 165.00
WELL DEPTH (FT.): 445.00
SWL (FT.): 121.00
AIRLINE LENGTH (FT.): 315.00
WELL DIAMETER (FT.): 0.67

TIME (MIN.)	Q (gpm)	GAUGE	DEPTH	Sw
5.00	170.00	72.00	148.68	27.68
10.00	170.00	71.00	150.99	29.99
15.00	170.00	71.00	150.99	29.99
20.00	170.00	71.00	150.99	29.99
25.00	170.00	70.00	153.30	32.30
30.00	168.00	70.00	153.30	32.30
35.00	168.00	70.00	153.30	32.30
40.00	168.00	70.00	153.30	32.30
45.00	168.00	70.00	153.30	32.30
50.00	168.00	70.00	153.30	32.30
55.00	168.00	70.00	153.30	32.30
60.00	168.00	70.00	153.30	32.30
120.00	165.00	66.00	162.54	41.54
180.00	165.00	62.00	171.78	50.78
240.00	165.00	60.00	176.40	55.40
300.00	165.00	58.00	181.02	60.02
360.00	165.00	57.00	183.33	62.33
420.00	165.00	56.00	185.64	64.64
480.00	165.00	55.00	187.95	66.95
540.00	165.00	54.00	190.26	69.26
600.00	165.00	53.00	192.57	71.57
660.00	165.00	52.00	194.88	73.88
720.00	165.00	51.00	197.19	76.19
1740.00	165.00	50.00	199.50	78.50
1860.00	165.00	49.00	201.81	80.81
2400.00	165.00	48.00	204.12	83.12
2760.00	165.00	47.00	206.43	85.43

IDENTIFICATION NUMBER: W-19
WELL NAME: BROOKWOOD #3
WELL YIELD: 2,309 FT3/DAY
WELL DEPTH (FT.): 225
SWL (FT.): 6
AIRLINE LENGTH (FT.): 210
WELL DIAMETER (FT.): 0.50

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
1.04E-02	2.89E+03	5.34	1.85E-03	1.67E-01
2.08E-02	2.89E+03	9.96	3.45E-03	3.33E-01
3.12E-02	2.89E+03	14.58	5.05E-03	5.00E-01
4.17E-02	2.89E+03	19.20	6.65E-03	6.67E-01
5.21E-02	2.89E+03	23.82	8.25E-03	8.33E-01
6.25E-02	2.89E+03	28.44	9.86E-03	1.00E+00
7.29E-02	2.89E+03	33.06	1.15E-02	1.17E+00
8.33E-02	2.89E+03	35.37	1.23E-02	1.33E+00
1.04E-01	2.89E+03	37.68	1.31E-02	1.67E+00
1.25E-01	2.89E+03	44.61	1.55E-02	2.00E+00
1.46E-01	2.89E+03	49.23	1.71E-02	2.33E+00
1.67E-01	2.89E+03	56.16	1.95E-02	2.67E+00
1.87E-01	2.89E+03	60.78	2.11E-02	3.00E+00
2.08E-01	2.89E+03	67.71	2.35E-02	3.33E+00
2.50E-01	2.89E+03	72.33	2.51E-02	4.00E+00
2.92E-01	2.89E+03	76.95	2.67E-02	4.67E+00
3.33E-01	2.89E+03	83.88	2.91E-02	5.33E+00
3.75E-01	2.89E+03	90.81	3.15E-02	6.00E+00
4.17E-01	2.89E+03	100.05	3.47E-02	6.67E+00
4.58E-01	2.40E+03	104.67	4.35E-02	7.33E+00
5.00E-01	2.40E+03	106.98	4.45E-02	8.00E+00
5.42E-01	2.40E+03	111.60	4.64E-02	8.67E+00
5.83E-01	2.40E+03	118.53	4.93E-02	9.33E+00
6.25E-01	2.40E+03	123.15	5.12E-02	1.00E+01
6.67E-01	2.40E+03	125.46	5.22E-02	1.07E+01
7.08E-01	2.40E+03	132.39	5.51E-02	1.13E+01
7.50E-01	2.40E+03	137.01	5.70E-02	1.20E+01
7.92E-01	2.40E+03	139.32	5.79E-02	1.27E+01
8.33E-01	2.40E+03	146.25	6.08E-02	1.33E+01
8.75E-01	2.40E+03	148.56	6.18E-02	1.40E+01
9.17E-01	2.40E+03	150.87	6.27E-02	1.47E+01

IDENTIFICATION NUMBER: W-20
WELL NAME: BROOKWOOD #1
WELL YIELD: 3,463 FT3/DAY
WELL DEPTH (FT.): 325
SWL (FT.): 12
AIRLINE LENGTH (FT.): 278
WELL DIAMETER (FT.): 0.50

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
1.04E-02	2.89E+03	4.97	1.72E-03	1.67E-01
2.08E-02	2.89E+03	11.90	4.12E-03	3.33E-01
4.17E-02	3.08E+03	35.00	1.14E-02	6.67E-01
6.25E-02	3.08E+03	44.24	1.44E-02	1.00E+00
8.33E-02	3.46E+03	60.41	1.74E-02	1.33E+00
1.04E-01	3.46E+03	65.03	1.88E-02	1.67E+00
1.25E-01	3.46E+03	74.27	2.14E-02	2.00E+00
1.46E-01	3.46E+03	78.89	2.28E-02	2.33E+00
1.67E-01	3.85E+03	99.68	2.59E-02	2.67E+00
2.08E-01	4.04E+03	118.16	2.92E-02	3.33E+00
2.50E-01	4.04E+03	145.88	3.61E-02	4.00E+00
2.92E-01	4.04E+03	171.29	4.24E-02	4.67E+00
3.33E-01	3.85E+03	187.46	4.87E-02	5.33E+00
3.75E-01	2.89E+03	208.25	7.22E-02	6.00E+00
4.17E-01	2.89E+03	210.56	7.30E-02	6.67E+00
4.58E-01	2.50E+03	210.56	8.42E-02	7.33E+00
5.00E-01	2.50E+03	210.56	8.42E-02	8.00E+00
5.42E-01	2.50E+03	210.56	8.42E-02	8.67E+00
5.83E-01	2.50E+03	210.56	8.42E-02	9.33E+00
6.25E-01	2.50E+03	210.56	8.42E-02	1.00E+01
6.67E-01	2.50E+03	212.87	8.51E-02	1.07E+01
7.08E-01	2.50E+03	212.87	8.51E-02	1.13E+01
7.50E-01	2.50E+03	212.87	8.51E-02	1.20E+01
7.92E-01	2.50E+03	217.49	8.70E-02	1.27E+01
8.33E-01	2.50E+03	217.49	8.70E-02	1.33E+01
8.75E-01	2.40E+03	217.49	9.04E-02	1.40E+01
9.17E-01	2.40E+03	217.49	9.04E-02	1.47E+01
9.58E-01	2.40E+03	217.49	9.04E-02	1.53E+01
1.00E+00	2.40E+03	217.49	9.04E-02	1.60E+01
1.04E+00	2.40E+03	217.49	9.04E-02	1.67E+01
1.08E+00	2.40E+03	217.49	9.04E-02	1.73E+01

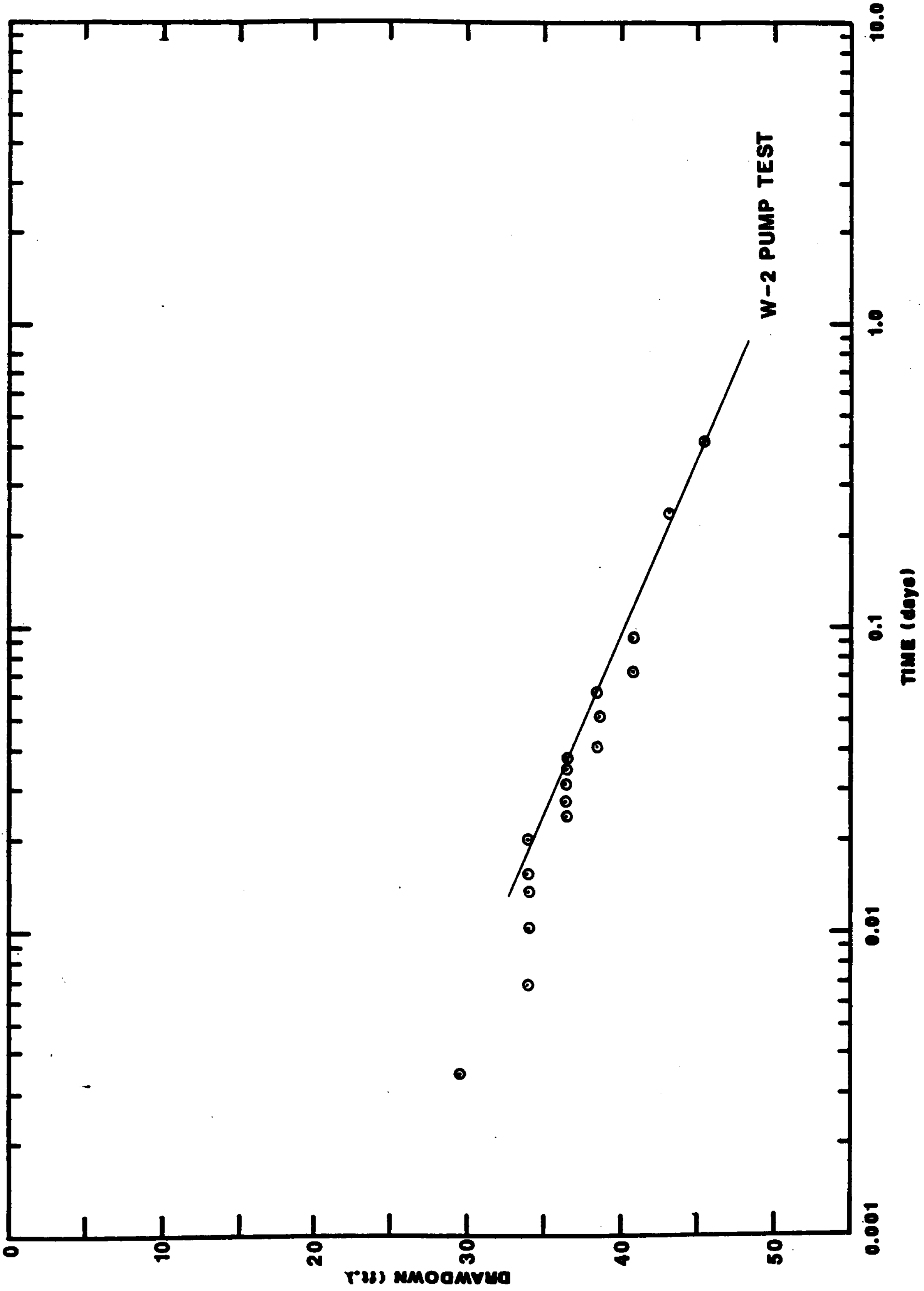
IDENTIFICATION NUMBER: W-21
WELL NAME: WILLIAM BYRD #3
WELL YIELD: 27,511 FT3/DAY
WELL DEPTH (FT.): 485
SWL (FT.): 149
AIRLINE LENGTH (FT.): 378
WELL DIAMETER (FT.): 0.67

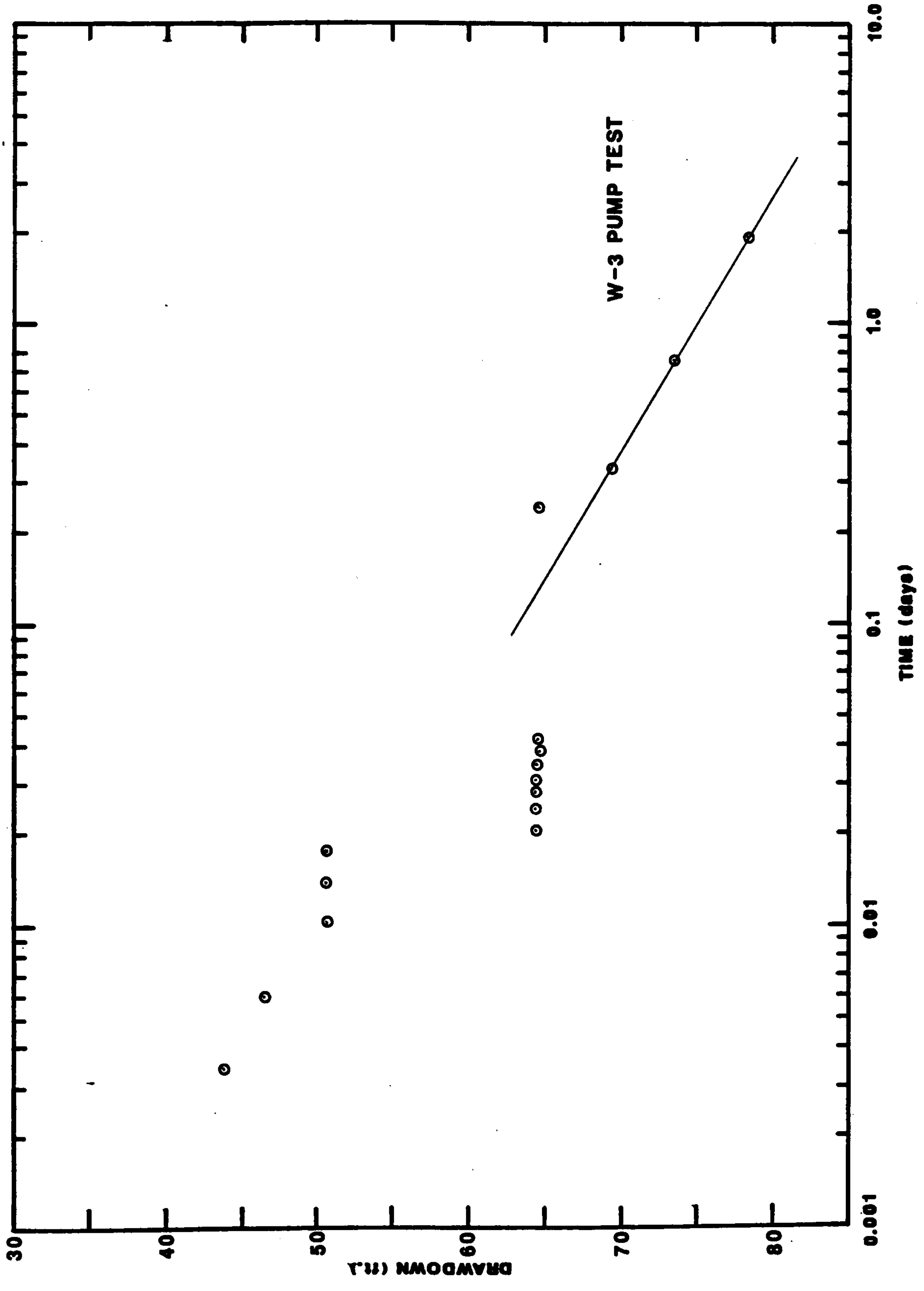
TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
3.47E-03	1.92E+04	34.96	1.82E-03	3.09E-02
6.94E-03	1.92E+04	78.85	4.10E-03	6.19E-02
1.04E-02	1.92E+04	83.47	4.34E-03	9.28E-02
1.39E-02	1.92E+04	90.40	4.70E-03	1.24E-01
1.74E-02	1.92E+04	90.40	4.70E-03	1.55E-01
2.08E-02	2.12E+04	95.02	4.49E-03	1.86E-01
2.43E-02	2.12E+04	108.88	5.15E-03	2.17E-01
2.78E-02	2.12E+04	108.88	5.15E-03	2.48E-01
3.12E-02	2.31E+04	136.60	5.92E-03	2.78E-01
3.47E-02	2.31E+04	159.70	6.92E-03	3.09E-01
3.82E-02	2.31E+04	159.70	6.92E-03	3.40E-01
4.17E-02	2.40E+04	182.80	7.60E-03	3.71E-01
1.67E-01	2.40E+04	187.42	7.79E-03	1.49E+00
2.92E-01	2.50E+04	201.28	8.05E-03	2.60E+00
4.17E-01	2.69E+04	205.90	7.64E-03	3.71E+00
5.00E-01	2.89E+04	210.52	7.30E-03	4.46E+00
1.12E+00	2.89E+04	212.83	7.38E-03	1.00E+01
1.21E+00	2.89E+04	215.14	7.46E-03	1.08E+01
2.00E+00	2.89E+04	219.76	7.62E-03	1.78E+01

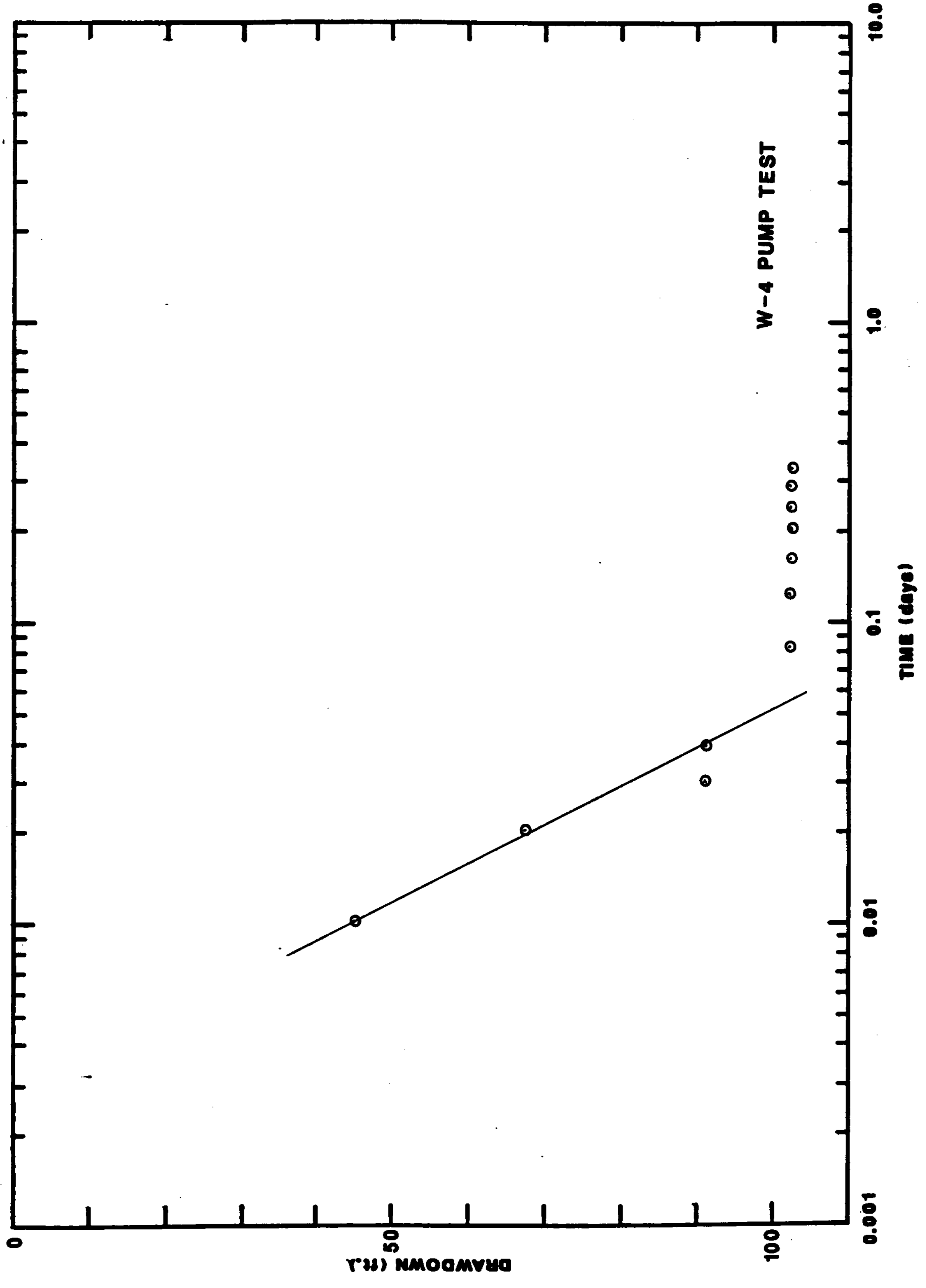
APPENDIX IV

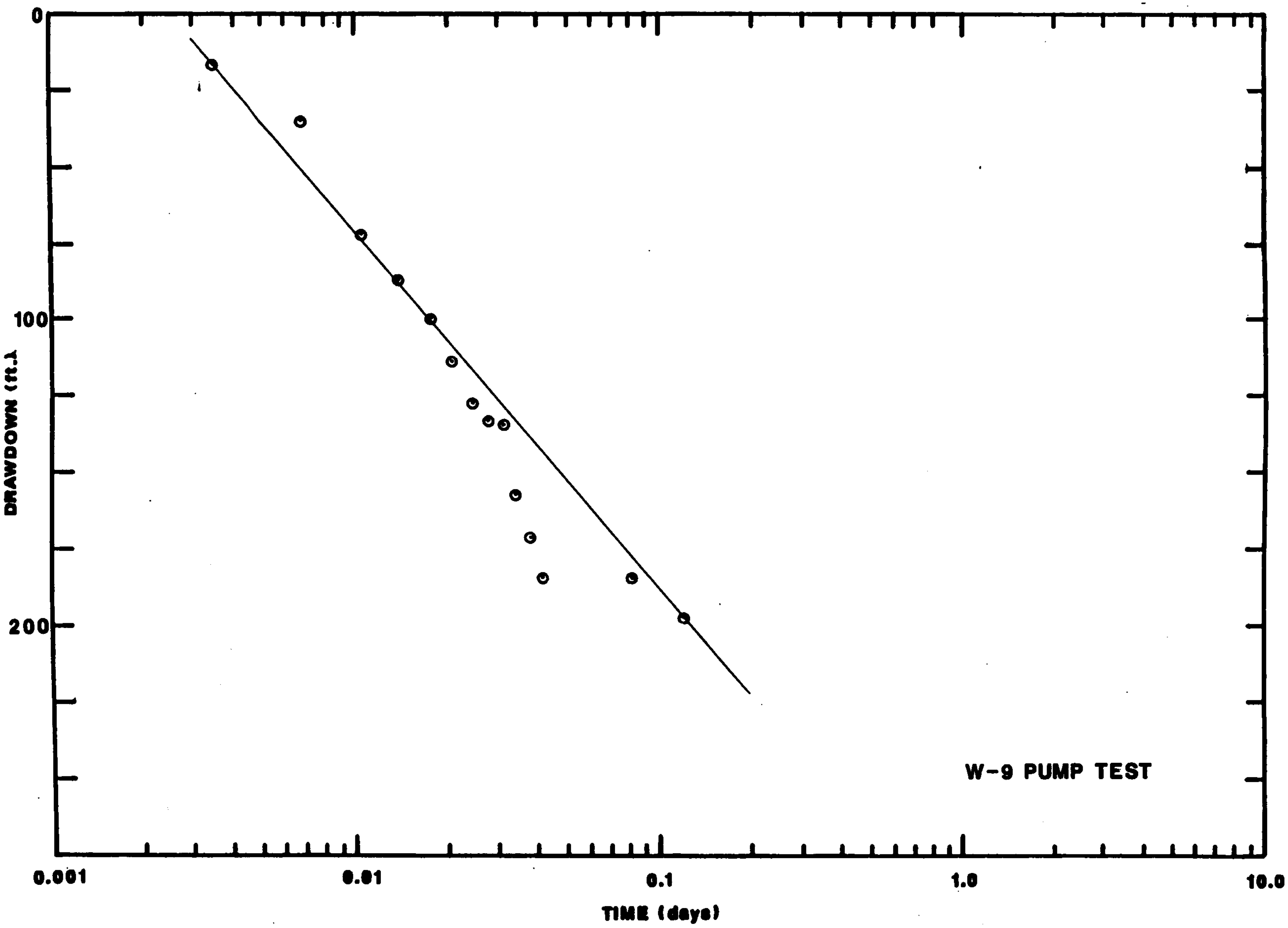
PRODUCTION WELL DRAWDOWN GRAPHS
(Type I)
(Type II)
(Type III)

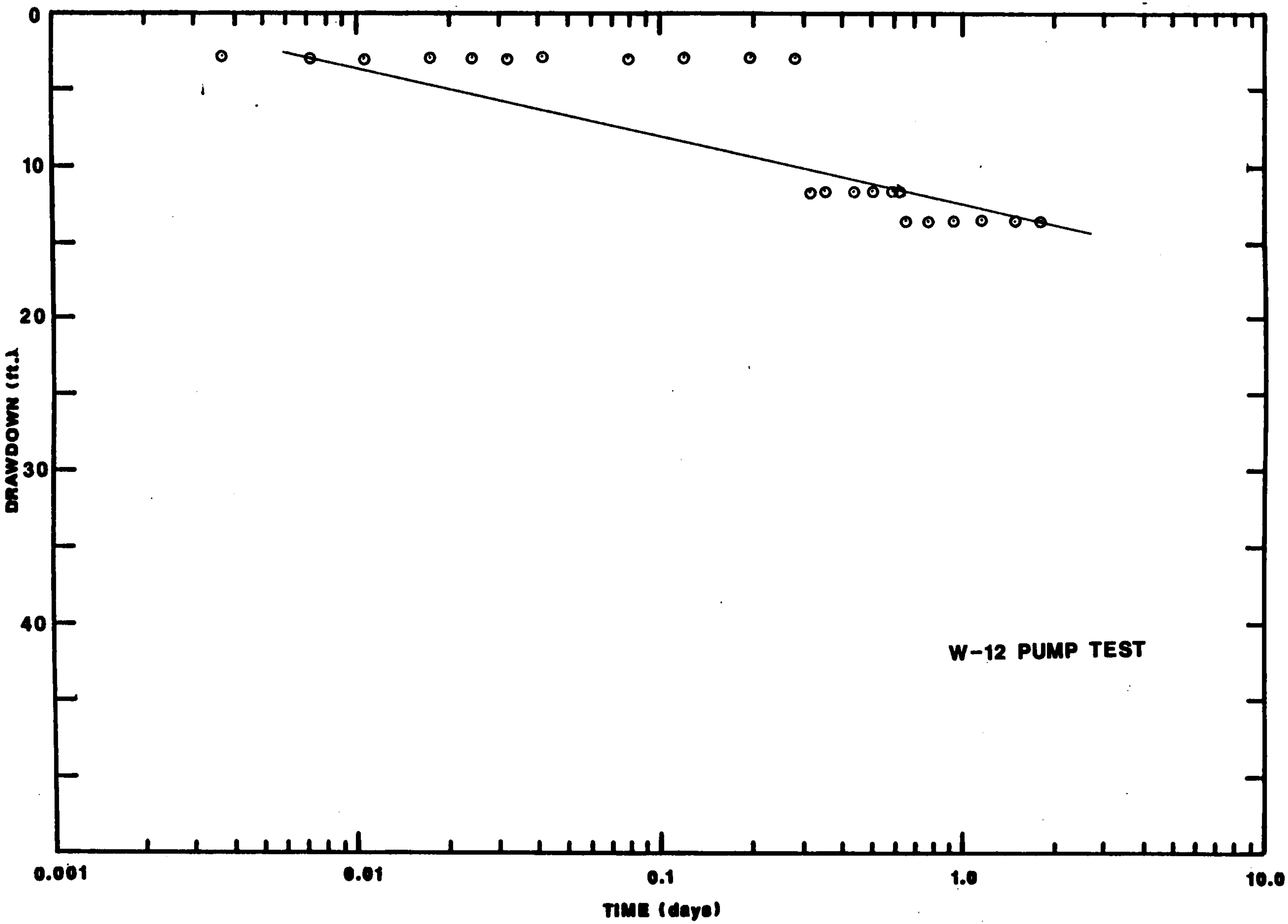
Type I Drawdown Graphs

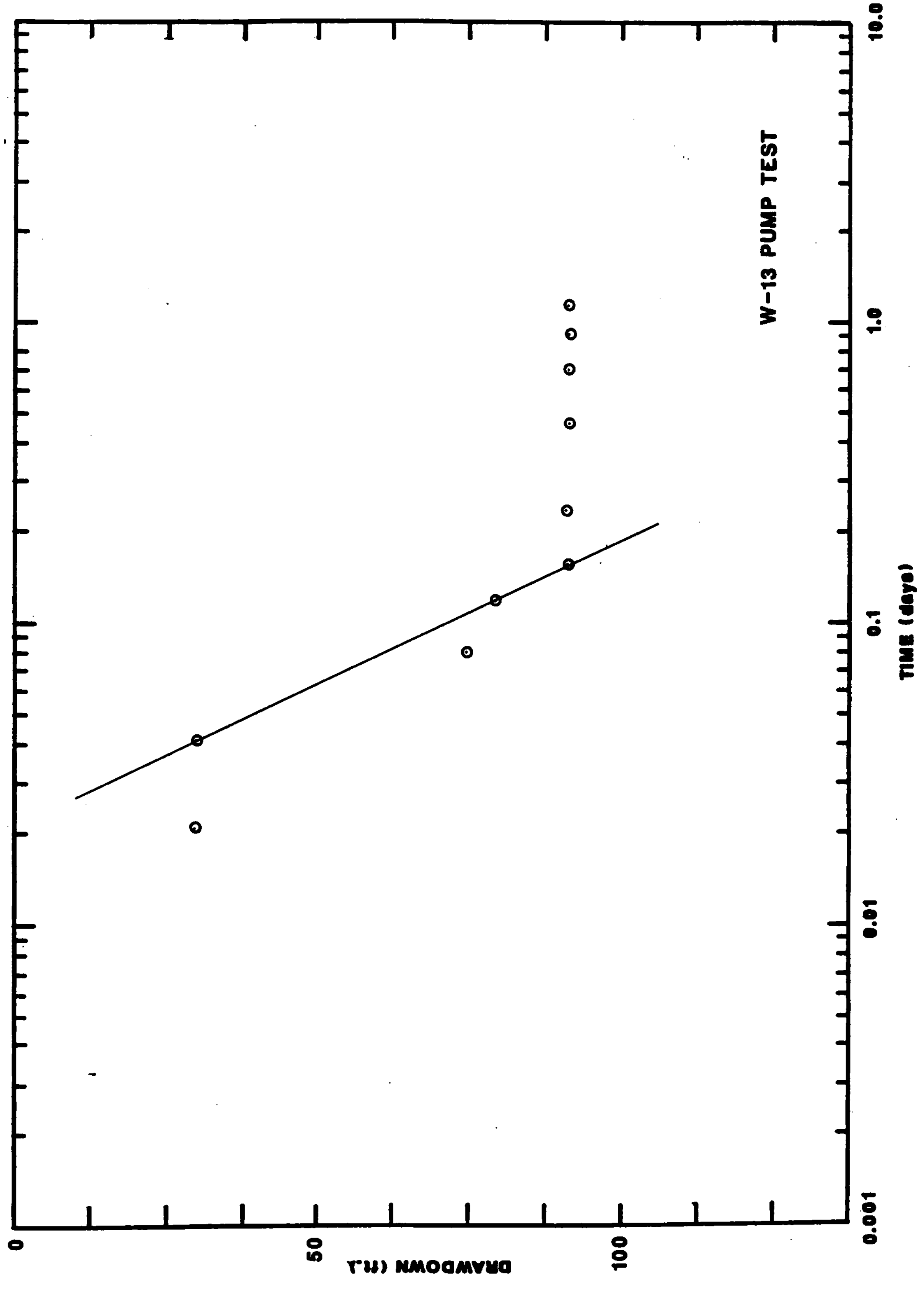

W–2 PUMP TEST
TIME (days)
0.001
0.01
0.1
1.0
10.0
DRAWDOWN (ft.)
0
10
20
30
40
50

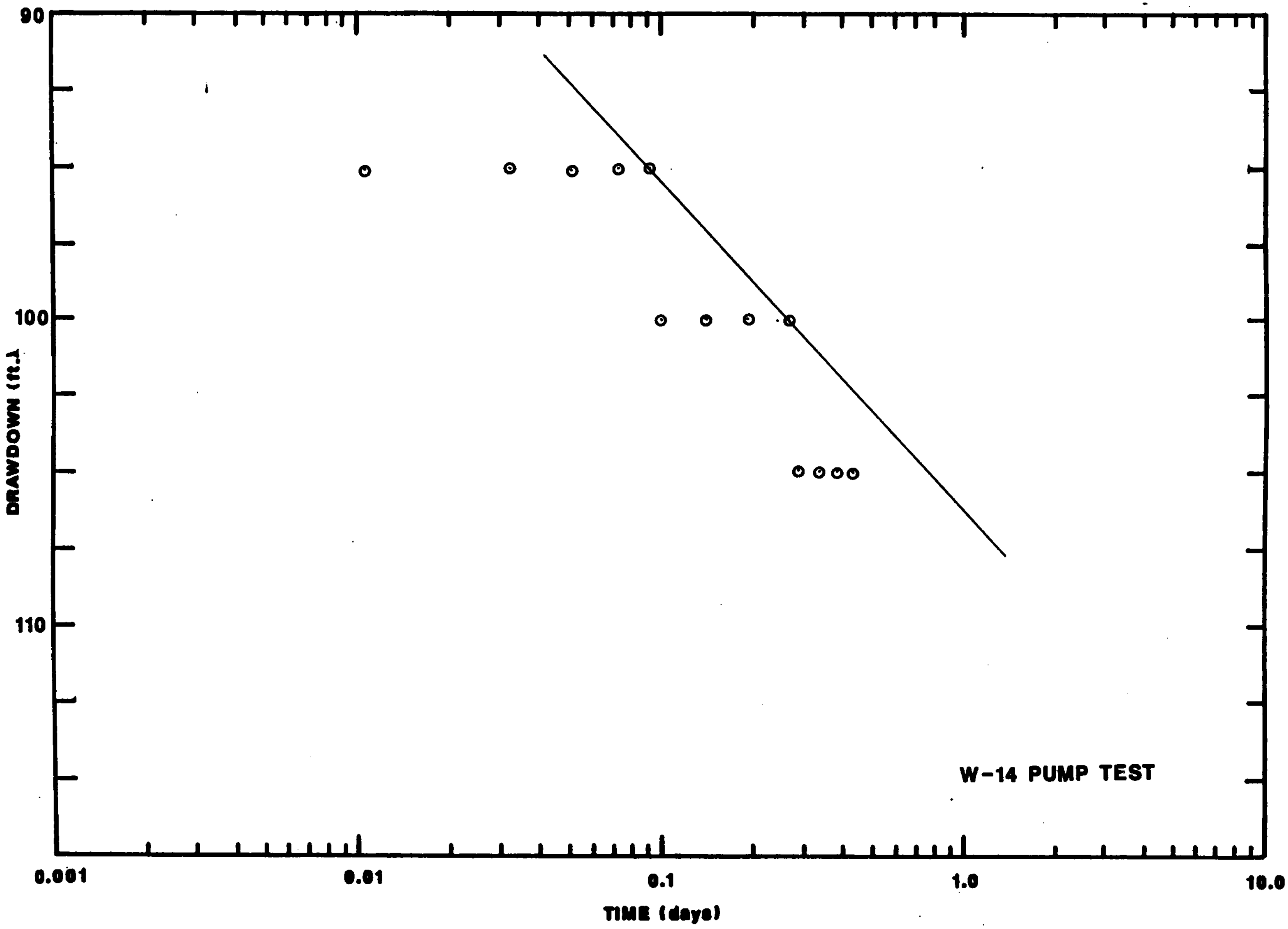

W-3 PUMP TEST
DRAWDOWN (ft.)
30
40
50
60
70
80
TIME (days)
0.001
0.01
0.1
1.0
10.0

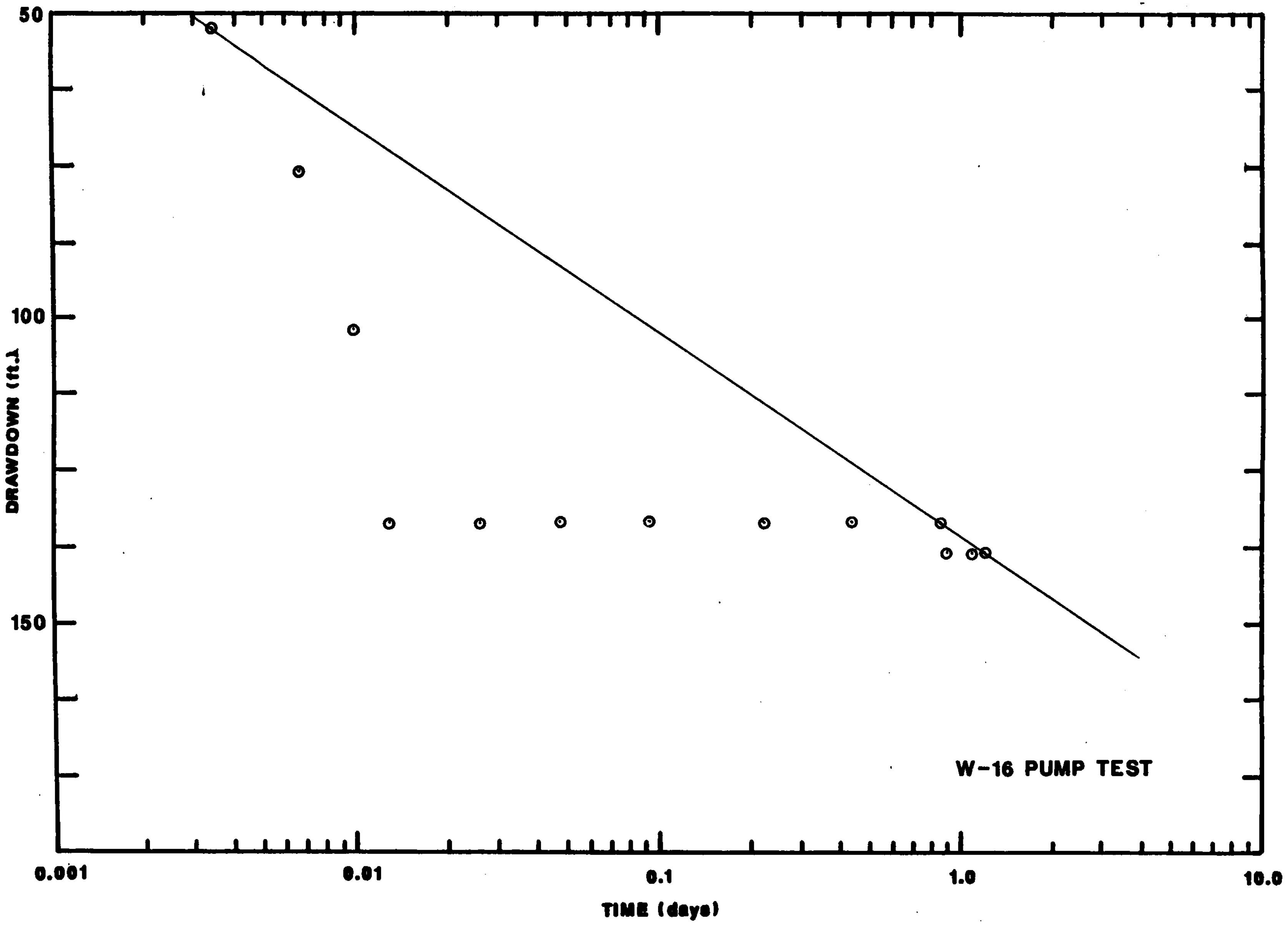

W-4 PUMP TEST
TIME (days)
0.001
0.01
0.1
1.0
10.0
DRAWDOWN (ft.)
0
50
100

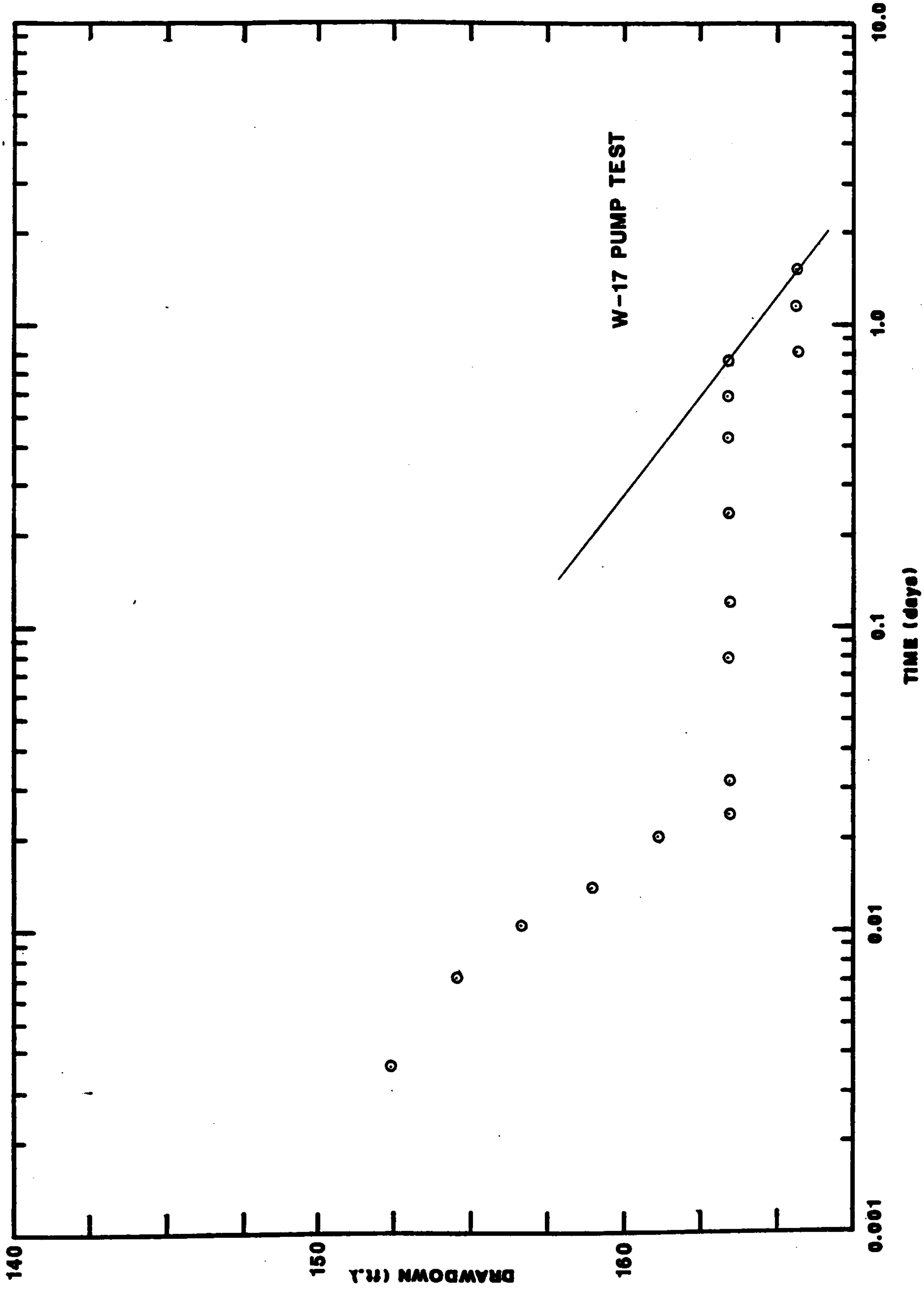

W-9 PUMP TEST
DRAWDOWN (ft.)
0
100
200
TIME (days)
0.001
0.01
0.1
1.0
10.0


W-12 PUMP TEST
DRAWDOWN (ft.)
0
10
20
30
40
TIME (days)
0.001
0.01
0.1
1.0
10.0

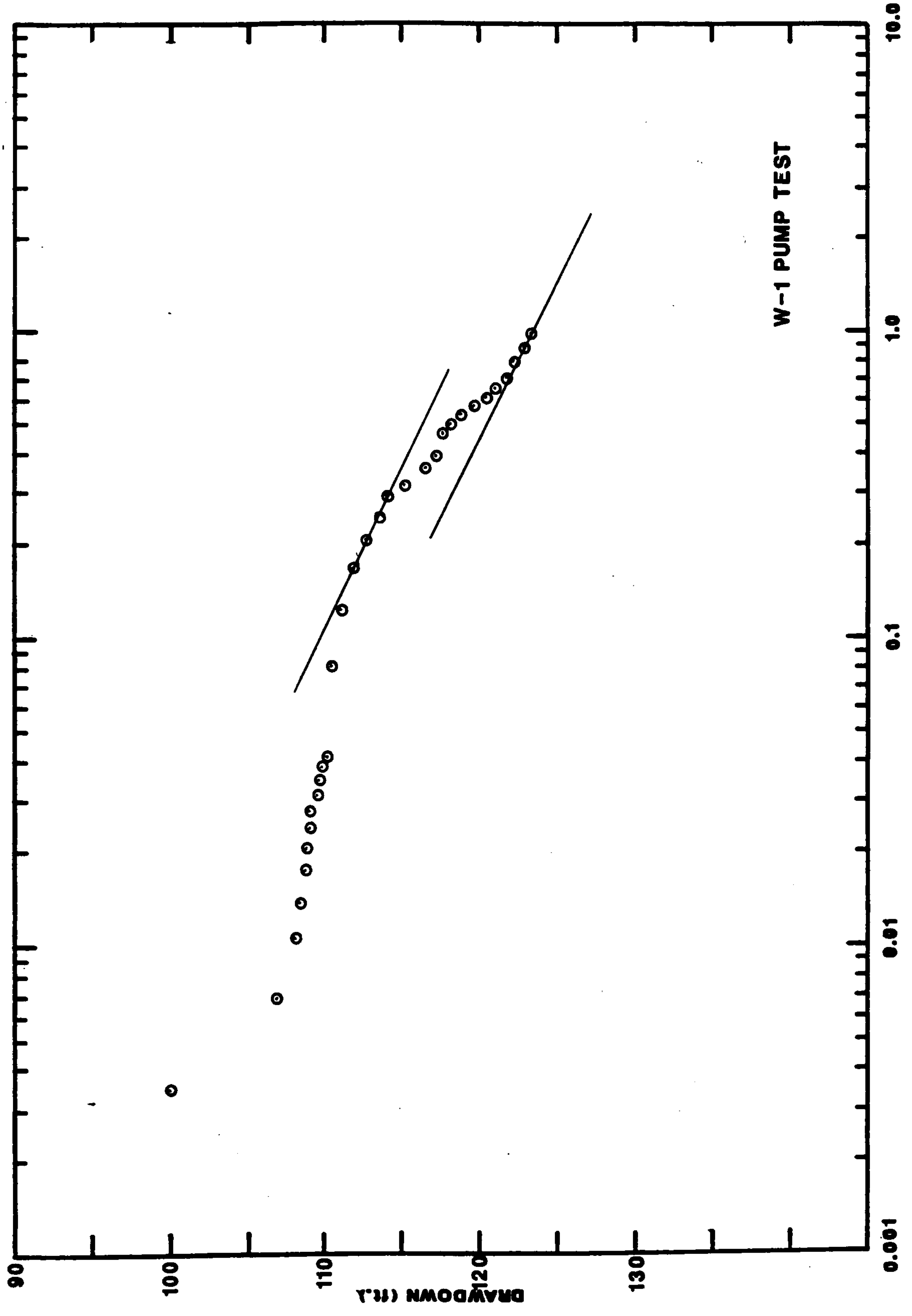

W-13 PUMP TEST
TIME (days)
0.001
0.01
0.1
1.0
10.0
DRAWDOWN (ft.)
0
50
100

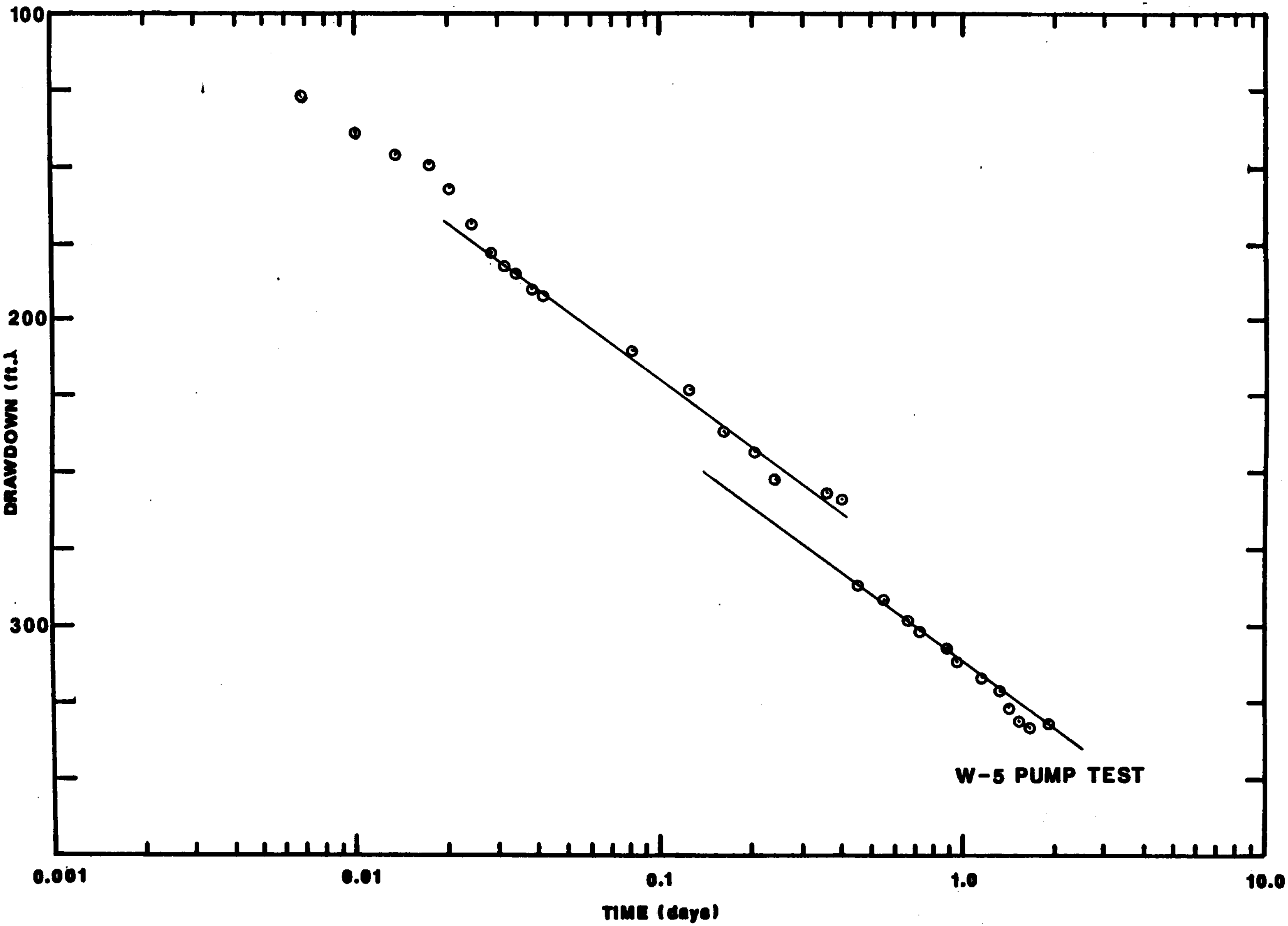

W-14 PUMP TEST
DRAWDOWN (ft.)
90
100
110
TIME (days)
0.001
0.01
0.1
1.0
10.0

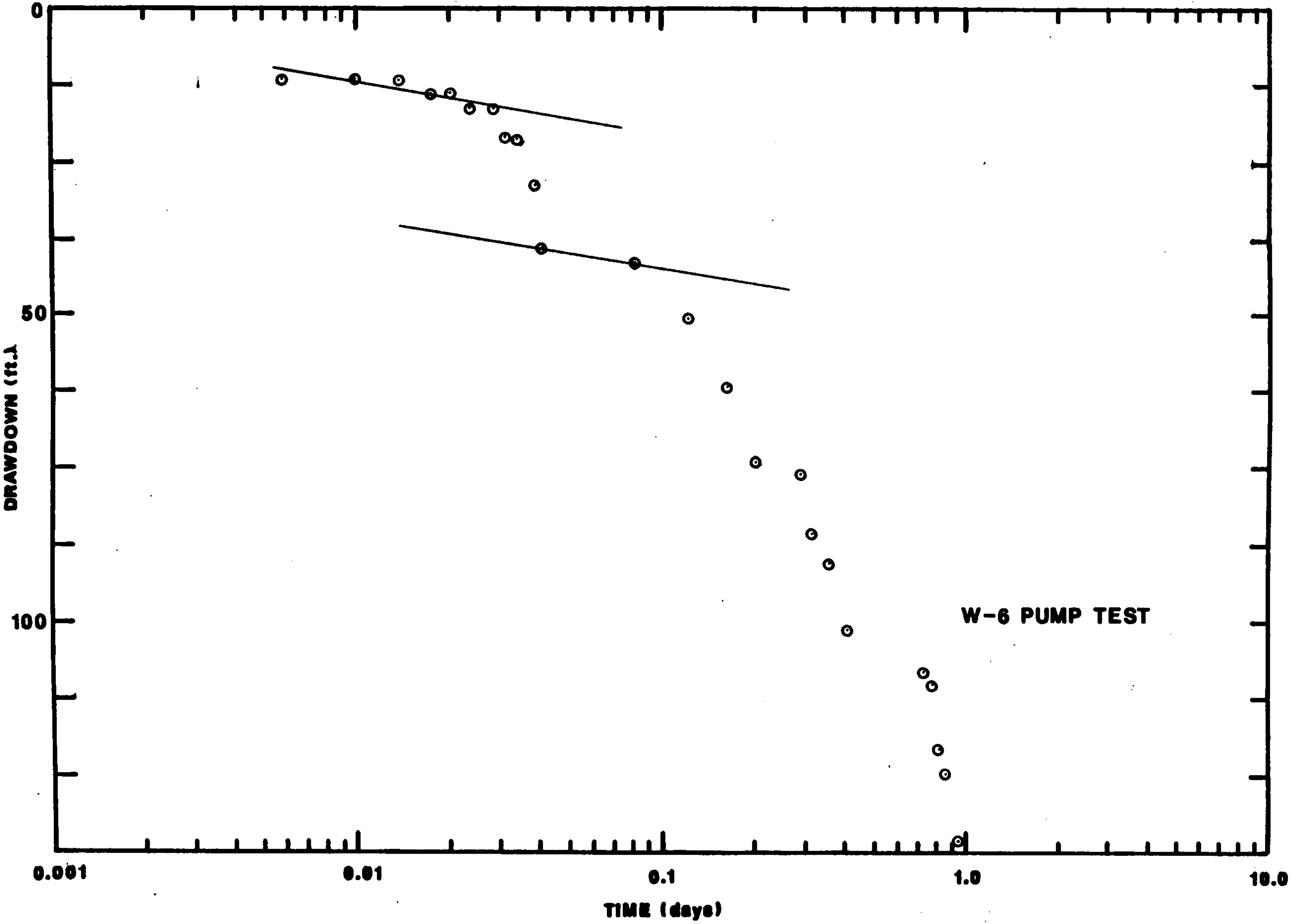

50
100
150
DRAWDOWN (ft.)
0.001
0.01
0.1
1.0
10.0
TIME (days)
W-16 PUMP TEST

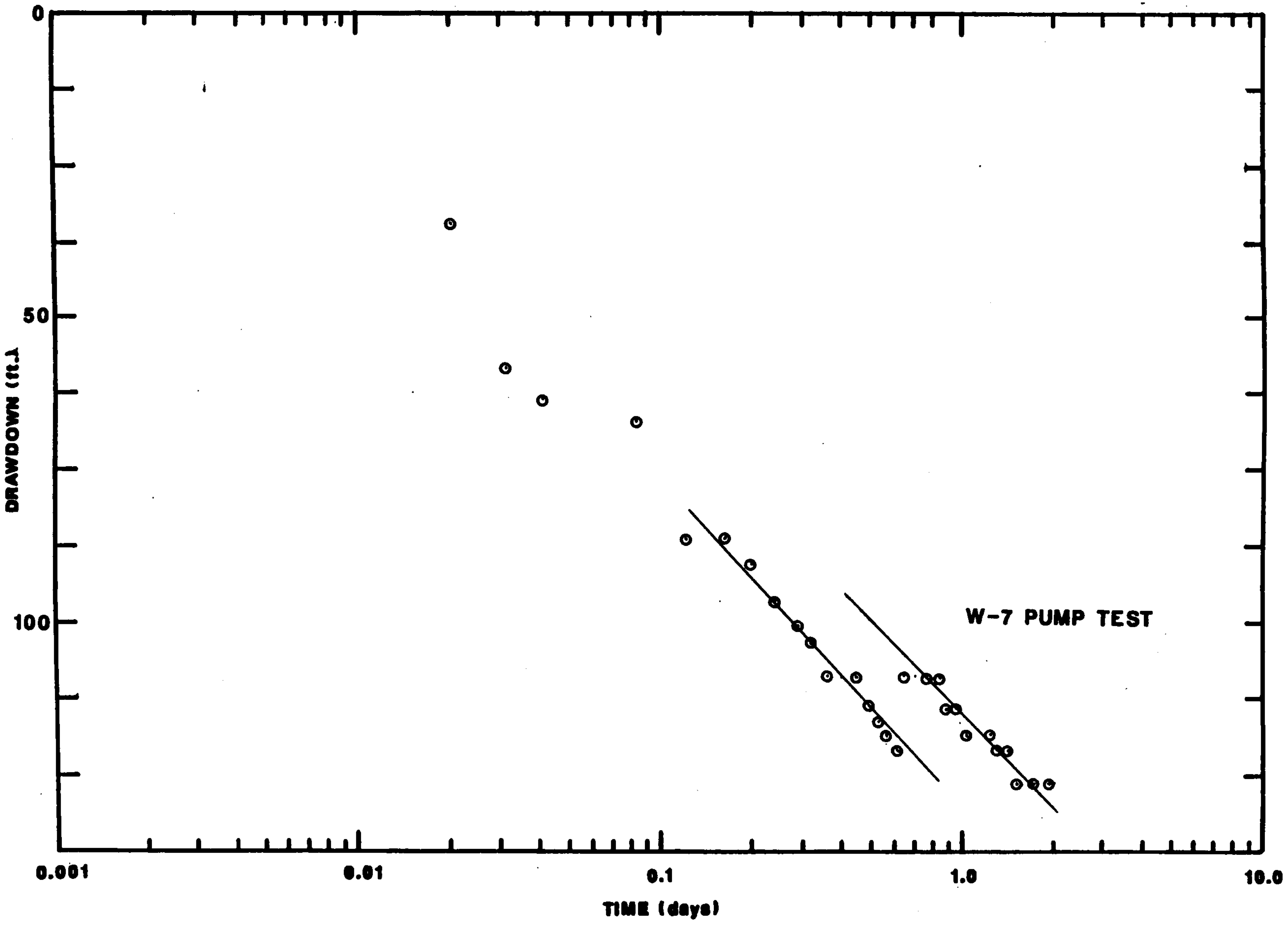

W-17 PUMP TEST
DRAWDOWN (ft.)
140
150
160
TIME (days)
0.001
0.01
0.1
1.0
10.0

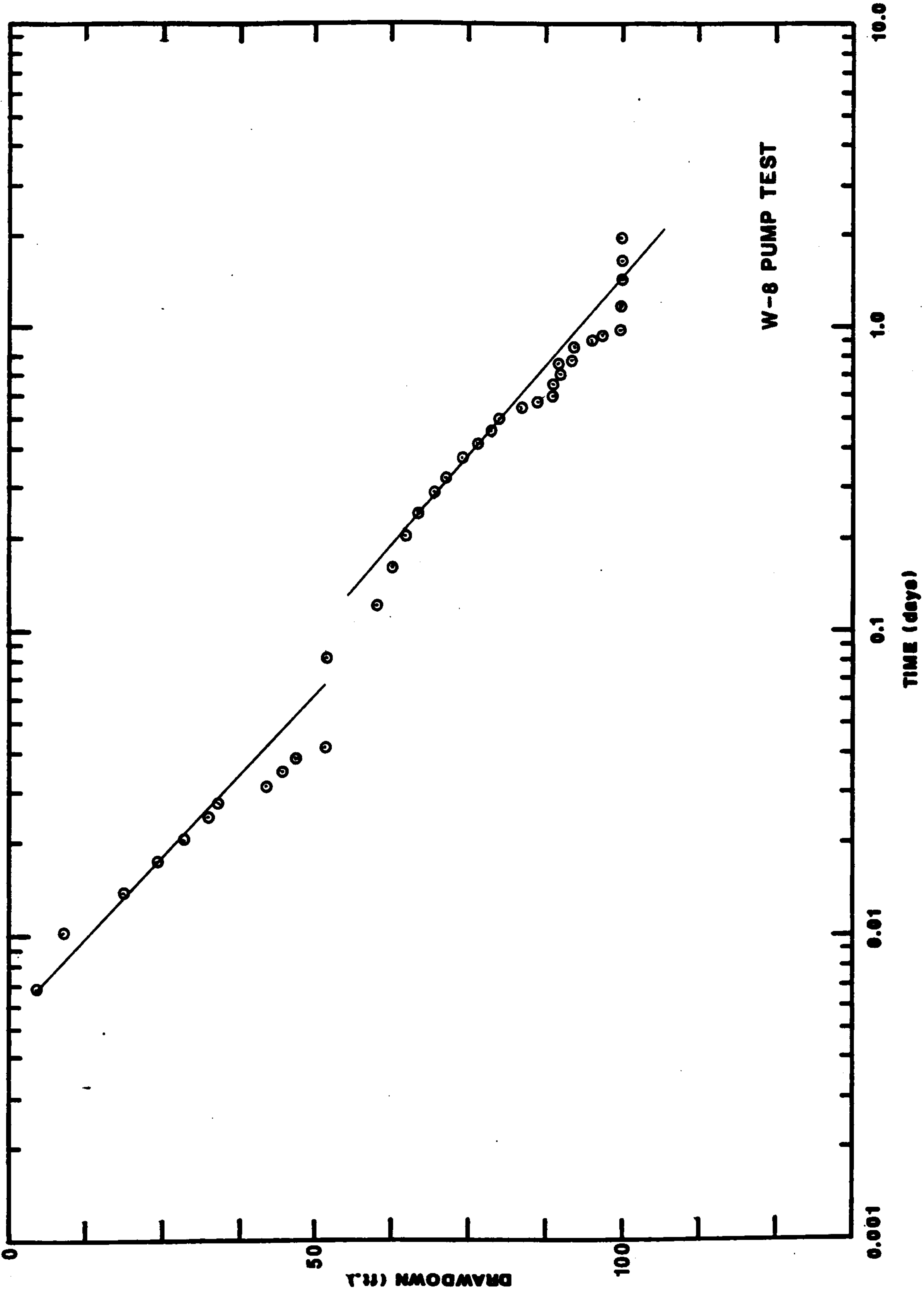
Type II Drawdown Graphs

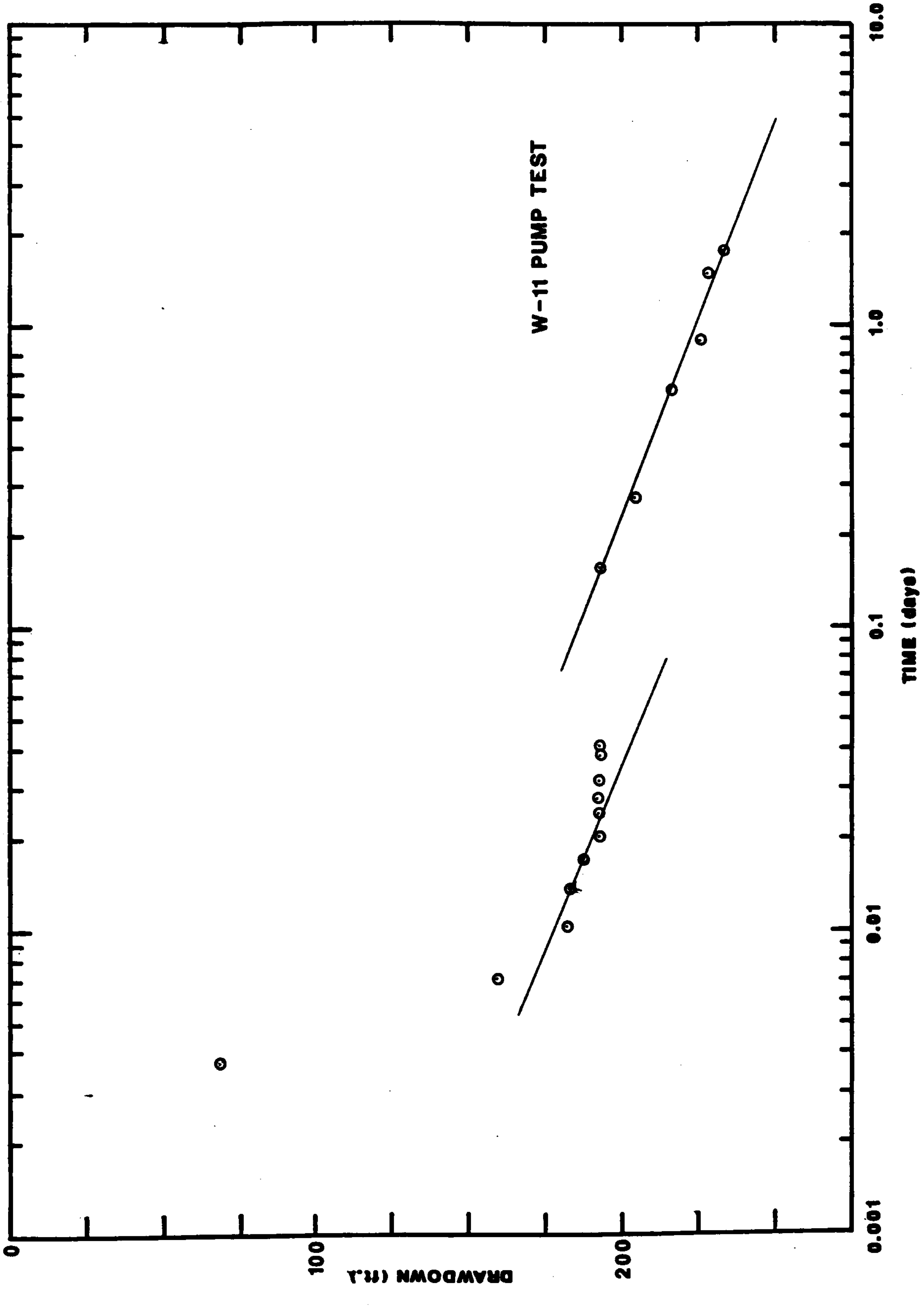

W-1 PUMP TEST
TIME (days)
0.001
0.01
0.1
1.0
10.0
DRAWDOWN (ft.)
90
100
110
120
130

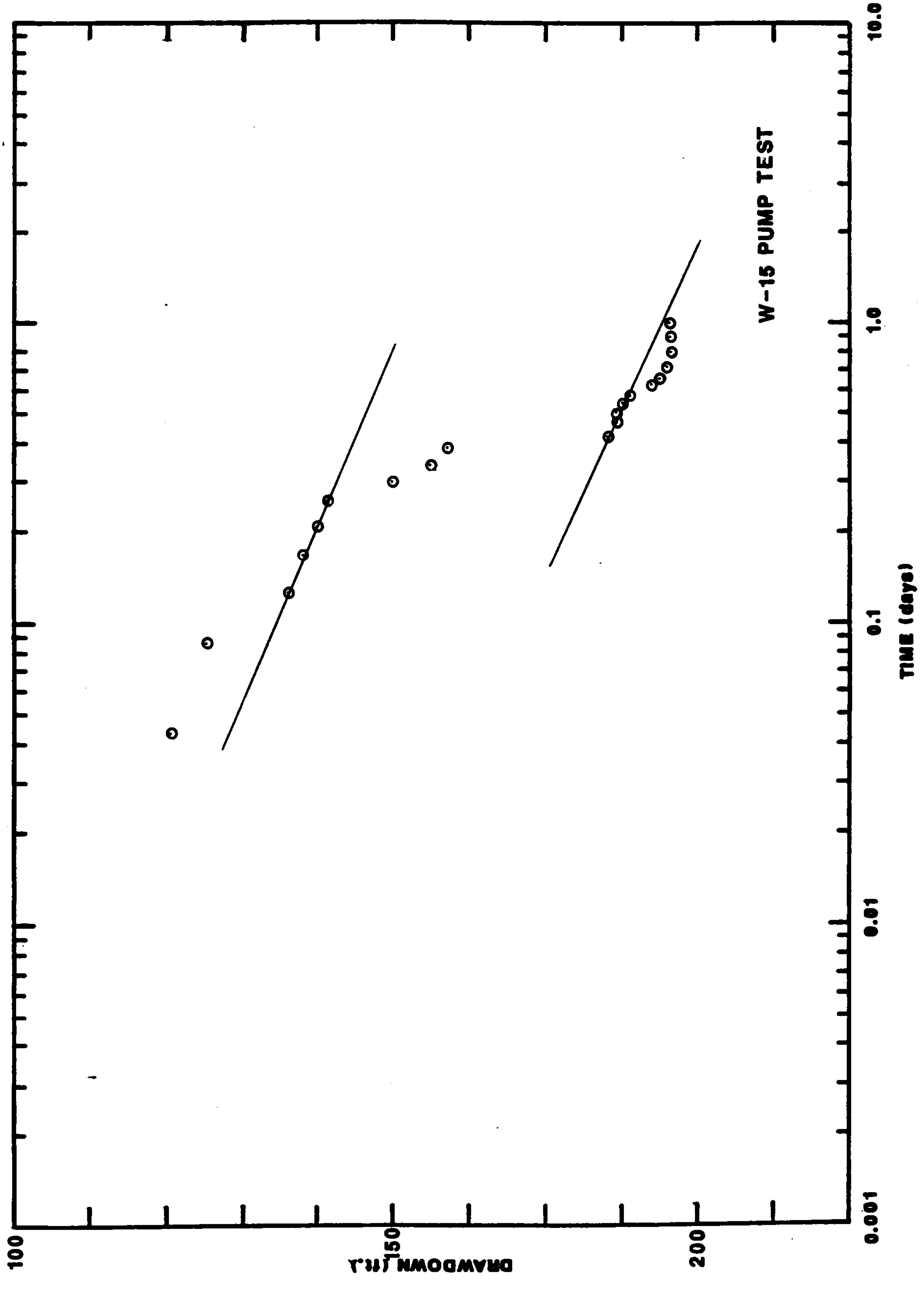

W-5 PUMP TEST
DRAWDOWN (ft.)
100
200
300
TIME (days)
0.001
0.01
0.1
1.0
10.0

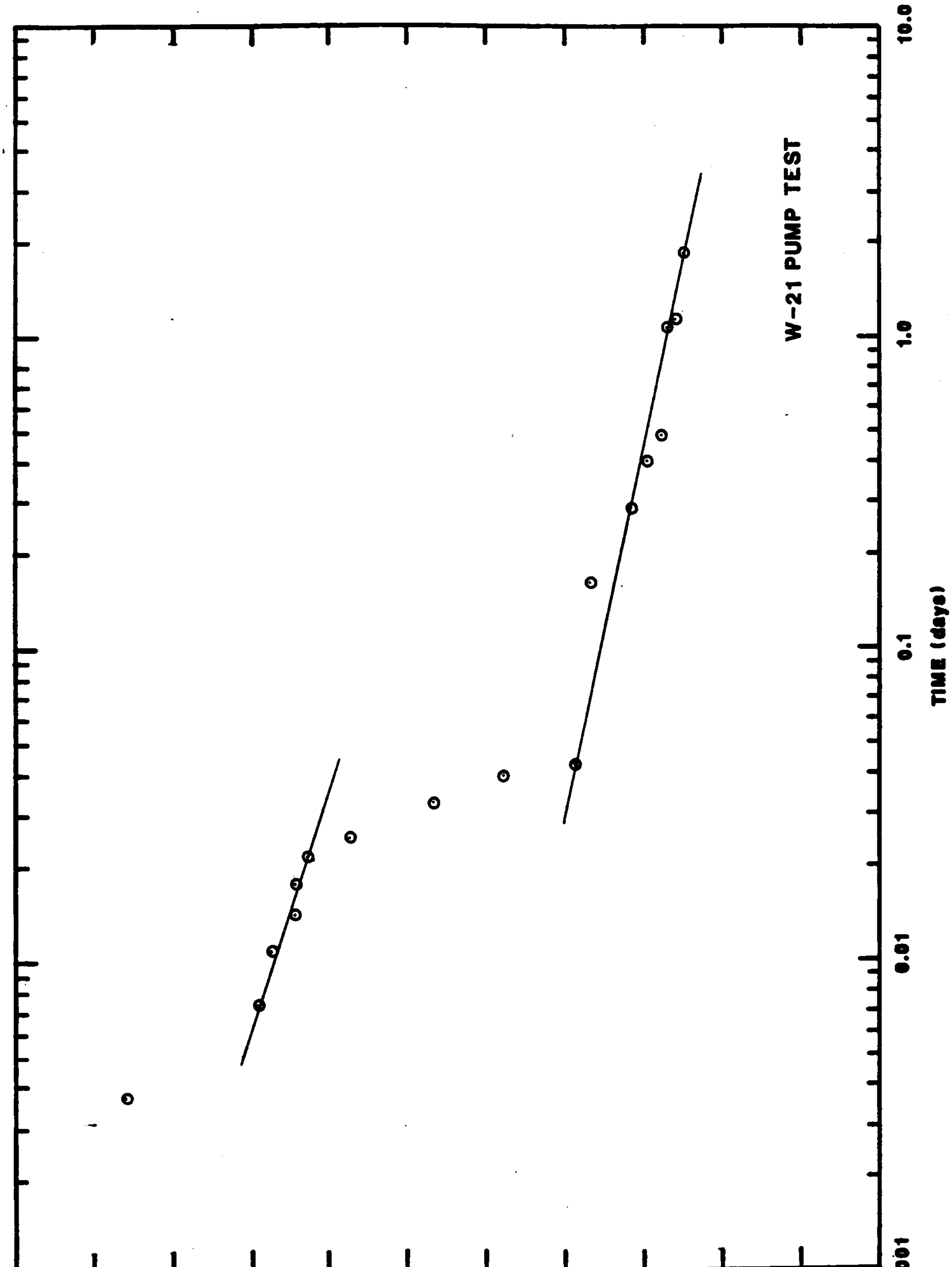

W-6 PUMP TEST
DRAWDOWN (ft.)
0
50
100
TIME (days)
0.001
0.01
0.1
1.0
10.0


W-7 PUMP TEST
DRAWDOWN (ft.)
0
50
100
TIME (days)
0.001
0.01
0.1
1.0
10.0

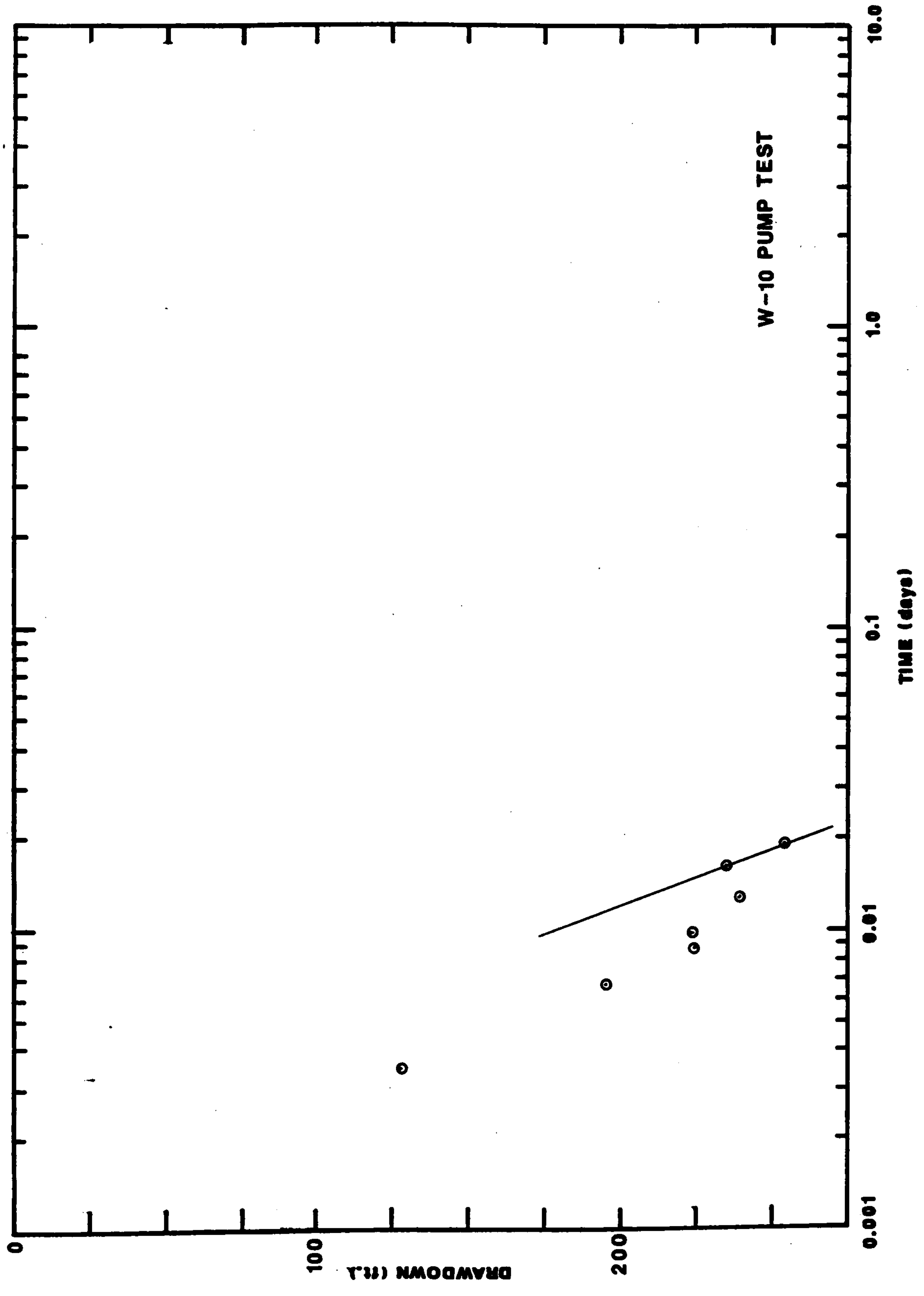

W-8 PUMP TEST
DRAWDOWN (ft.)
0
50
100
TIME (days)
0.001
0.01
0.1
1.0
10.0

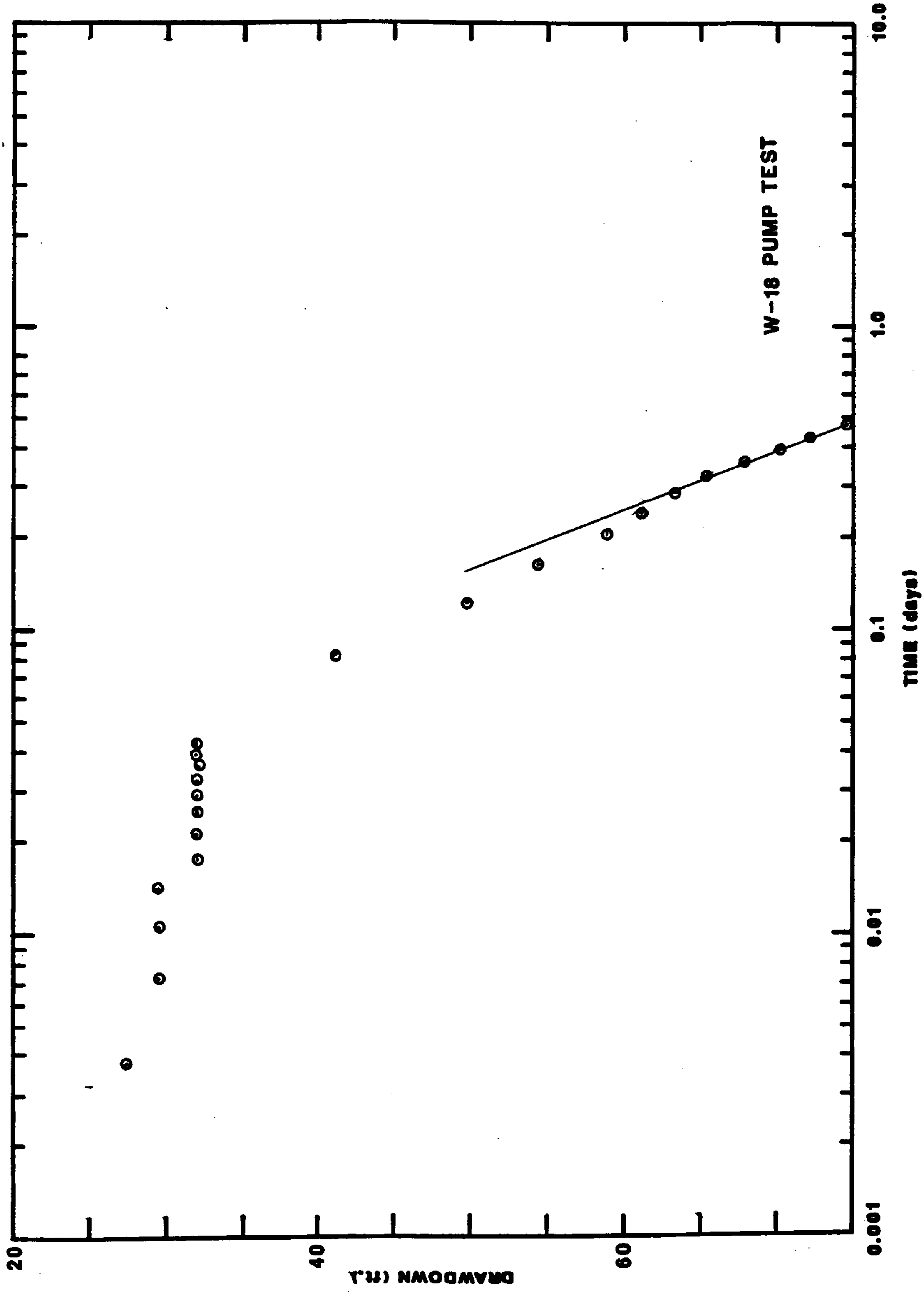

W-11 PUMP TEST
TIME (days)
0.001
0.01
0.1
1.0
10.0
DRAWDOWN (ft.)
0
100
200

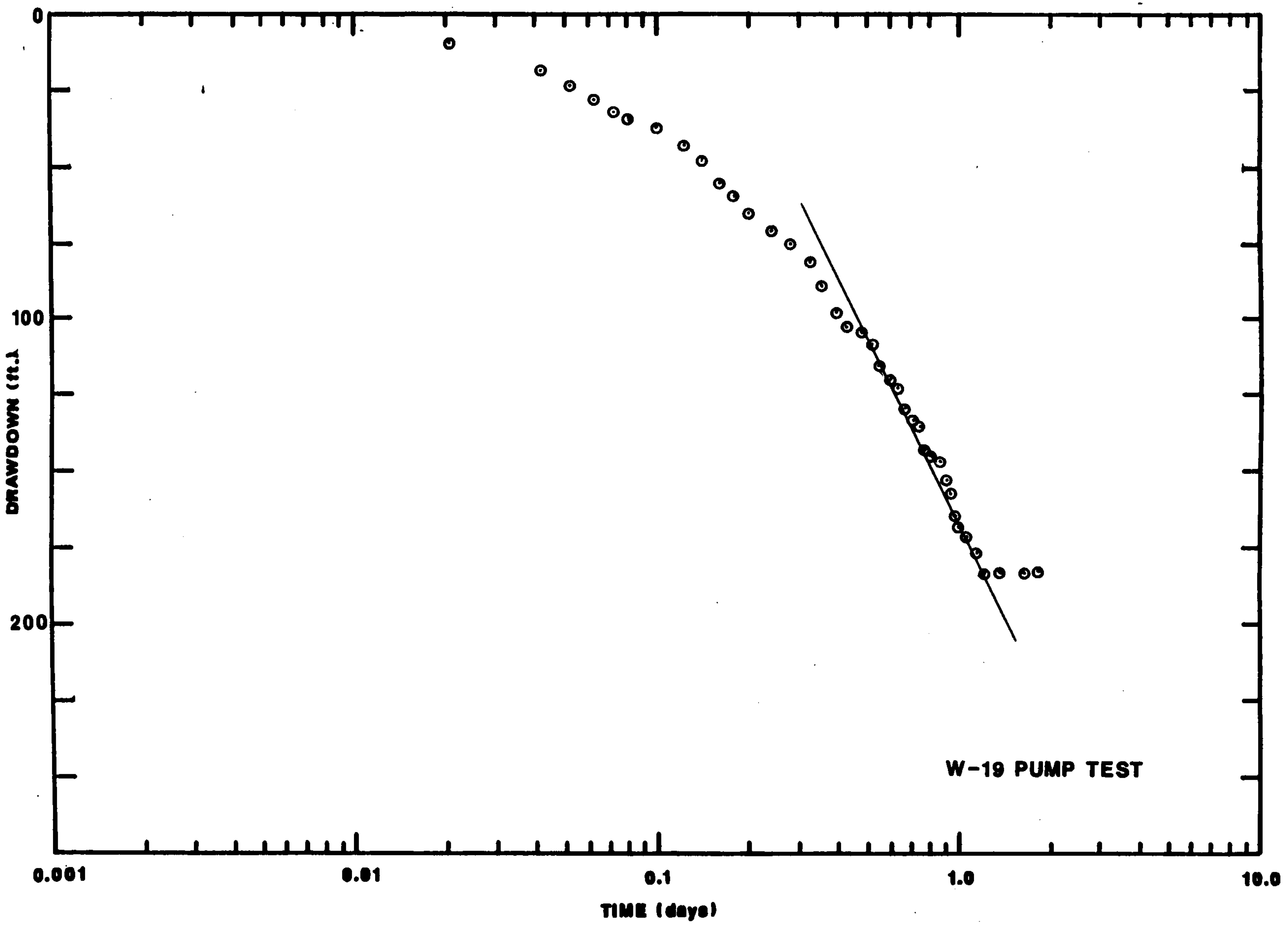

W-15 PUMP TEST
TIME (days)
0.001
0.01
0.1
1.0
10.0
DRAWDOWN (ft.)
100
150
200

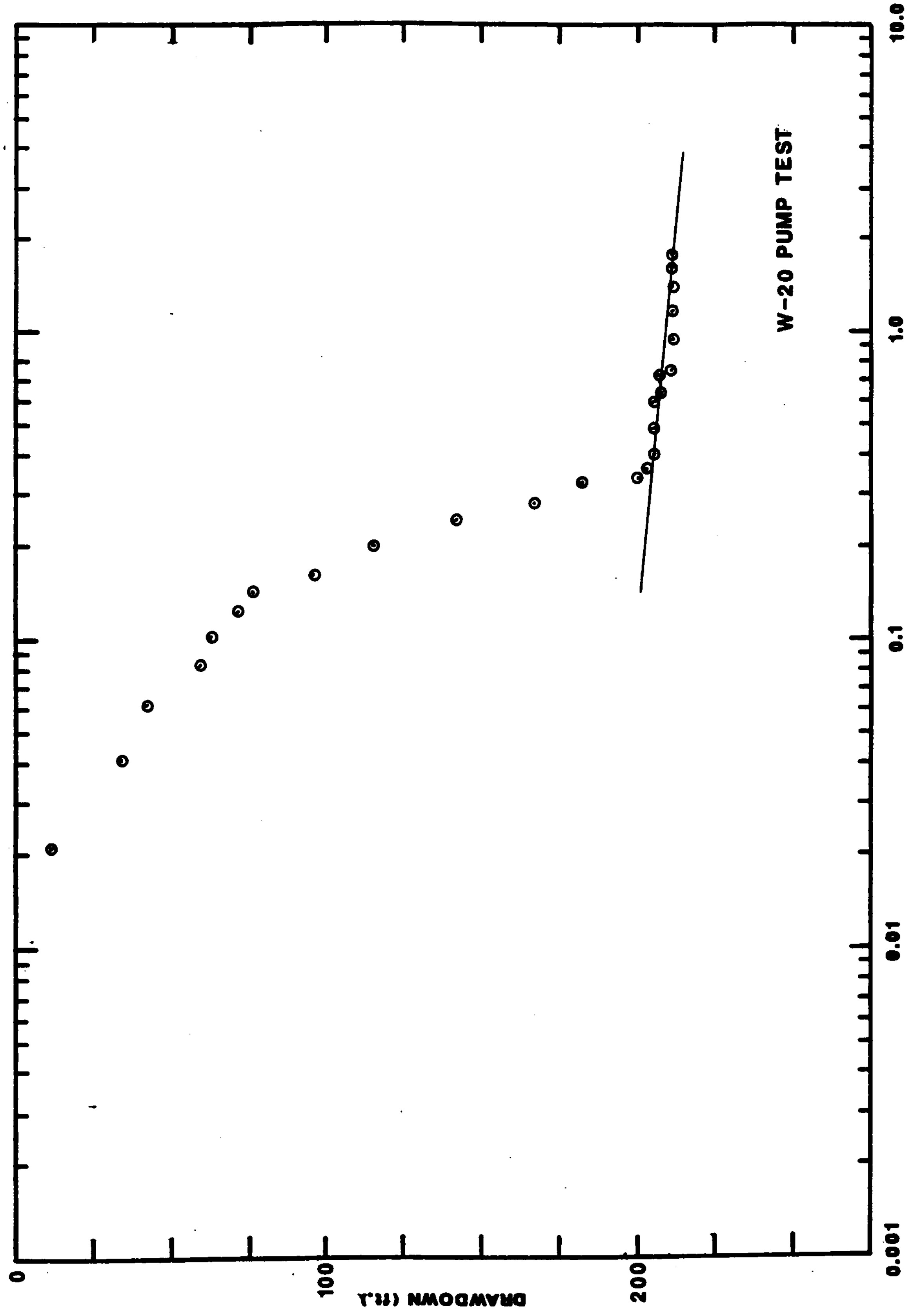

W-21 PUMP TEST
0.001
0.01
0.1
1.0
10.0
TIME (days)
0
100
200
DRAWDOWN (ft.)

Type III Drawdown Graphs


W-10 PUMP TEST
DRAWDOWN (ft.)
0
100
200
TIME (days)
0.001
0.01
0.1
1.0
10.0


W-18 PUMP TEST
TIME (days)
0.001
0.01
0.1
1.0
10.0
DRAWDOWN (ft.)
20
40
60


W-19 PUMP TEST
DRAWDOWN (ft.)
0
100
200
TIME (days)
0.001
0.01
0.1
1.0
10.0


W-20 PUMP TEST
TIME (days)
0.001
0.01
0.1
1.0
10.0
DRAWDOWN (ft.)
0
100
200

APPENDIX V

WELL W-1 PUMP TEST DRAWDOWN DATA
IN OBSERVATION WELL W-17

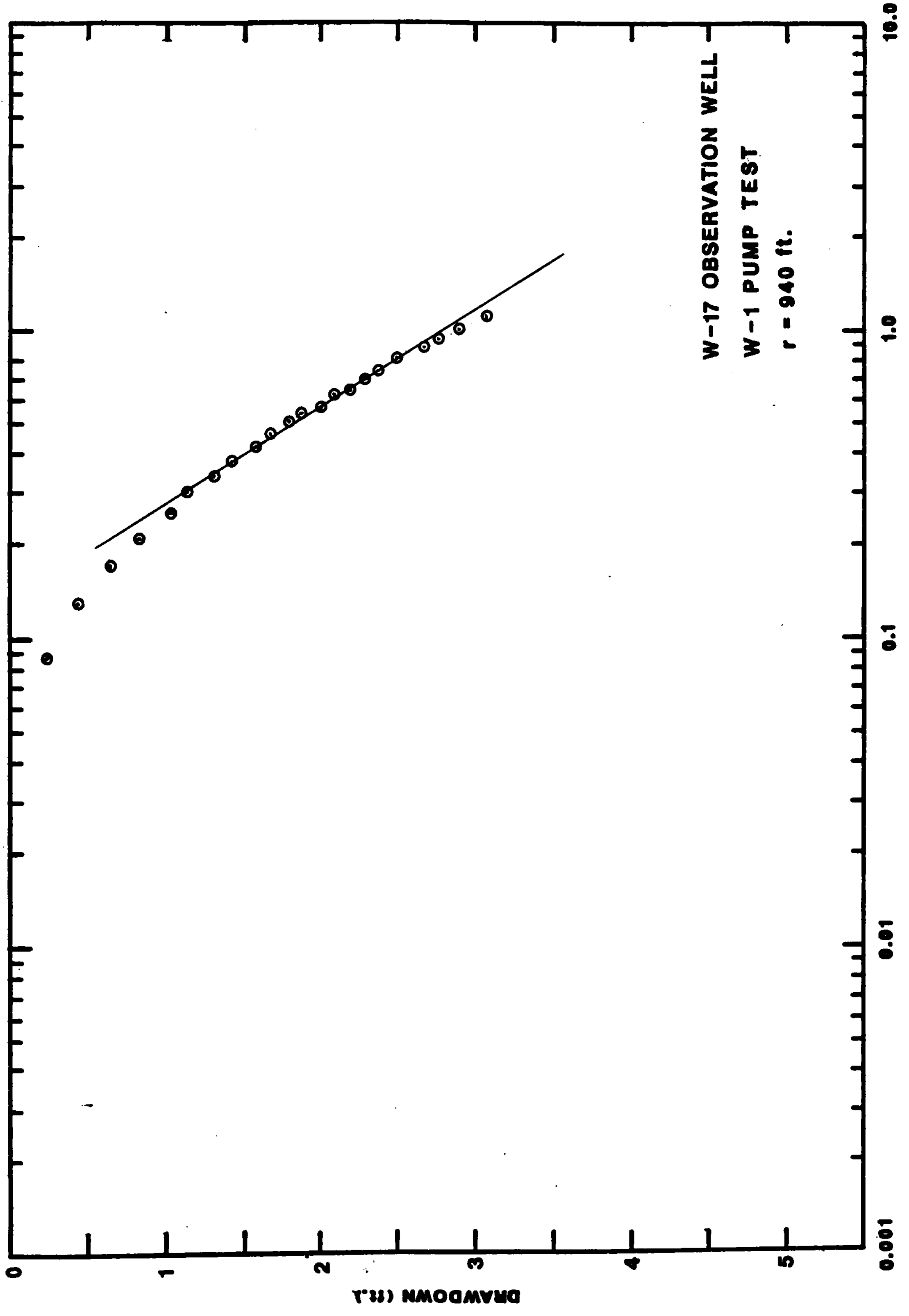
(Drawdown Data)
(Drawdown Graph)

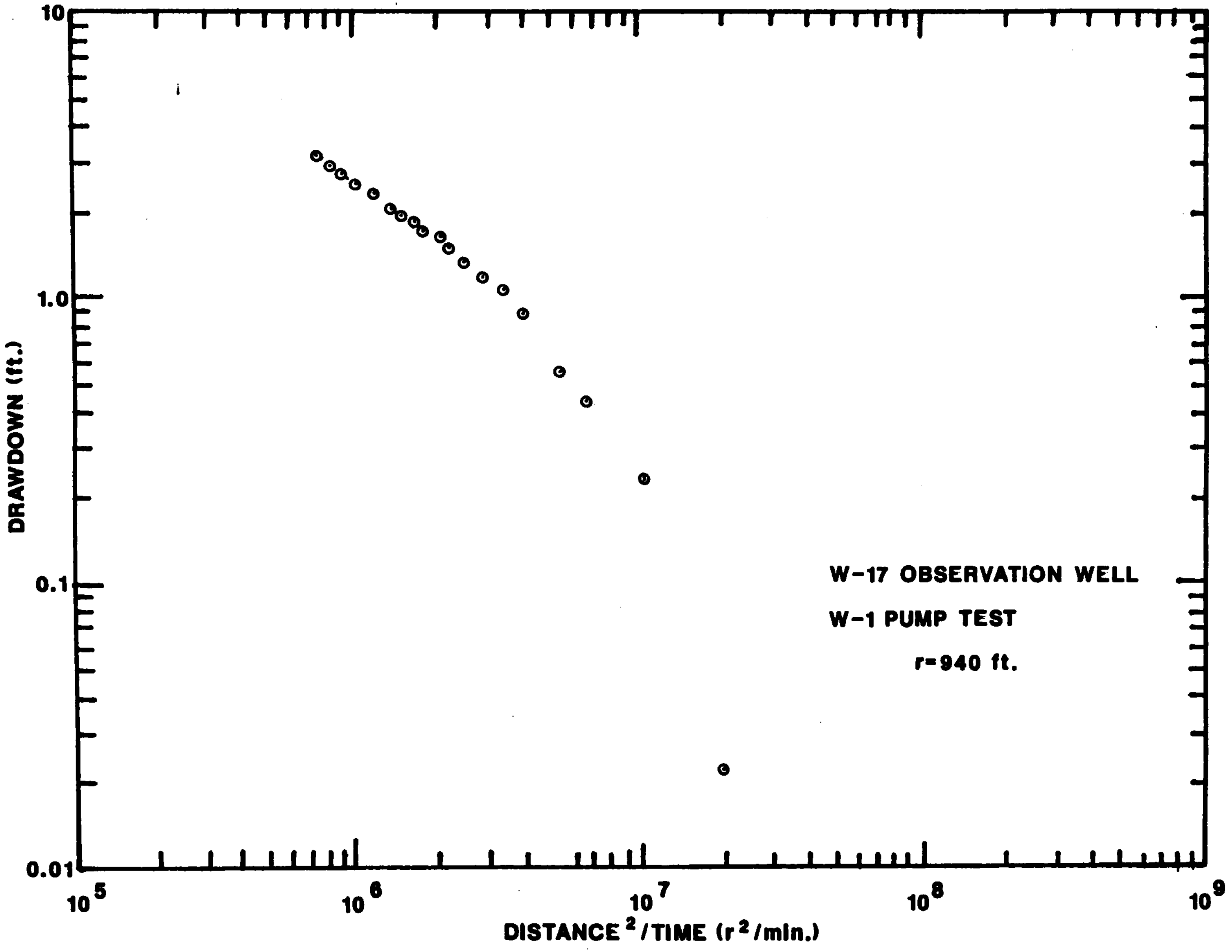
Drawdown Data

IDENTIFICATION NUMBER: W-17
OBSERVATION WELL: CRAIG AVENUE #1
WELL YIELD (CRAIG AVENUE #2): 77,916 FT3/DAY
WELL DEPTH (FT.): 412
SWL (FT.): 11.63
WELL DIAMETER (FT.): 0.67
DISTANCE FROM CRAIG #2: 940 FT.

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
4.17E-02	8.18E+04	0.02	2.45E-07	4.72E-08
8.33E-02	8.18E+04	0.22	2.69E-06	9.43E-08
1.25E-01	8.18E+04	0.42	5.14E-06	1.41E-07
1.67E-01	7.70E+04	0.67	8.71E-06	1.89E-07
2.08E-01	7.70E+04	0.87	1.13E-05	2.36E-07
2.50E-01	7.70E+04	1.05	1.36E-05	2.83E-07
2.92E-01	7.70E+04	1.18	1.53E-05	3.30E-07
3.33E-01	7.70E+04	1.33	1.73E-05	3.77E-07
3.75E-01	7.70E+04	1.49	1.94E-05	4.24E-07
4.17E-01	7.70E+04	1.61	2.09E-05	4.72E-07
4.58E-01	7.70E+04	1.71	2.22E-05	5.19E-07
5.00E-01	7.70E+04	1.82	2.37E-05	5.66E-07
5.42E-01	7.70E+04	1.92	2.50E-05	6.13E-07
5.83E-01	7.70E+04	2.03	2.64E-05	6.60E-07
6.25E-01	7.70E+04	2.12	2.75E-05	7.07E-07
6.67E-01	7.70E+04	2.22	2.88E-05	7.54E-07
7.08E-01	7.70E+04	2.32	3.01E-05	8.02E-07
7.50E-01	7.70E+04	2.42	3.14E-05	8.49E-07
7.92E-01	7.70E+04	2.47	3.21E-05	8.96E-07
8.33E-01	7.70E+04	2.54	3.30E-05	9.43E-07
8.75E-01	7.70E+04	2.62	3.40E-05	9.90E-07
9.17E-01	7.70E+04	2.73	3.55E-05	1.04E-06
9.58E-01	7.70E+04	2.82	3.66E-05	1.08E-06
1.00E+00	7.70E+04	2.92	3.79E-05	1.13E-06
1.04E+00	7.70E+04	2.97	3.86E-05	1.18E-06
1.08E+00	7.70E+04	3.06	3.98E-05	1.23E-06
1.12E+00	7.70E+04	3.16	4.11E-05	1.27E-06

Drawdown Graph


W-17 OBSERVATION WELL
W-1 PUMP TEST
r = 940 ft.
TIME (days)
0.001
0.01
0.1
1.0
10.0
DRAWDOWN (ft.)
0
1
2
3
4
5


W-17 OBSERVATION WELL
W-1 PUMP TEST
r=940 ft.
DRAWDOWN (ft.)
10
1.0
0.1
0.01
10^5
10^6
10^7
10^8
10^9
DISTANCE ^{2}/TIME (r^2/min.)

APPENDIX VI

CITY OF BEDFORD WELL FIELD AQUIFER TEST SUMMARY
(Summary Description)
(Drawdown Data)
(Drawdown Graphs)

Summary Description

CITY OF BEDFORD WELL FIELD AQUIFER TEST SUMMARY

The City of Bedford, Virginia, developed five ground water supply wells in the Kelso Mills area of Bedford County (see location Map) to supplement the City's public water supply needs. To evaluate the characteristics of the fractured aquifer in which the wells were developed, the author supervised an aquifer pump test of this well field during the period of August 25-27, 1981. The wells were developed in the Precambrian age Marshall Gneiss and wells locations were selected to lie on mapped fracture traces in the area, or at the intersection of fracture traces (see study area map, Appendix I).

The pump test involved the simultaneous pumping of five production wells, with drawdown measurements collected in these wells, in addition to three privately owned observation wells. The relative positions of the production and observation wells are indicated on the location map.

Drawdown data for the production wells, in terms of s_w/Q versus t/r_w^2, are plotted on semilogarithmic graph paper and indicate an overall aquifer transmissivity of 126 ft^2/day. The drawdown data from the observation wells were evaluated using the Hantush Modified Method curve matching technique, assuming an average withdrawal rate and average distance from the well field. This analysis indicated two transmissivities in the aquifer at 361 ft^2/day and 303 ft^2/day, with corresponding storage coefficients of 4.58×10^{-5} and 2.53×10^{-5}, respectively.

The overall aquifer transmissivity derived from the Straight-Line Method is probably low for the aquifer, since the time period for data collection was not sufficiently long to overcome well loss problems and interference between the production wells. As review of the drawdown graph for this method indicates, the drawdown data points were starting to fall along the same line, but data was not available for a long enough period of time to fully demonstrate this trend.

Drawdown Data

IDENTIFICATION NUMBER: W-22
WELL NAME: CITY OF BEDFORD #2
WELL YIELD: 27,896 FT3/DAY
WELL DEPTH (FT.): 450
SWL (FT.): 6.00
AIRLINE LENGTH (FT.): 227.54
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
2.15E-02	3.31E+04	82.94	2.51E-03	1.92E-01
4.44E-02	3.08E+04	87.56	2.84E-03	3.96E-01
7.99E-02	3.14E+04	87.56	2.79E-03	7.12E-01
1.17E-01	3.17E+04	89.87	2.83E-03	1.04E+00
1.58E-01	3.04E+04	94.49	3.11E-03	1.40E+00
1.61E-01	3.04E+04	92.18	3.03E-03	1.44E+00
1.65E-01	3.06E+04	92.18	3.01E-03	1.47E+00
1.68E-01	3.06E+04	92.18	3.01E-03	1.50E+00
2.08E-01	3.00E+04	87.56	2.92E-03	1.86E+00
2.40E-01	2.98E+04	94.49	3.17E-03	2.14E+00
2.87E-01	3.04E+04	96.8	3.18E-03	2.56E+00
3.26E-01	2.98E+04	96.8	3.25E-03	2.90E+00
3.69E-01	2.98E+04	96.8	3.25E-03	3.29E+00
4.09E-01	2.92E+04	96.8	3.31E-03	3.64E+00
4.50E-01	3.00E+04	94.49	3.15E-03	4.01E+00
4.92E-01	2.90E+04	96.8	3.33E-03	4.38E+00
5.31E-01	2.89E+04	99.11	3.43E-03	4.73E+00
5.76E-01	2.94E+04	101.42	3.45E-03	5.13E+00
6.15E-01	2.87E+04	101.42	3.54E-03	5.48E+00
6.63E-01	2.94E+04	101.42	3.45E-03	5.91E+00
7.00E-01	2.85E+04	101.42	3.56E-03	6.24E+00
7.42E-01	2.94E+04	101.42	3.45E-03	6.61E+00
7.87E-01	2.94E+04	92.18	3.13E-03	7.01E+00
8.29E-01	2.83E+04	89.87	3.18E-03	7.39E+00
1.02E-01	2.83E+04	101.42	3.59E-03	9.10E-01
9.05E-01	2.96E+04	101.42	3.42E-03	8.06E+00
9.44E-01	2.89E+04	101.42	3.51E-03	8.42E+00
9.88E-01	2.83E+04	103.73	3.67E-03	8.81E+00
1.03E+00	2.81E+04	103.73	3.69E-03	9.17E+00
1.07E+00	2.77E+04	103.73	3.74E-03	9.55E+00
1.11E+00	2.85E+04	103.73	3.64E-03	9.93E+00

IDENTIFICATION NUMBER: W-23
WELL NAME: CITY OF BEDFORD #5
WELL YIELD: 15,391 FT3/DAY
WELL DEPTH (FT.): 450
SWL (FT.): 9.0
AIRLINE LENGTH (FT.): 217.14
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
4.31E-02	2.12E+04	23.34	1.10E-03	0.38
6.25E-02	1.92E+04	27.96	1.45E-03	0.56
9.86E-02	1.92E+04	30.27	1.57E-03	0.88
1.40E-01	1.89E+04	32.58	1.73E-03	1.24
1.72E-01	1.87E+04	32.58	1.75E-03	1.53
2.06E-01	1.87E+04	39.51	2.12E-03	1.83
2.35E-01	1.87E+04	34.89	1.87E-03	2.09
2.53E-01	1.85E+04	37.2	2.01E-03	2.26
3.03E-01	1.77E+04	39.51	2.23E-03	2.70
3.30E-01	1.81E+04	41.82	2.31E-03	2.94
3.69E-01	1.79E+04	41.82	2.34E-03	3.29
4.12E-01	1.79E+04	44.13	2.47E-03	3.68
4.52E-01	1.75E+04	46.44	2.65E-03	4.03
4.93E-01	1.73E+04	46.44	2.68E-03	4.39
5.35E-01	1.71E+04	46.44	2.71E-03	4.76
5.76E-01	1.69E+04	48.75	2.88E-03	5.14
6.19E-01	1.69E+04	48.75	2.88E-03	5.51
6.58E-01	1.67E+04	48.75	2.91E-03	5.86
7.08E-01	1.67E+04	51.06	3.05E-03	6.31
7.40E-01	1.65E+04	51.06	3.09E-03	6.59
7.81E-01	1.64E+04	51.06	3.12E-03	6.96
8.22E-01	1.62E+04	57.99	3.59E-03	7.32
8.64E-01	1.62E+04	57.99	3.59E-03	7.70
9.01E-01	1.62E+04	60.3	3.73E-03	8.03
9.37E-01	1.60E+04	60.3	3.78E-03	8.35
9.83E-01	1.58E+04	62.61	3.97E-03	8.76
1.02E+00	1.58E+04	62.61	3.97E-03	9.13
1.06E+00	1.54E+04	62.61	4.07E-03	9.49
1.11E+00	1.54E+04	62.61	4.07E-03	9.88
1.15E+00	1.54E+04	64.92	4.22E-03	10.24
1.19E+00	1.54E+04	64.92	4.22E-03	10.64
1.23E+00	1.54E+04	64.92	4.22E-03	10.98
1.27E+00	1.50E+04	64.92	4.33E-03	11.35
1.32E+00	1.54E+04	67.23	4.37E-03	11.73
1.36E+00	1.52E+04	64.92	4.27E-03	12.14
1.40E+00	1.52E+04	64.92	4.27E-03	12.46
1.45E+00	1.54E+04	64.92	4.22E-03	12.88
1.48E+00	1.52E+04	64.92	4.27E-03	13.21
1.53E+00	1.52E+04	64.92	4.27E-03	13.61
1.57E+00	1.52E+04	64.92	4.27E-03	13.95

1.61E+00	1.54E+04	64.92	4.22E-03	14.33
1.65E+00	1.54E+04	64.92	4.22E-03	14.70
1.69E+00	1.54E+04	64.92	4.22E-03	15.08
1.73E+00	1.52E+04	64.92	4.27E-03	15.46
1.78E+00	1.54E+04	64.92	4.22E-03	15.83
1.82E+00	1.52E+04	64.92	4.27E-03	16.21
1.86E+00	1.52E+04	64.92	4.27E-03	16.58
1.90E+00	1.48E+04	69.54	4.69E-03	16.91
1.95E+00	1.52E+04	67.23	4.42E-03	17.36
1.99E+00	1.52E+04	67.23	4.42E-03	17.73
2.03E+00	1.52E+04	67.23	4.42E-03	18.10
2.07E+00	1.50E+04	67.23	4.48E-03	18.41
2.11E+00	1.50E+04	67.23	4.48E-03	18.78
2.15E+00	1.48E+04	67.23	4.54E-03	19.18
2.19E+00	1.48E+04	67.23	4.54E-03	19.53
2.23E+00	1.50E+04	67.23	4.48E-03	19.89

IDENTIFICATION NUMBER: W-24
WELL NAME: CITY OF BEDFORD #6
WELL YIELD (FT3/DAY): 9,234
WELL DEPTH (FT): 310
SWL (FT.): 87.78
AIRLINE LENGTH (FT.): 272.58
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
1.39E-03	1.52E+04	46.2	3.04E-03	1.24E-02
4.86E-03	1.44E+04	73.92	5.12E-03	4.33E-02
1.25E-02	1.39E+04	110.88	8.00E-03	1.11E-01
3.19E-02	1.21E+04	166.32	1.37E-02	2.85E-01
3.33E-02	1.23E+04	170.94	1.39E-02	2.97E-01
4.03E-02	1.19E+04	177.87	1.49E-02	3.59E-01
7.92E-02	1.19E+04	184.8	1.55E-02	7.05E-01
8.33E-02	0.00E+00	11.55	0.00E+00	7.43E-01
1.08E-01	1.54E+04	11.55	7.50E-04	9.59E-01
1.12E-01	1.46E+04	60.06	4.11E-03	9.96E-01
1.14E-01	1.42E+04	83.16	5.84E-03	1.01E+00
1.17E-01	1.37E+04	110.88	8.12E-03	1.05E+00
1.24E-01	1.04E+04	140.91	1.36E-02	1.11E+00
1.47E-01	1.08E+04	138.6	1.29E-02	1.31E+00
1.90E-01	1.06E+04	138.6	1.31E-02	1.70E+00
2.30E-01	1.02E+04	150.15	1.47E-02	2.05E+00
2.67E-01	9.81E+03	161.7	1.65E-02	2.38E+00
3.12E-01	9.62E+03	152.46	1.58E-02	2.78E+00
3.55E-01	1.00E+04	152.46	1.52E-02	3.16E+00
3.96E-01	9.23E+03	161.7	1.75E-02	3.53E+00
4.35E-01	9.23E+03	164.01	1.78E-02	3.87E+00
4.85E-01	8.85E+03	164.01	1.85E-02	4.33E+00
5.21E-01	8.66E+03	166.32	1.92E-02	4.64E+00
5.66E-01	8.46E+03	173.25	2.05E-02	5.04E+00
6.07E-01	8.46E+03	173.25	2.05E-02	5.41E+00
6.49E-01	8.27E+03	173.25	2.09E-02	5.79E+00
6.88E-01	8.27E+03	173.25	2.09E-02	6.13E+00
7.26E-01	8.08E+03	173.25	2.14E-02	6.47E+00
7.68E-01	8.08E+03	173.25	2.14E-02	6.84E+00
8.11E-01	8.46E+03	164.01	1.94E-02	7.23E+00
8.57E-01	7.70E+03	175.56	2.28E-02	7.64E+00
9.01E-01	7.89E+03	97.02	1.23E-02	8.03E+00
9.43E-01	7.89E+03	103.95	1.32E-02	8.40E+00
9.91E-01	7.89E+03	103.95	1.32E-02	8.83E+00
1.03E+00	7.89E+03	103.95	1.32E-02	9.20E+00
1.76E+00	7.70E+03	103.95	1.35E-02	1.57E+01
1.11E+00	7.70E+03	106.26	1.38E-02	9.91E+00
1.16E+00	7.89E+03	103.95	1.32E-02	1.03E+01
1.20E+00	7.89E+03	106.26	1.35E-02	1.07E+01
1.24E+00	7.70E+03	106.26	1.38E-02	1.10E+01
1.27E+00	7.70E+03	106.26	1.38E-02	1.14E+01

1.32E+00	7.70E+03	106.26	1.38E-02	1.18E+01
1.36E+00	7.70E+03	110.88	1.44E-02	1.21E+01
1.40E+00	7.70E+03	110.88	1.44E-02	1.25E+01
1.45E+00	7.70E+03	106.26	1.38E-02	1.29E+01
1.49E+00	7.70E+03	106.26	1.38E-02	1.33E+01
1.53E+00	7.70E+03	110.88	1.44E-02	1.36E+01
1.57E+00	7.70E+03	115.5	1.50E-02	1.40E+01
1.62E+00	7.70E+03	115.5	1.50E-02	1.44E+01
1.66E+00	7.70E+03	120.12	1.56E-02	1.48E+01
1.69E+00	7.50E+03	122.43	1.63E-02	1.51E+01
1.74E+00	8.27E+03	110.88	1.34E-02	1.55E+01
1.79E+00	7.70E+03	131.67	1.71E-02	1.59E+01
1.83E+00	7.89E+03	138.6	1.76E-02	1.63E+01
1.86E+00	7.70E+03	143.22	1.86E-02	1.66E+01
1.90E+00	7.50E+03	150.15	2.00E-02	1.70E+01
1.95E+00	7.50E+03	152.46	2.03E-02	1.74E+01
1.99E+00	7.70E+03	154.77	2.01E-02	1.77E+01
2.03E+00	7.50E+03	154.77	2.06E-02	1.81E+01

IDENTIFICATION NUMBER: W-25
WELL NAME: CITY OF BEDFORD #7
WELL YIELD: 36,552 FT3/DAY
WELL DEPTH (FT.): 400
SWL (FT.): 8.80
AIRLINE LENGTH (FT.): 235.62
WELL DIAMETER (FT.): 0.67

TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
6.39E-02	4.04E+04	28.16	6.97E-04	5.69E-01
1.19E-01	4.00E+04	32.78	8.19E-04	1.06E+00
1.56E-01	3.91E+04	35.09	8.99E-04	1.39E+00
2.01E-01	0.00E+00	14.3	0.00E+00	1.79E+00
2.31E-01	4.10E+04	37.4	9.13E-04	2.06E+00
2.40E-01	3.85E+04	30.47	7.92E-04	2.13E+00
2.65E-01	3.91E+04	37.4	9.58E-04	2.36E+00
3.17E-01	3.85E+04	37.4	9.72E-04	2.83E+00
3.58E-01	3.85E+04	42.02	1.09E-03	3.19E+00
3.96E-01	3.85E+04	42.02	1.09E-03	3.53E+00
4.39E-01	3.85E+04	44.33	1.15E-03	3.91E+00
4.79E-01	3.85E+04	44.33	1.15E-03	4.27E+00
5.21E-01	3.85E+04	44.33	1.15E-03	4.64E+00
5.62E-01	3.85E+04	44.33	1.15E-03	5.01E+00
6.04E-01	3.85E+04	44.33	1.15E-03	5.38E+00
6.46E-01	3.85E+04	46.64	1.21E-03	5.75E+00
6.85E-01	3.75E+04	46.64	1.24E-03	6.11E+00
7.33E-01	3.77E+04	46.64	1.24E-03	6.53E+00
7.70E-01	3.81E+04	46.64	1.22E-03	6.86E+00
8.12E-01	3.85E+04	46.64	1.21E-03	7.24E+00
8.58E-01	3.85E+04	46.64	1.21E-03	7.64E+00
8.99E-01	3.85E+04	53.57	1.39E-03	8.01E+00
9.37E-01	3.75E+04	53.57	1.43E-03	8.35E+00
9.77E-01	3.73E+04	53.57	1.44E-03	8.71E+00
1.02E+00	3.73E+04	53.57	1.44E-03	9.06E+00
1.06E+00	3.71E+04	53.57	1.44E-03	9.42E+00
1.10E+00	3.71E+04	55.88	1.51E-03	9.81E+00
1.14E+00	3.66E+04	53.57	1.47E-03	1.02E+01
1.18E+00	3.69E+04	53.57	1.45E-03	1.06E+01
1.23E+00	3.67E+04	53.57	1.46E-03	1.09E+01
1.27E+00	3.69E+04	55.88	1.51E-03	1.13E+01
1.31E+00	3.66E+04	55.88	1.53E-03	1.17E+01
1.35E+00	3.66E+04	55.88	1.53E-03	1.20E+01
1.40E+00	3.56E+04	55.88	1.57E-03	1.24E+01
1.44E+00	3.66E+04	58.19	1.59E-03	1.28E+01
1.48E+00	3.66E+04	58.19	1.59E-03	1.32E+01
1.52E+00	3.64E+04	55.88	1.54E-03	1.35E+01
1.57E+00	3.66E+04	60.5	1.66E-03	1.40E+01
1.60E+00	3.64E+04	60.5	1.66E-03	1.43E+01
1.64E+00	3.64E+04	60.5	1.66E-03	1.46E+01

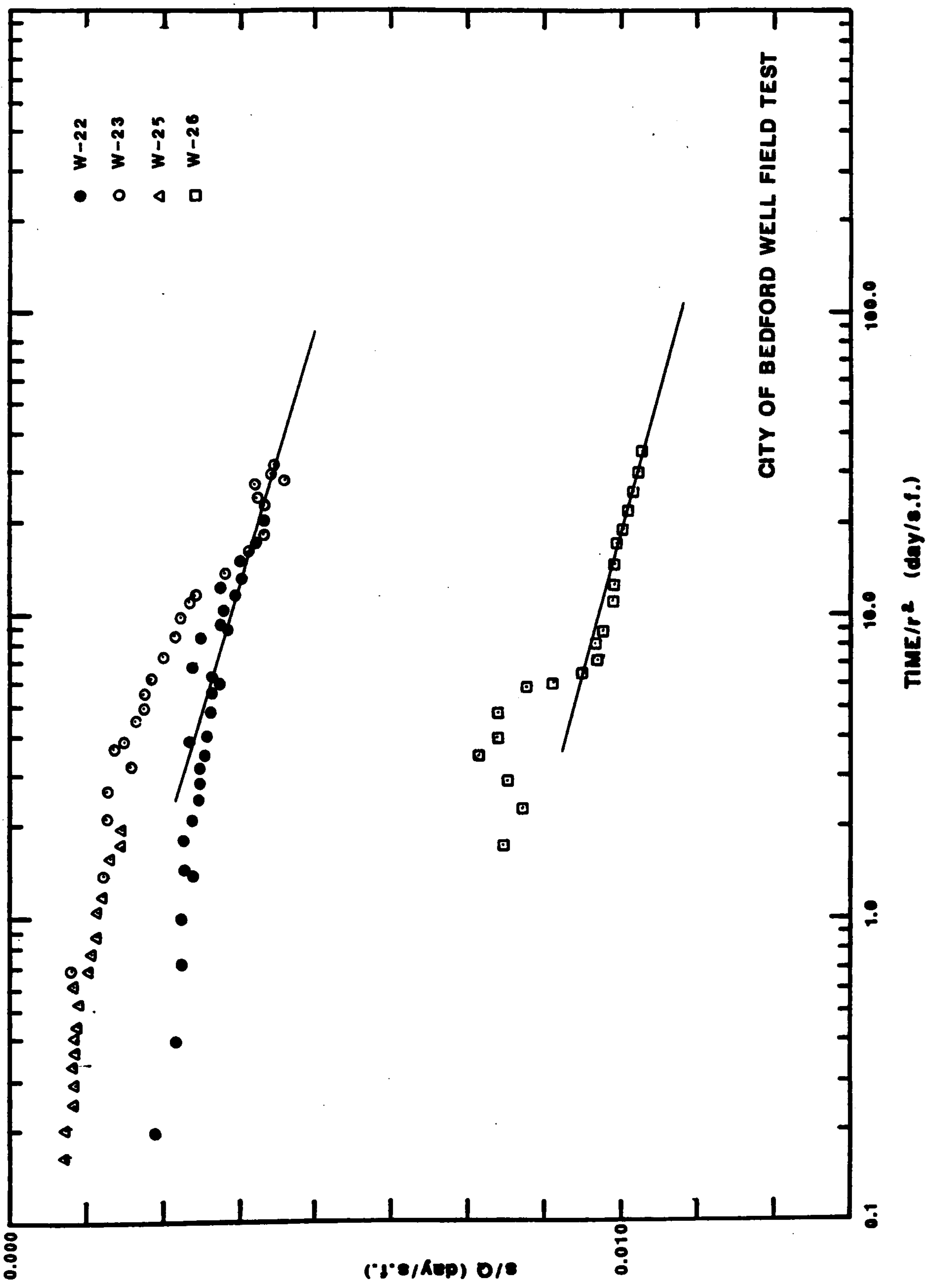
1.69E+00	3.62E+04	60.5	1.67E-03	1.50E+01
1.73E+00	3.62E+04	60.5	1.67E-03	1.54E+01
1.77E+00	3.67E+04	65.12	1.77E-03	1.58E+01
1.81E+00	3.73E+04	65.12	1.74E-03	1.61E+01
1.85E+00	3.60E+04	65.12	1.81E-03	1.65E+01
1.90E+00	3.58E+04	65.12	1.82E-03	1.69E+01
1.93E+00	3.52E+04	67.43	1.92E-03	1.72E+01
1.98E+00	3.56E+04	67.43	1.89E-03	1.77E+01
2.02E+00	3.56E+04	69.74	1.96E-03	1.80E+01
2.06E+00	3.54E+04	69.74	1.97E-03	1.84E+01
2.10E+00	3.56E+04	65.12	1.83E-03	1.87E+01
2.14E+00	3.54E+04	65.12	1.84E-03	1.91E+01
2.20E+00	3.54E+04	65.12	1.84E-03	1.96E+01
2.23E+00	3.54E+04	65.12	1.84E-03	1.99E+01
2.27E+00	3.52E+04	69.74	1.98E-03	2.02E+01
2.29E+00	3.52E+04	69.74	1.98E-03	2.04E+01

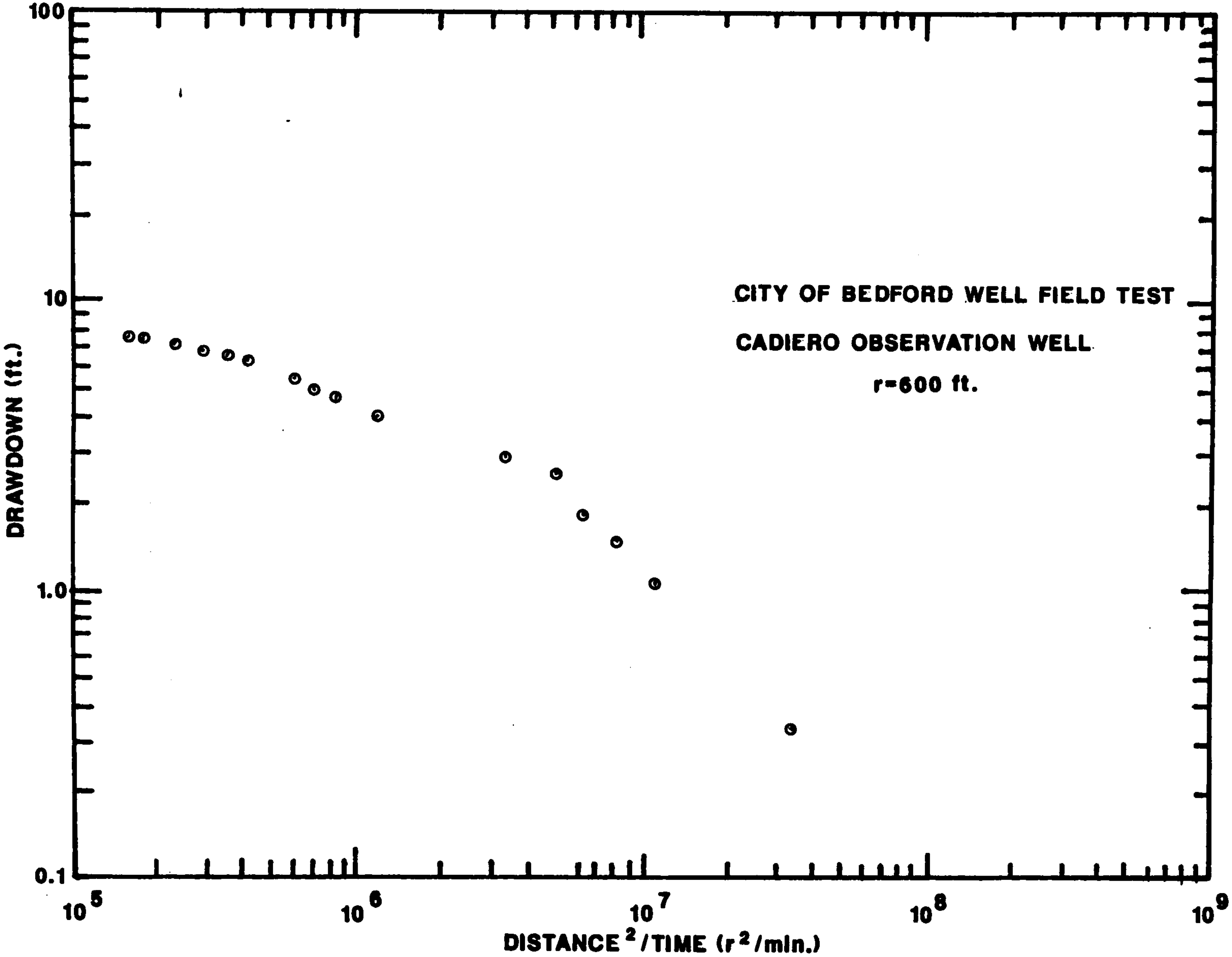
IDENTIFICATION NUMBER: W-26
WELL NAME: CITY OF BEDFORD #8
WELL YIELD: 12,505 FT3/DAY
WELL DEPTH (FT.): 250
SWL (FT.): 23.10
AIRLINE LENGTH (FT.): 219.45
WELL DIAMETER (FT.): 0.67

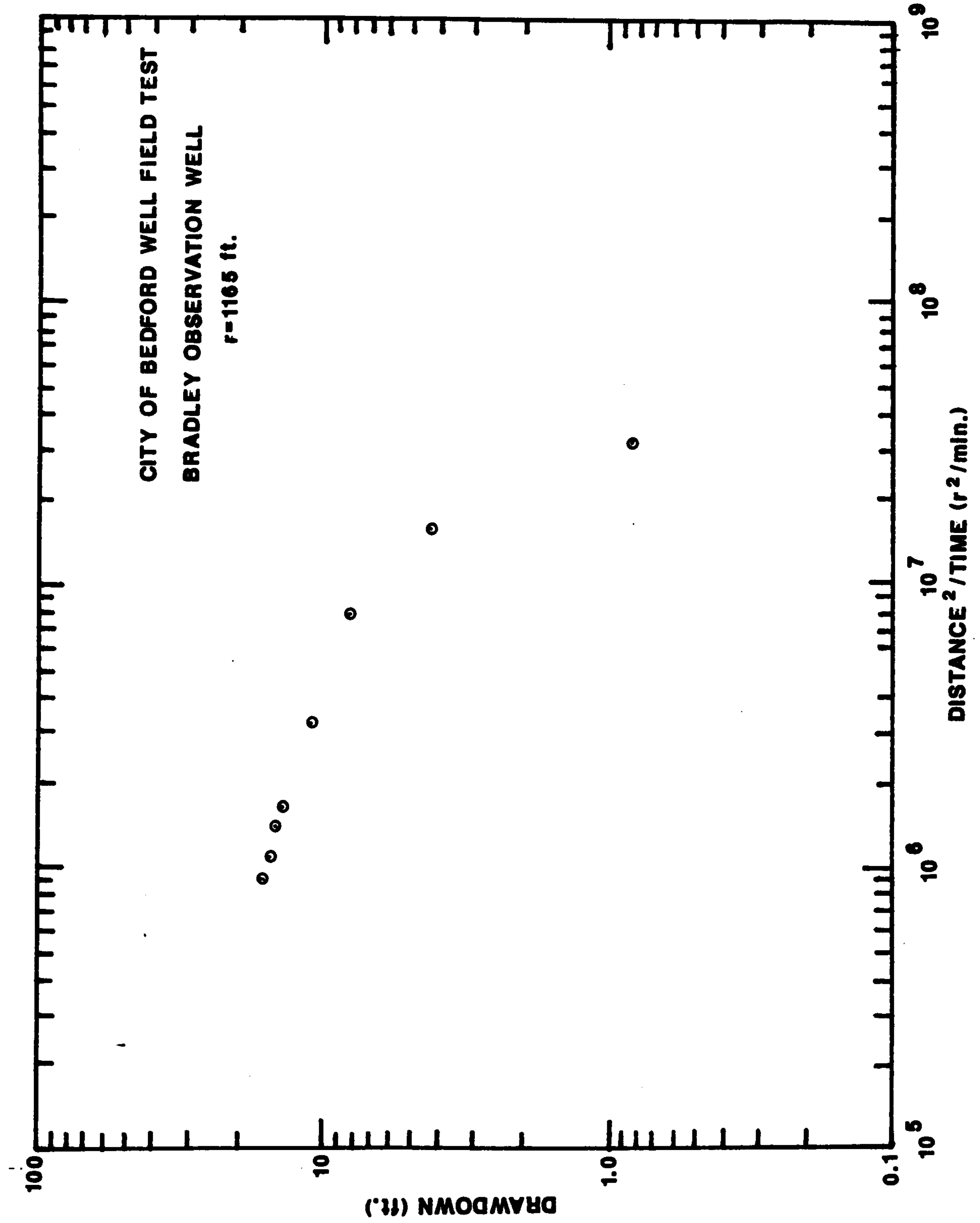
TIME (d)	Q (cf/d)	Sw	Sw/Q	T/Rw^2
6.25E-02	20969.42	150.15	7.16E-03	5.57E-01
1.15E-01	19045.62	159.39	8.37E-03	1.02E+00
1.53E-01	18276.10	159.39	8.72E-03	1.36E+00
1.89E-01	18853.24	159.39	8.45E-03	1.68E+00
2.28E-01	19430.38	154.77	7.97E-03	2.03E+00
2.61E-01	19045.62	157.08	8.25E-03	2.33E+00
3.17E-01	19045.62	157.08	8.25E-03	2.82E+00
3.62E-01	19045.62	157.08	8.25E-03	3.22E+00
3.85E-01	18468.48	161.7	8.76E-03	3.43E+00
3.97E-01	17891.34	164.01	9.17E-03	3.53E+00
4.38E-01	17314.20	168.63	9.74E-03	3.90E+00
4.74E-01	16929.44	168.63	9.96E-03	4.22E+00
5.14E-01	17121.82	168.63	9.85E-03	4.58E+00
5.53E-01	16929.44	168.63	9.96E-03	4.93E+00
5.94E-01	16544.68	168.63	1.02E-02	5.29E+00
6.35E-01	16159.92	170.94	1.06E-02	5.66E+00
6.77E-01	15967.54	173.25	1.09E-02	6.03E+00
7.19E-01	15582.78	173.25	1.11E-02	6.40E+00
7.60E-01	15390.40	173.25	1.13E-02	6.78E+00
8.02E-01	15390.40	173.25	1.13E-02	7.15E+00
8.44E-01	14620.88	173.25	1.18E-02	7.52E+00
8.85E-01	15005.64	173.25	1.15E-02	7.89E+00
9.27E-01	15005.64	173.25	1.15E-02	8.26E+00
9.69E-01	14428.50	173.25	1.20E-02	8.63E+00
1.01E+00	14428.50	173.25	1.20E-02	9.03E+00
1.07E+00	14428.50	175.56	1.22E-02	9.56E+00
1.09E+00	14236.12	175.56	1.23E-02	9.75E+00
1.13E+00	14236.12	175.56	1.23E-02	1.01E+01
1.17E+00	14043.74	175.56	1.25E-02	1.05E+01
1.22E+00	13466.60	173.25	1.29E-02	1.08E+01
1.26E+00	13466.60	173.25	1.29E-02	1.12E+01
1.30E+00	13274.22	173.25	1.31E-02	1.16E+01
1.34E+00	13081.84	173.25	1.32E-02	1.19E+01
1.38E+00	12889.46	173.25	1.34E-02	1.23E+01
1.42E+00	12697.08	173.25	1.36E-02	1.27E+01
1.47E+00	12312.32	173.25	1.41E-02	1.31E+01
1.51E+00	12312.32	173.25	1.41E-02	1.35E+01
1.55E+00	12119.94	173.25	1.43E-02	1.38E+01
1.59E+00	12119.94	173.25	1.43E-02	1.42E+01
1.64E+00	11927.56	173.25	1.45E-02	1.46E+01

1.69E+00	11735.18	175.56	1.50E-02	1.50E+01
1.72E+00	11542.80	175.56	1.52E-02	1.53E+01
1.76E+00	11735.18	177.87	1.52E-02	1.57E+01
1.80E+00	11542.80	177.87	1.54E-02	1.61E+01
1.84E+00	11542.80	177.87	1.54E-02	1.64E+01
1.89E+00	11350.42	177.87	1.57E-02	1.68E+01
1.93E+00	11350.42	177.87	1.57E-02	1.72E+01
1.97E+00	11542.80	177.87	1.54E-02	1.75E+01
2.01E+00	10965.66	177.87	1.62E-02	1.79E+01
2.05E+00	11158.04	180.18	1.61E-02	1.83E+01
2.09E+00	12312.32	164.01	1.33E-02	1.87E+01
2.14E+00	10388.52	166.32	1.60E-02	1.91E+01
2.18E+00	10580.90	168.63	1.59E-02	1.94E+01
2.22E+00	10388.52	173.25	1.67E-02	1.98E+01
2.26E+00	10196.14	173.25	1.70E-02	2.01E+01
2.30E+00	10196.14	173.25	1.70E-02	2.05E+01
2.34E+00	10196.14	173.25	1.70E-02	2.09E+01
2.39E+00	10003.76	173.25	1.73E-02	2.13E+01
2.40E+00	10003.76	173.25	1.73E-02	2.14E+01

Drawdown Graphs
(Well Field Straight Line Graph)
(Cadiero Observation Well Graph)
(Bradley Observation Well Graph)


CITY OF BEDFORD WELL FIELD TEST
● W-22
○ W-23
△ W-25
□ W-26
0.1
1.0
10.0
100.0
TIME/r² (day/s.f.)
0.000
0.010
s/Q (day/s.f.)


CITY OF BEDFORD WELL FIELD TEST
CADIERO OBSERVATION WELL
r=600 ft.
DRAWDOWN (ft.)
100
10
1.0
0.1
10^5
10^6
10^7
10^8
10^9
DISTANCE ^{2}/TIME (r^2/min.)


CITY OF BEDFORD WELL FIELD TEST
BRADLEY OBSERVATION WELL
r=1165 ft.
DRAWDOWN (ft.)
100
10
1.0
0.1
DISTANCE ^{2}/TIME (r^2/min.)
10^5
10^6
10^7
10^8
10^9