APPENDIX C

FIELD PUMPING TESTS

C-1. General. There are two basic types of pumping tests: *equilibrium* (steady-state flow) and *nonequilibrium* (transient flow).

a. Equilibrium-type test. When a well is pumped, the water discharged initially comes from aquifer storage adjacent to the well. As pumping continues, water is drawn from an expanding zone until a state of equilibrium has been established between well discharge and aquifer recharge. A state of equilibrium is reached when the *zone of influence* has become sufficiently enlarged so that: natural flow into the aquifer equals the pumping rate; a stream or lake is intercepted that will supply the well (fig. C-1); or vertical recharge from precipitation on the area above the zone of influence equals the pumping rate. If a well is pumped at a constant rate until the zone of drawdown has become stabilized, the coefficient of permeability of the aquifer can be computed from *equilibrium* formulas subsequently presented.

b. Nonequilibrium-type test.

(1) *In* this type of test, the value of k is computed from a relation between the rate of pumping Q, drawdown H' at a point P near the well, distance from the well to the point of drawdown measurement r, coefficient of storage of the aquifer S, and elapsed pumping time t. This relation permits determination of k from aquifer performance, while water is being drawn from storage and before stabilization occurs.

(2) Nonequilibrium equations are directly applicable to confined (artesian) aquifers and may also be used with limitations to unconfined aquifers (gravity flow conditions). These limitations are related to the percentage of drawdown in observation wells related to the total aquifer thickness. Nonequilibrium equations should not be used if the drawdown exceeds 25 percent of the aquifer thickness at the wall. Little error is introduced if the percentage is less than 10.

c. *Basic assumptions.*

(1) Both *equilibrium and nonequilibrium* methods for analyzing aquifer performance are generally based on the assumptions that:

(a) The aquifer is homogeneous and isotropic.

(b) The aquifer is infinite in extent in the horizontal direction from the well and has a constant thickness.

(c) The well screen fully penetrates the pervious formation.

(d) The flow is laminar.

(e) The initial static water level is horizontal.

(2) Although the assumptions listed above would seem to limit the analysis of pumping test data, in reality they do not. For example, most pervious formations do not have a constant k or transmissibility T(T = k × aquifer thickness), but the average T can readily be obtained from a pumping test. Where the flow is artesian, stratification has relatively little im-

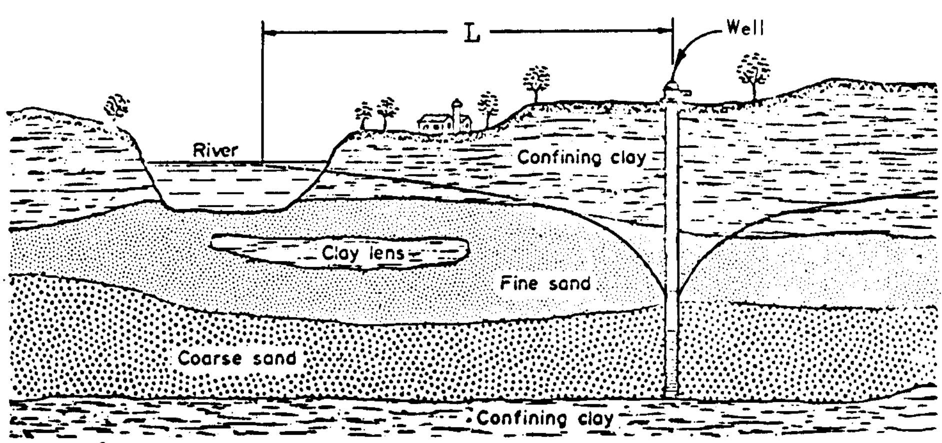

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Figure *C-1.* Seepage *into an aquifer from an adjacent river.*

portance if the well screen fully penetrates the aquifer; of course, the derived permeability for this case is actually k_h. If the formation is stratified and $k_h \geq k_v$, and the flow to the well is gravity in nature, the computed permeability k would be $<k_h$ and $>k_v$.

(3) Marked changes of well or aquifer performance during a nonequilibrium test indicate that the physical conditions of the aquifer do not conform to the assumptions made in the development of the formula for nonsteady flow to a well. However, such a departure does not necessarily invalidate the test data; in fact, analysis of the change can be used as a tool to better determine the flow characteristics of the aquifer.

C-2. Pumping test equipment and procedures. Determination of k from a pumping test requires: (a) installation of a test well, (b) two, and preferably more, observation wells or piezometers, (c) a suitable pump, (d) equipment for sounding the well and adjacent piezometers, and (e) some means for accurately measuring the flow from the well.

a. *Test and observation wells. The* test well should fully penetrate the aquifer to avoid uncertainties involved in the analysis of partially penetrating wells, and the piezometers should be installed at depths below any anticipated drawdown during the pumping test. The number, spacing, and arrangement of the observation wells or piezometers will depend on the characteristics of the aquifer and the geology of the area (figs. C-2 and C-3). Where the test well is located adjacent to a river or open water, one line of piezometers should be installed on a line perpendicular to the river, one line parallel to the river, and, if possible, one line away from the river. At least one line of piezometers should extend 500 feet or more out from the test well. The holes made for installing piezometers should be logged for use in the analysis of the test. The distance from the test well to each piezometer should be meas-

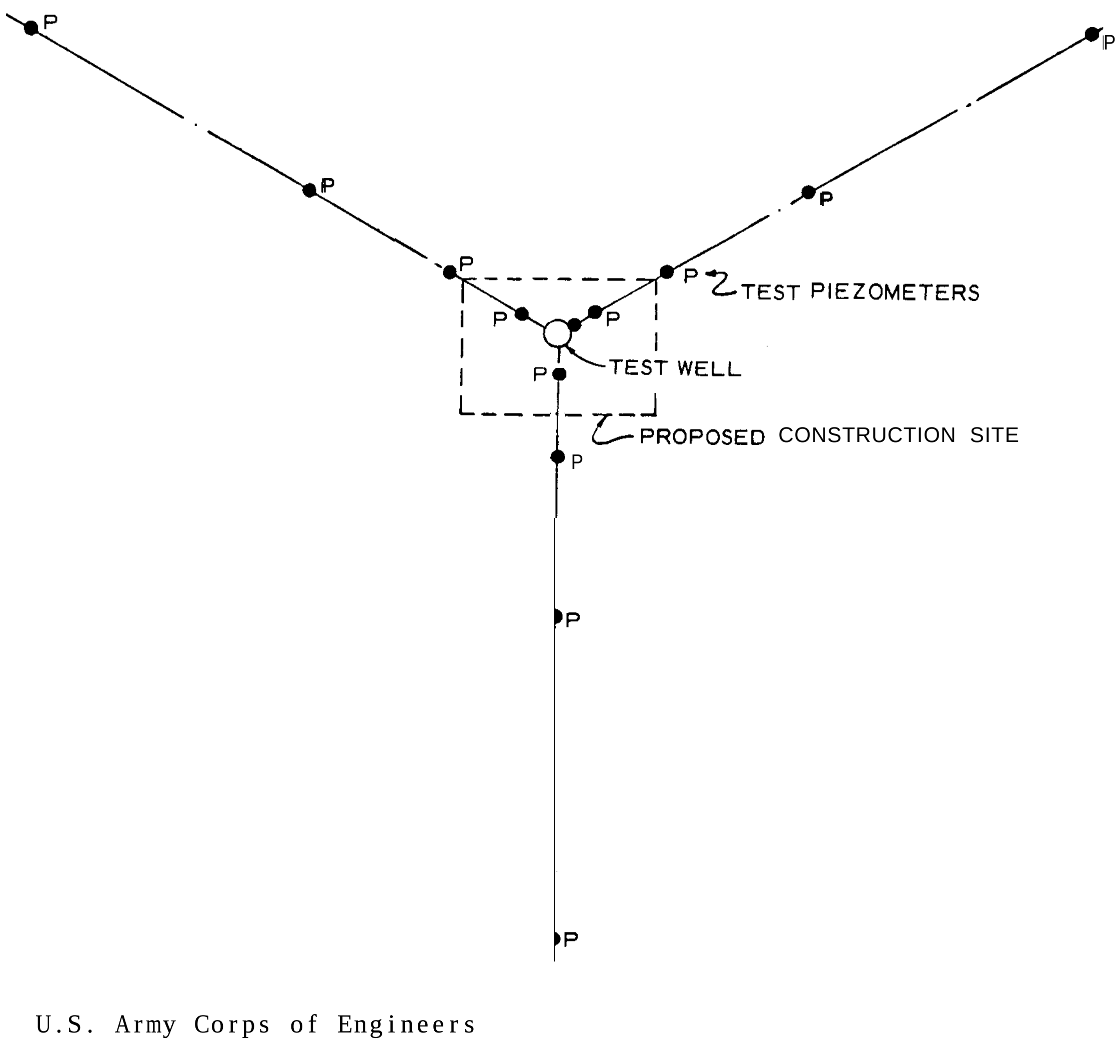

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Figure C-2. *Layout of piezometers for a pumping test.*

ured, and the elevation of the top of each accurately determined. Each piezometer should be capped with a vented cap to keep out dirt or trash and to permit change in water level in the piezometer without creating a partial vacuum or pressure. The test well and piezometers should be carefully installed and developed, and their performance checked by individual pumping or falling head tests in accordance with the procedures discussed in chapter 5 of the main text.

b. Pumps.

(1) The test pump should be a centrifugal, or more preferably, a turbine or submersible pump. It should be capable of lowering the water level in the well at least 10 feet or more depending upon the characteristics of the formation being tested. The pump should preferably be powered with an electric motor, or with an engine capable of operating continuously for the duration of the test. The pump discharge line should be equipped with a valve so that the rate of discharge can be accurately controlled. At the beginning of the test, the valve should be partially closed so that back pressure on the pump can be varied as the test progresses to keep the rate of flow constant.

(2) During a pumping test, it is imperative that the rate of pumping be maintained constant. Lowering of the water level in the well will usually cause the pumping rate to decrease unless the valve in the discharge line is opened to compensate for the additional head or lift created on the pump. If the pump is powered with a gas or diesel engine, changes in temperature and humidity of the air may affect appreciably the operation of the engine and thus cause variations in the pumping rate. Variations in line voltage may similarly affect the speed of electric motors and thus the pumping rate. Any appreciable variation in pumping rate should be recorded, and the cause of the variation noted.

(3) The flow from the test well must be conveyed from the test site so that recharge of the aquifer from water being pumped does not occur within the zone of influence of the test well.

c. *Flow and drawdown measurements.*

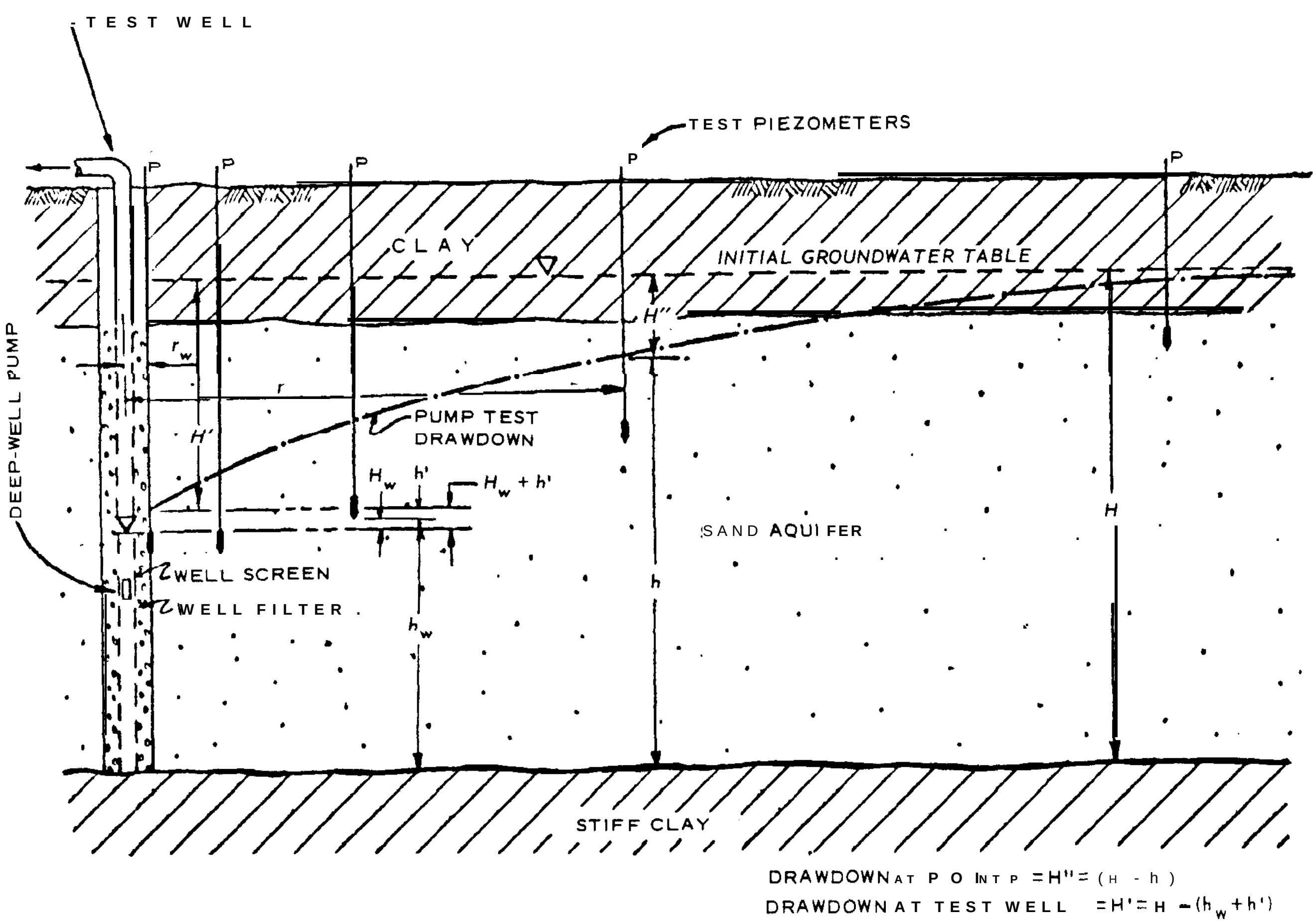

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Figure C-3. Section of *well and piezometers for a pumping test with gravity flow near well.*

(1) The discharge from the well can be measured by means of an orifice, pitometer, venturi, or flowmeter installed in the discharge pipe, or an orifice installed at the end of the discharge pipe, as described in appendix G. The flow can also be estimated from the jet issuing froma smooth discharge pipe, or measured by means of a weir or flume installed in the discharge channel. For such flow measurements, appropriate consideration must be given to the pipe or channel hydraulics in the vicinity of the flow-measuring device. Formulas, graphs, and tables for measuring flow from a test well are given in appendix G.

(2) In thick aquifers, or in deposits where the material varies with depth, it may be desirable to determine the permeability of the various strata of the formations in order to better determine the required length and depth or well screens of wellpoints for the design of a dewatering or drainage system. This permeability can be determined by measuring the vertical flow within the well screen at various levels with a flowmeter. The flow from the various strata can be obtained by taking the difference in flow at adjacent measuring levels; the flow-meter, equipped with a centering device, is placed in the well before the pump is installed. Typical data obtained from such well-flow measurements in a test well are shown in figure C-4. These data can be used to compute the coefficient of permeability of the various strata tested as shown, The

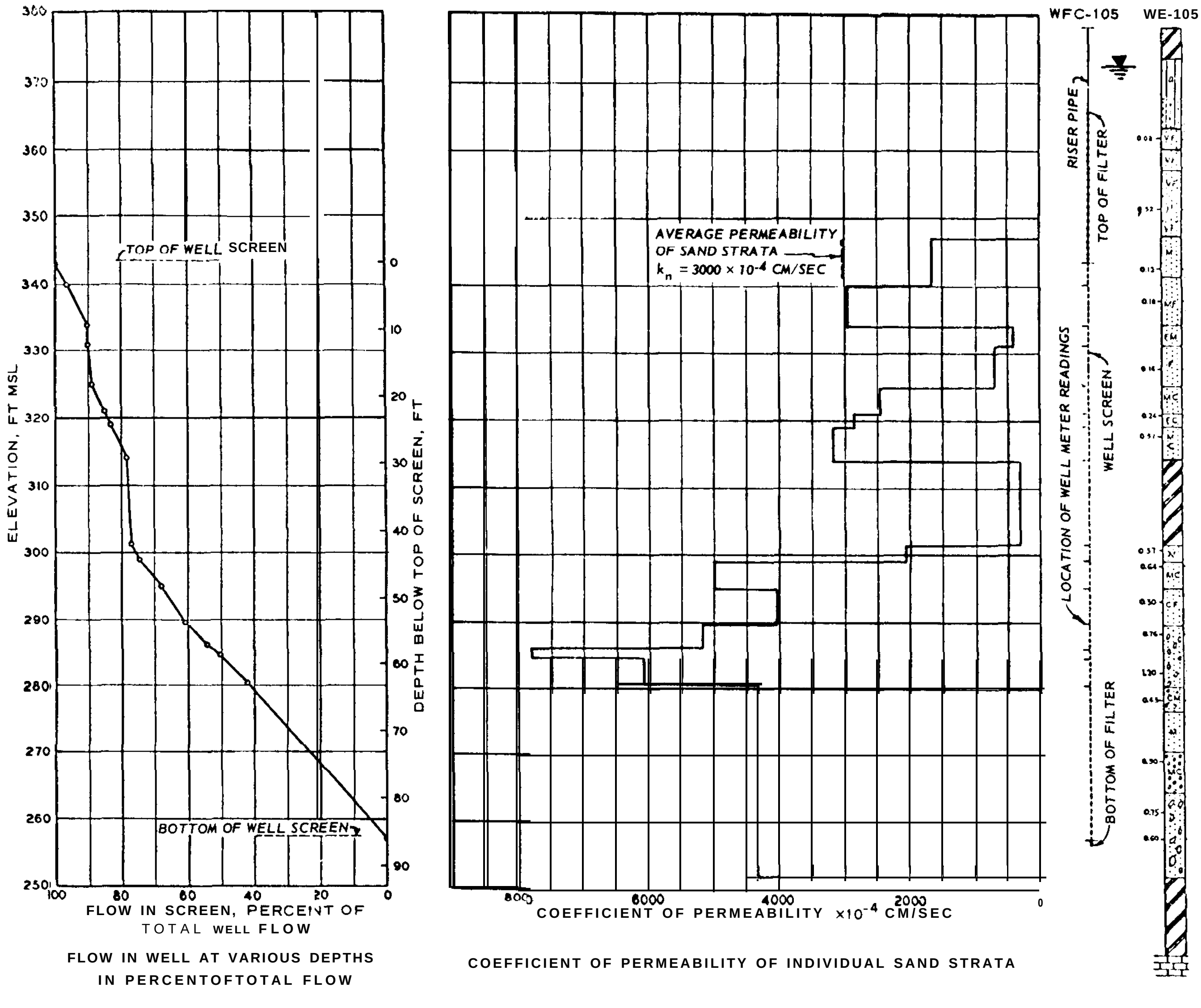

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Figure C-4. Coefficient of permeability k_h of various strata determined from a pumping test and flow measurements in the well screen.

correlation between D_{10} and k_h shown in figure C-4 was based on laboratory sieve analyses and on such well-flow tests.

d. Geneml test procedures.

(1) Before a pump test is started, the test well should be pumped for a brief period to ensure that the pumping equipment and measuring devices are functioning properly and to determine the approximate valve and power settings for the test. The water level in the well and all observation piezometers should be observed for at least 24 hours prior to the test to determine the initial groundwater table. If the groundwater prior to the test is not stable, observations should be continued until the rate of change is clearly established; these data should be used to adjust the actual test drawdown data to an approximate equilibrium condition for analysis. Pumping of any wells in the vicinity of the test well, which may influence the test results, should be regulated to discharge at a constant, uninterrupted rate prior to and during the complete test.

(2) Drawdown observations in the test well itself are generally less reliable than those in the piezometers because of pump vibrations and momentary variations in the pumping rate that cause fluctuations in the water surface within the well. A sounding tube with small perforations installed inside the well screen can be used to dampen the fluctuation in the water level and improve the accuracy of well soundings, All observations of the groundwater level and pump discharge should include the exact time that the observation was made.

(3) As changes in barometric pressure may cause the water level in test wells to fluctuate, the barometric pressure should be recorded during the test.

(4) When a pumping test is started, changes in water levels occur rapidly, and readings should be taken as often as practicable for certain selected pie-. zometers (e.g., t = 2, 5, 8, 10, 15, 20, 30, 4.5, and 60 minutes) after which the period between observations may be increased. Sufficient readings should be taken to define accurately a curve of water level or drawdown versus (log) elapsed pumping time. After pumping has stopped, the rate of groundwater-level recovery should be observed. Frequently, such data are important in evaluating the performance and characteristics of an aquifer.

C-3. Equilibrium pumping test.

a. In an equilibrium type of pumping test, the well is pumped at a constant rate until the drawdown in the well and piezometers becomes stable.

b. A typical timedrawdown curve for a piezometer near a test well is plotted to an arithmetical scale in figure C-5 and to a semilog scale in figure C-6. (The computations in fig C-6 are discussed subsequently.) Generally, a time-drawdown curve plotted to a semilog scale becomes straight after the first few minutes of pumping. If true equilibrium conditions are established, the drawdown curve will become horizontal.

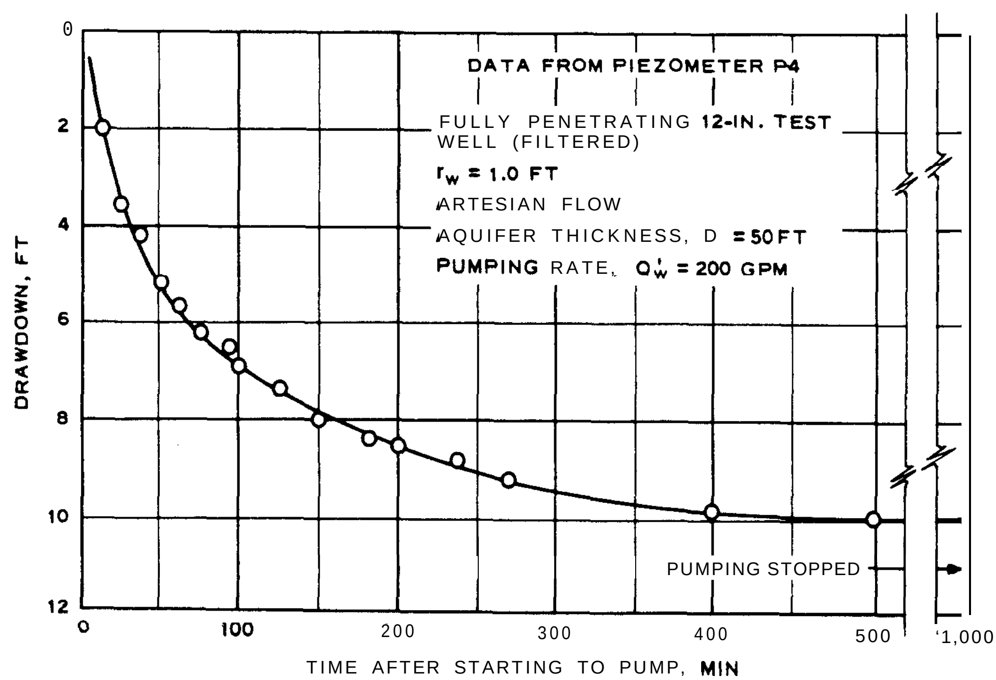

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Figure C-5. Dmwdown in an observation well versus pumping time (arithmetical scale).

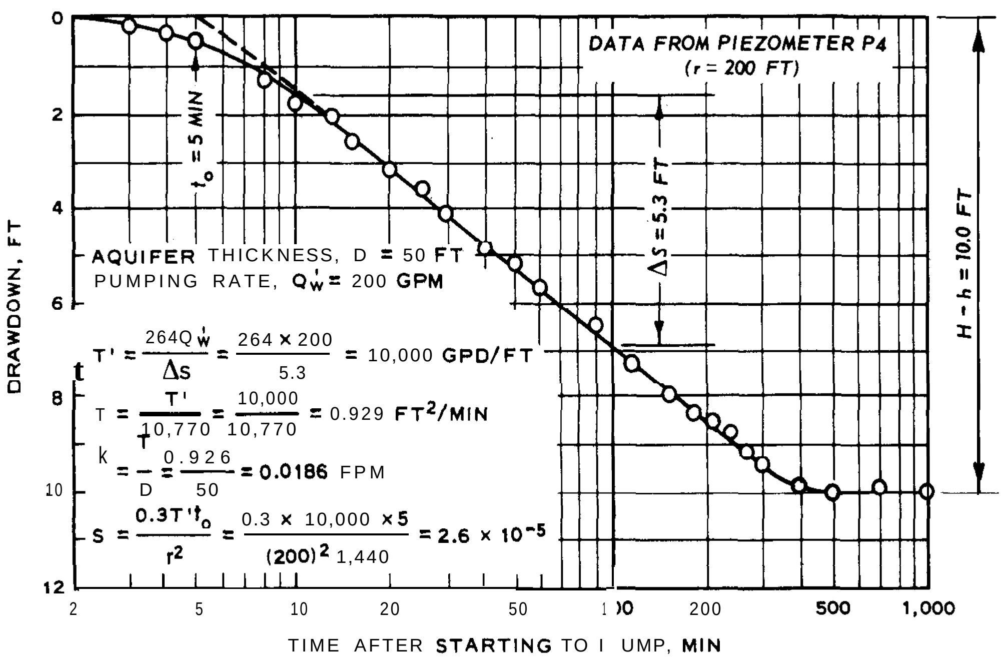

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Figure C-6. Drawdown in an observation well versus pumping time (semilog scale).

The drawdown measured in the test well and adjacent observation wells or piezometers should always be plotted versus (log) time during the test to check the performance of the well and aquifer. Although the example presented in figure C-6 shows stabilization to have essentially occurred after 500 minutes, it is considered good practice to pump *artesian* wells for 12 to 24 hours and to pump test wells where *gruuity flow* conditions exist for 2 or 3 days.

c. The drawdown in an artesian aquifer as measured by piezometers on a radial line from a test well is plotted versus (log) distance from the test well in figure C-7. In a homogeneous, isotropic aquifer with artesian flow, the drawdown (H-h) versus (log) distance from the test well will plot as a straight line when the flow in the aquifer has stabilized. The drawdown $H^2—h^2$ versus (log) distance will also plot as a straight line for *gruuity flow.* However, the drawdown in the well may be somewhat greater than would be indicated by a projection of this straight line to the well because of well entrance losses and the effect of a "free" flow surface at *gravity* wells. Extension of the drawdown versus (log) distance line to zero drawdown indicates the effective source of seepage or radius of influence R, beyond which no drawdown would be produced by pumping the test well (fig, C-7).

d. For flow from a circular source of seepage, the coefficient of permeability k can be computed from the formulas for fully penetrating wells.

Artesiun Flow.

$$Q_w = \frac{2\pi kD(H—h)}{\ln(R/r)} \quad \text{(C-1)}$$

Gravity Flow,

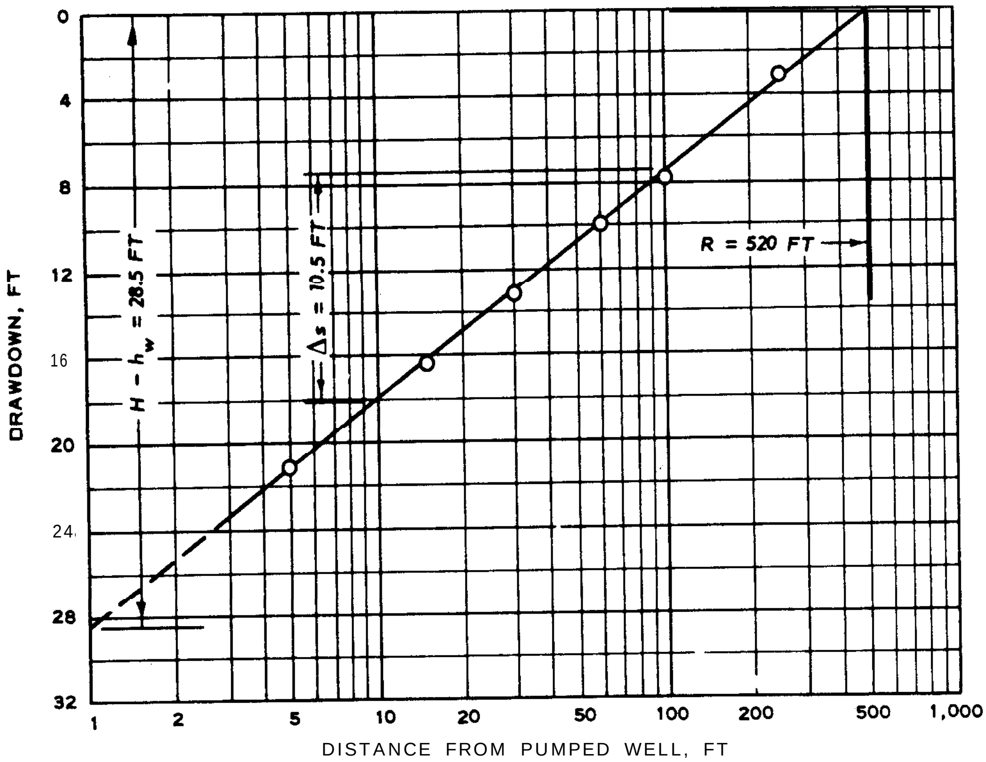
$$Q_w = \frac{\pi k(H^2—h^2)}{\ln(R/r)} \quad \text{(C-2)}$$

where

Q_w = flow from the well
D = aquifer thickness
H = initial height of groundwater table (GWT)
h = height of GWT at r
(H-h) or $(H^2—h^2)$ = drawdown at distance r from well
R = radius of influence

An example of the determination of R and k from an equilibrium pumping test is shown in figure C-7.

e. For combined artesian-gravity flow, seepage from a line source and a partially penetrating well, the coefficient of permeability can be computed from well-flow formulas presented in chapter 4.



NOTE: DRAWDOWNS PLOTTED WERE MEASURED AFTER GROUND WATER TABLE HAD STABILIZED.

EXAMPLE: FULLY PENETRATING 12-IN. TEST WELL (FILTERED), r_w = 1.0 FT
ARTESIAN FLOW
AQUIFER THICKNESS, D = SO FT
PUMPING RATE, Q'_w = 200 GPM
PUMPING PERIOD = 1,000 MIN

$$k = \frac{Q'_w \ln (R/r_w)}{2\pi D (H - h_w)} = \frac{200 \ln (520/1)}{7.5 (2\pi) (50) (28.5)} = 0.0189 \text{ FPM}$$

(Courtesy of UOP Johnson Division)

Figure C-7. Drawdown versus distance from test well.

C-4. Nonequilibrium pumping test.

a. Constant discharge tests. The coefficients of transmissibility T, permeability k, and storage S of a homogeneous, isotropic aquifier of infinite extent with no recharge can be determined from a *nonequilibrium* type of pumping test. Average values of S and T in the vicinity of a well can be obtained by measuring the drawdown with time in one or more piezometers while pumping the well at a known constant rate and analyzing the data according to methods described in (1), (2), and (3) below.

(1) *Method 1.* The formula for nonequilibrium flow can be expressed as

$$H - h = \frac{115Q'_w W(u)}{T'} \qquad \text{(C-3)}$$

where

H - h = drawdown at observation peizometer, feet
Q'_w = well discharge, gallons per minute
W(u) = exponential integral termed a "well function" (see table C-1)
T' = coefficient of transmissibility, gallons per day per foot width

and

$$u = \frac{1.87r^2S}{T't'} \qquad \text{(C-4)}$$

Table C-l. Values of $W(u)$ for values of u.

u	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0
$\times 1$	0.219	0.049	0.013	0.0038	0.0011	0.00036	0.000~2	0.000038	0.0000~2
$\times 10^{-1}$	1.82	1.22	0.91	0.70	0.56	0.45	0.37	0.31	0.26
$\times 10^{-2}$	4.04	3.35	2.96	2.68	2.47	2.30	2.15	2.03	1.92
$x 10^{-3}$	6.33	5.64	5.23	4.95	4.73	4.54	4.39	4.26	4.14
$\times 10^{-4}$	8.63	7.94	7.53	7.25	7.02	6.84	6.69	6.55	6.44
$\times 10^{-5}$	10.94	10.24	9.84	9.55	9.33	9.14	8.99	8.86	8.74
$\times 10^{-6}$	i3.24	i2.55	12.14	11.85	ii.63	ii.45	ii.29	11.16	11.04
$\times 10^{-7}$	i5.54	14.85	14.44	14.15	i3.93	i3.75	13.60	13.46	i3.34
$\times 10^{-8}$	17.84	17.15	16.74	i6.46	i6.23	16.05	15.90	15.76	15.65
$\times 10^{-9}$	20.15	19.45	19.05	18.76	18.54	18.35	18.20	18.07	17.95
$\times 10^{-10}$	22.45	21.76	2i.35	21.06	20.84	20.66	20.50	20.37	20.25
$\times 10^{-11}$	24.75	24.06	23.65	23.36	23.14	22.96	22.81	22.67	22.55
$\times 10^{-12}$	27.05	26.36	25.96	25.67	25.44	25.26	25.11	24.97	24.86
$\times 10^{-13}$	29.36	28.66	28.26	27.97	27.75	27.56	27.41	27.28	27.16
$\times 10^{-14}$	31.66	30.97	30.56	30.27	30.05	29.87	29.71	29.58	29.46
$\times 10^{-15}$	33.96	33.27	32.86	32.58	32.35	32.17	32.02	31.88	31.76

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where

r = distance from test well to observation piezometer, feet

s = coefficient of storage

t′ = elapsed pumping time in days

The formation constants can be obtained approximately from the pumping test data using a graphical method of superposition, which is outlined below.

Step 1. Plot W(u) versus u on log graph paper, known as a "type-curve," using table C-l as in figure c-8.

Step 2. Plot drawdown (H-h) versus r^2/t' on log graph paper of same size as the type-curve in figure C-8.

Step 3. Superimpose observed data curve on type-curve, keeping coordinates axes of the two curves parallel, and adjust until a position is found by trial whereby most of the plotted data fall on a segment of the type-curve as in figure C-8.

Step 4. Select an arbitrary point on coincident segment, and record coordinates of matching point (fig. C-8).

Step 5. With value of W(u), u, H-h, and r^2/t' thus determined, compute S and T' from equations (C-3) and (C-4).

Step 6. T and k from the following equations:

$$T = \frac{T'}{10,770} \quad \text{(square feet per minute)} \qquad \text{(C-5)}$$

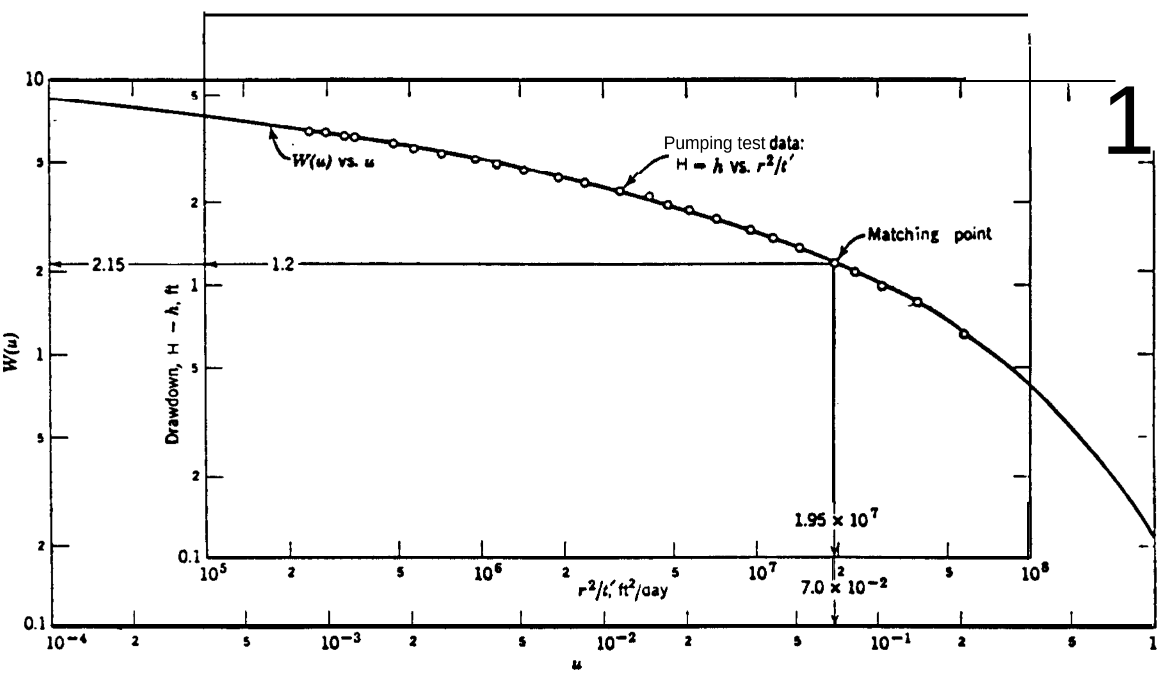
$$k = \frac{T'}{10,770D} \quad \text{(feet per minute)} \qquad \text{(C-6)}$$

(2) *Method 2.* This method can be used as an approximate solution for *nonequilibrium flow* to a well to avoid the curve-fitting techniques of method 1 by using the techniques outlined below.

Step 1. Plot time versus drawdown on semilog graph as in figure C-9.

Step 2. Choose an arbitrary point on time-drawdown curve, and note coordinates t and H-h.

Step 3. Draw a tangent to the time-drawdown



EXAMPLE: Q'_w = 500 GPM

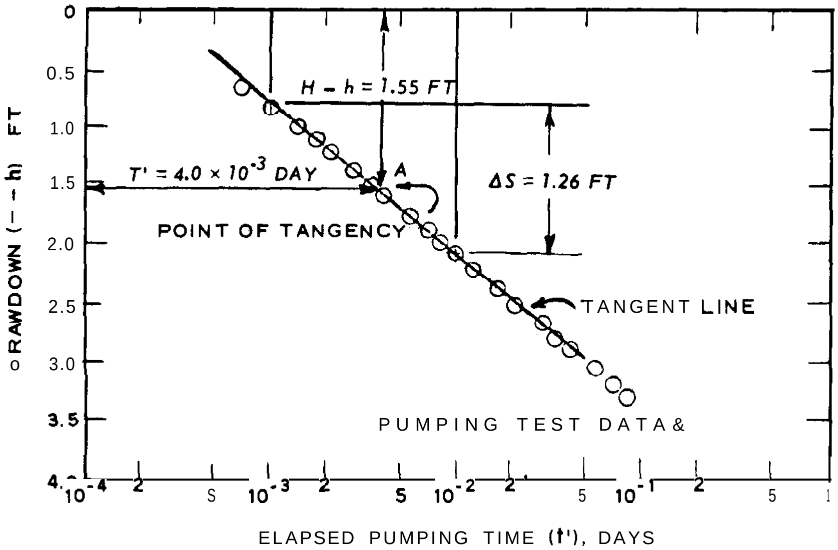
r = ZOO FT

$$T' = \frac{115\, Q'_w\, W(u)}{H - h} = \frac{115(500)(2.15)}{1.2} = 103,000 \text{ GPD/ FT}$$

$$S = \frac{(7.0 \times 10^{-2})}{1.97\, r^2/t'} \frac{(103,000)}{1.87(1.95 \times 10^7)} = 1.98 \times 10^{-3}$$

*(From "Ground Water **Hydrology**" by D. K. Todd, 1959, Wiley & Sons, Inc. Used with permission of Wiley & Sons, Inc.)*

Figure C-8. Method 1 (Superposition) for solution of the nonequilibrium equation.



EXAMPLE: Q'_w = 500 GPM

DISTANCE TO OBSERVATION WELL, r = 200 FT

AT POINT A: t' = 4.0 × 10^{-3} DAY

H - h = 1.55 FT

TANGENT THROUGH A: ΔS = 1.26 FT/LOG CYCLE OF PUMPING TIME IN DAYS

THEN $F(u) = \frac{H-h}{\Delta S} = \frac{1.55}{1.26} = 1.23$ [SEE FIG. C-10 FOR F(u)]

$$T' = \frac{115\, Q'_w W(u)}{H-h} = \frac{115(500)(2.72)}{1.55} = 101{,}000 \text{ GPD/FT}$$

$$S = \frac{T't'u}{1.87r^2} = \frac{101{,}000\ (4.0 \times 10^{-3})\ (0.038)}{1.87(200)^2} = 2.05 \times 10^{-4}$$

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Figure C-9. Method 2 for solution of the nonequilibrium equation.

curve through the selected point, and deterine As, the drawdown in feet per log cycle of time.

Step 4. Compute F(u) = H - h/As, and determine corresponding W(u) and u from figure C-10.

Step 5. Determine the formation constants by equations (C-3) and (C-4).

(3) *Method 3.* This method can be used as an approximate solution for *nonequilibrium flow* to a well if the time-drawdown curve plotted to a semilog scale becomes a straight line (fig. C-6). The formation constants (T' and S) can be computed from

$$T' = \frac{264Q'_w}{As} \qquad \text{(C-7)}$$

and

$$S = \frac{0.3T't_0}{r^2} \qquad \text{(C-8)}$$

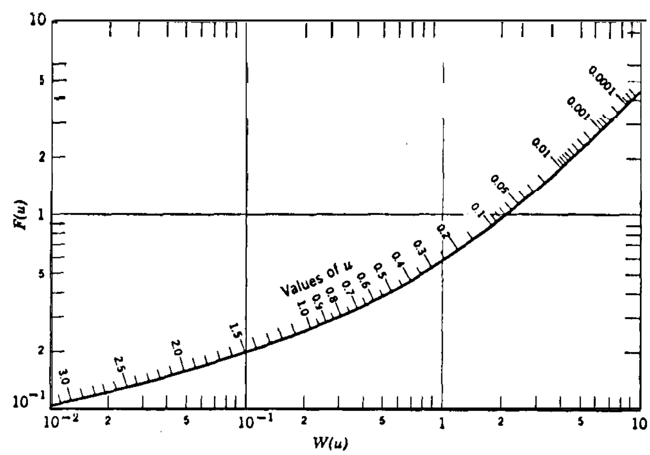

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Figure C-10. Relation among F(u), W(u), and u.

where

Δs = drawdown in feet per cycle of (log) time-drawdown curve

t_0 = time at zero drawdown in days

An example of the use of this method of analysis in determining values of T, S, and k is given in figure C-6, using the nonequilibrium portion of the time-drawdown curve.

(4) *Gravity flow.* Although the equations for nonequilibrium pumping tests are derived for artesian flow, they may be applied to gravity flow if the drawdown is small with respect to the saturated thickness of the aquifer and is equal to the specific yield of the dewatered portion of the aquifer plus the yield caused by compression of the saturated portion of the aquifer as a result of lowering the groundwater. The procedure for computing T' and S for *nonequilibrium gravity flow* conditions is outlined below.

Step 1. Compute T' from equation (C-3).

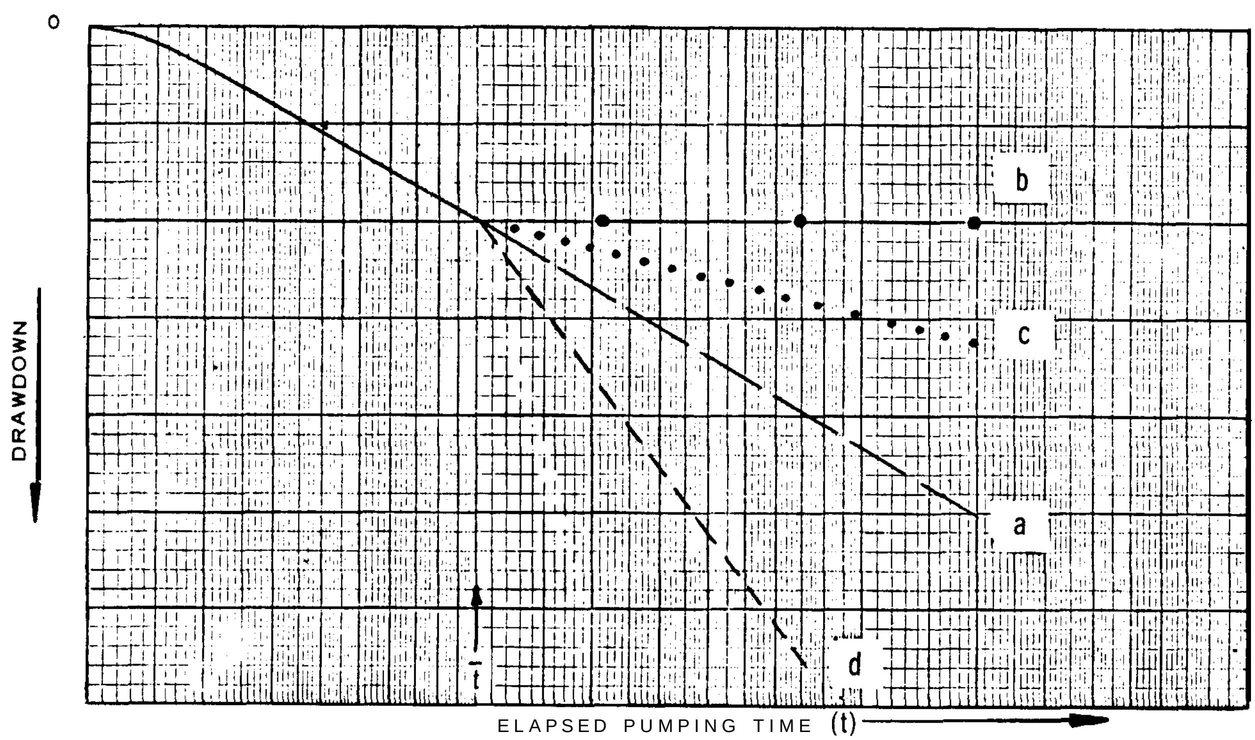
Step 2. Compute S from equation (C-4) for various elapsed pumping times during the test period, and plot S versus (log) t'.

Step 3. Extrapolate the S versus (log) t' curve to an ultimate value for S'.

Step 4. Compute u from equation (C-4), using the extrapolated S', the originally computed T', and the original value of r^2/t'.

Step 5. Recompute T' from equation (C-3) using a W(u) corresponding to the computed value of u.

(5) *Recharge.* Time-drawdown curves of a test well are significantly affected by recharge or depletion of the aquifer, as shown in figure C-11. Where recharge does not occur, and all water is pumped from storage, the H' versus (log) t curve would resemble curve a. Where the zone of influence intercepts a source of seepage, the H' versus (log) t curve would resemble curve b. There may be geological and recharge conditions where there is some recharge but not



CURVE a - ALL WATER FROM STORAGE-NO AQUIFER RECHARGE.

b - CONE OF INFLUENCE INTERCEPTS A SOURCE OF SEEPAGE AT TIME $\bar{t}$.

c - CONE OF INFLUENCE INTERCEPTS A SOURCE OF SEEPAGE AT TIME $\bar{t}$ WITH SUPPLY LESS THAN RATE OF PUMPING AT TIME $\bar{t}$.

d - CONE OF INFLUENCE INTERCEPTS AN IMPERMEABLE BOUNDARY AT TIME $\bar{t}$.

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Figure C-11. Time-drawdown curves for various conditions of recharge enough to equal the rate of well flow (e.g., curve c). In many areas, formation boundary conditions exist that limit the area1 extent of aquifers. The effect of such a boundary on an H’ versus (log) t graph is in reverse to the effect of recharge. Thus, when an impermeable boundary is encountered, the slope of the H’ versus (log) t curve steepens as illustrated by curve d. It should be noted that a *nonequilibrium* analysis of a pumping test is valid only for the first segment of a time-drawdown curve.

b. Step-drawdown pump test.

(1) The efficiency of a well with respect to entrance losses and friction losses can be determined from a *step-dmwdown* pumping test, in which the well is pumped at a constant rate of flow until either the drawdown becomes stabilized or a straight-line relation of the time-drawdown curve plotted to a semilog scale is established. Then, the rate of pumping is increased and the above-described procedure repeated until the well has been pumped at three or four rates. The drawdown from each step should be plotted as a continuous time-drawdown curve as illustrated in figure C-12. The straight-line portion of the time-drawdown curves is extended as shown by the dashed lines in figure C-12, and the incremental drawdown AH’ for each step is determined as the difference between the plotted and extended curves at an equal time after each step in pumping. The drawdown H’ for each step is the sum of the preceding incremental drawdowns and can be plotted vesus the pumping rate as shown in figure C-13. If the flow is entirely laminar, the drawdown (H-h for *artesiun flow* and H^2—h^2 for *gmvity flow)* versus pumping rate will plot as a straight line; if any of the flow is turbulent, the plot will be curved.

(2) The well-entrance loss H_e, consisting of friction losses at the aquifer and filter interface through the filter and through the well screen, can be deter-

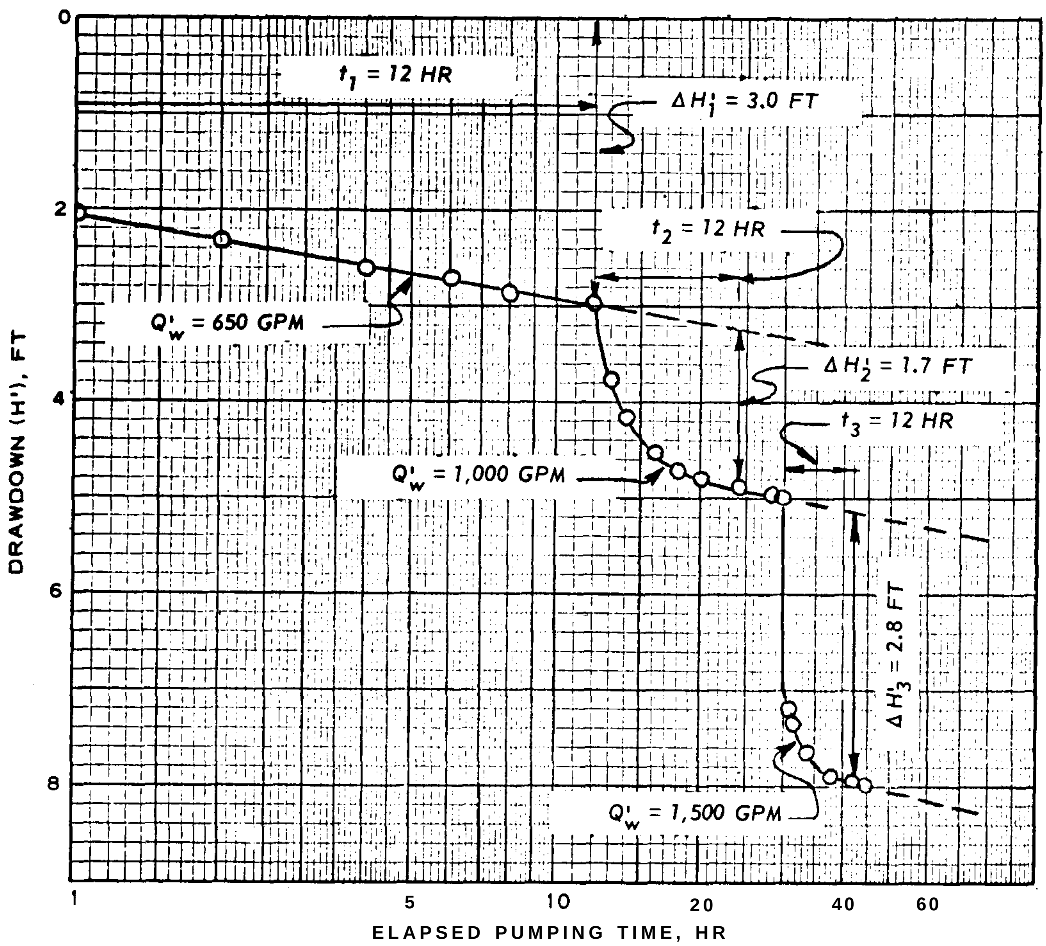

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Figure C-12. Drawdown versus elapsed pumping time for a step-drawdown test.

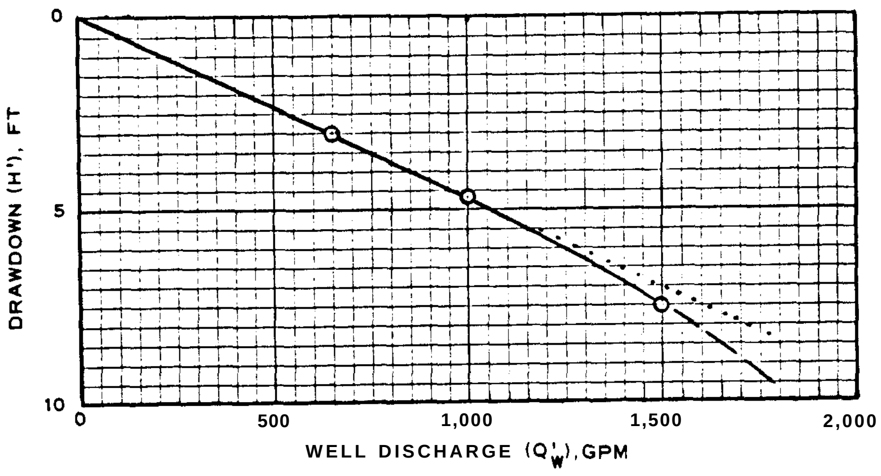

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Figure C-13. Dmwdown versus pumping mte for a step-drawdown test.

mined from the drawdown versus distance plots for a step-drawdown pump test as illustrated in figure C-14. The difference in drawdown between the extended drawdown-distance curve and the water elevation measured in the well represents the well-entrance loss and can be plotted versus the pumping rate as shown in figure C-15. Curvature of the H_w versus Q_w line indicates that some of the entrance head loss is the result of turbulent flow into or in the well.

c. Recovery test.

(1) A recovery test may be made at the conclusion of a pumping test to provide a check of the pumping test results and to verify recharge and aquifer boundary conditions assumed in the analysis of the pumping test data. A recovery test is valid only if the pumping test has been conducted at a *constant* rate of discharge. A recovery test made after a *step-drawdown* test cannot be analyzed.

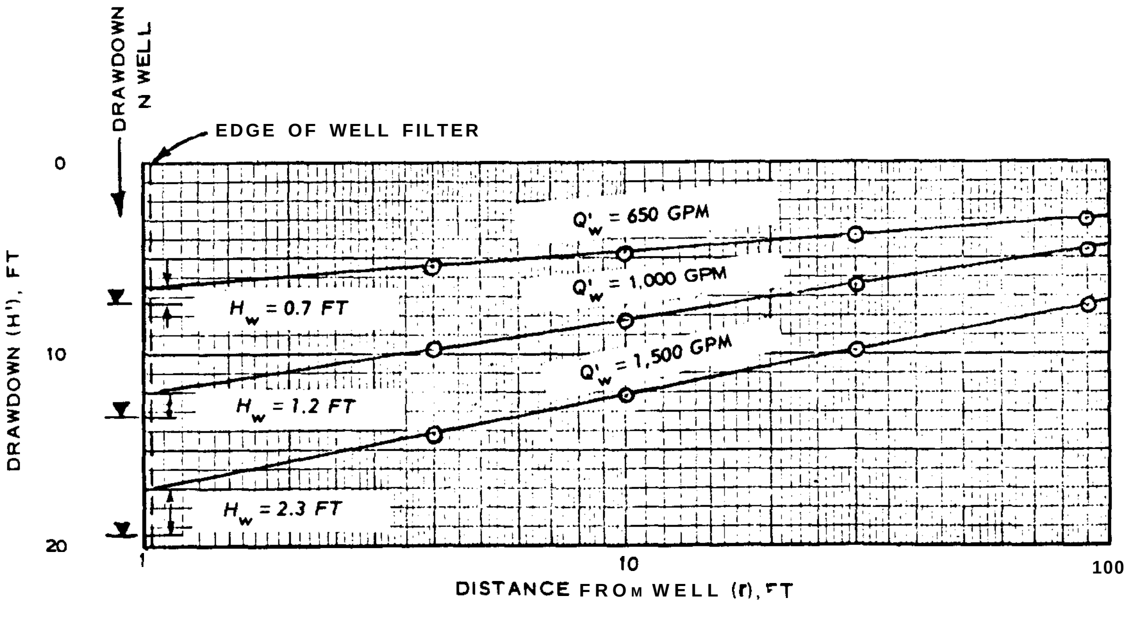

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Figure C-14. Dmwdown versus distance for a step-drawdown test for determining well-entrance loss.

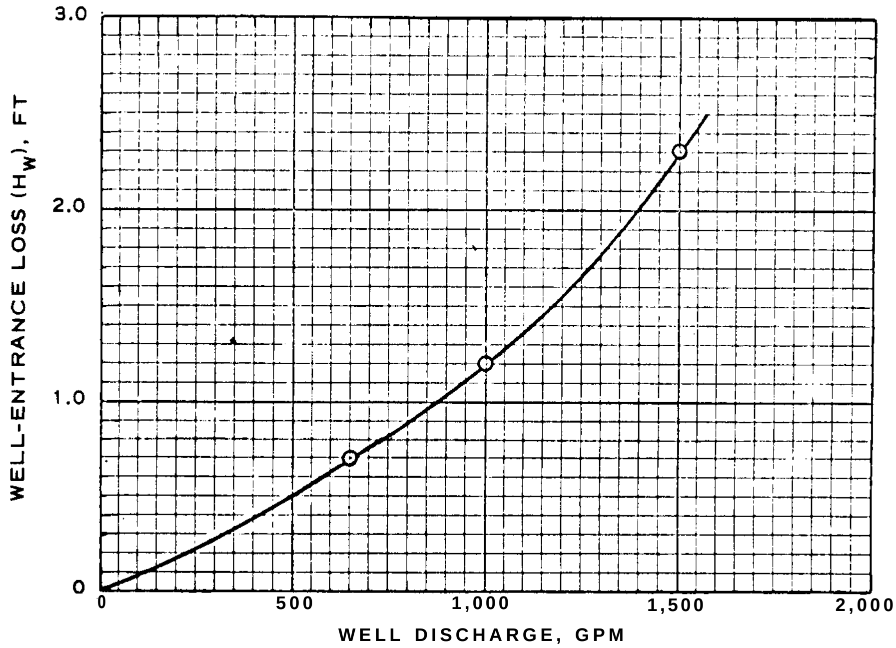

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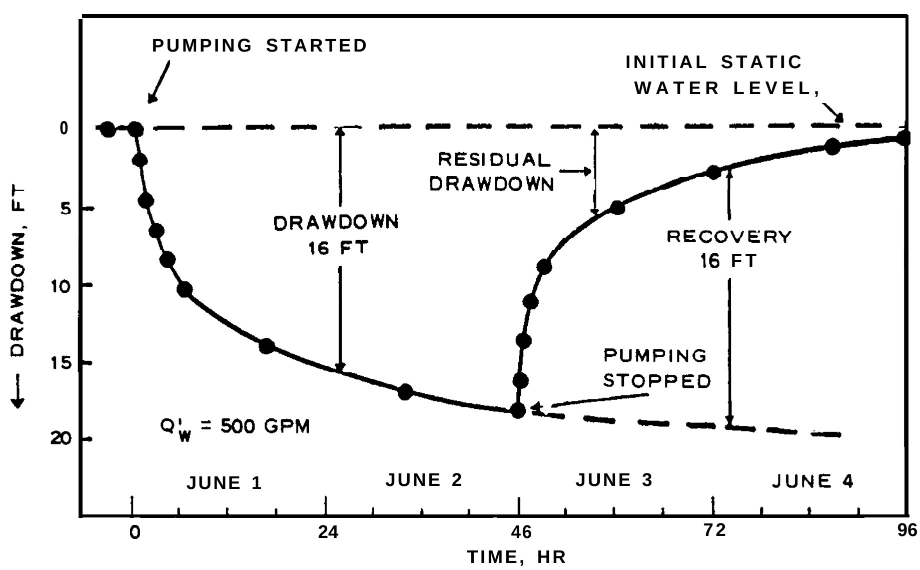
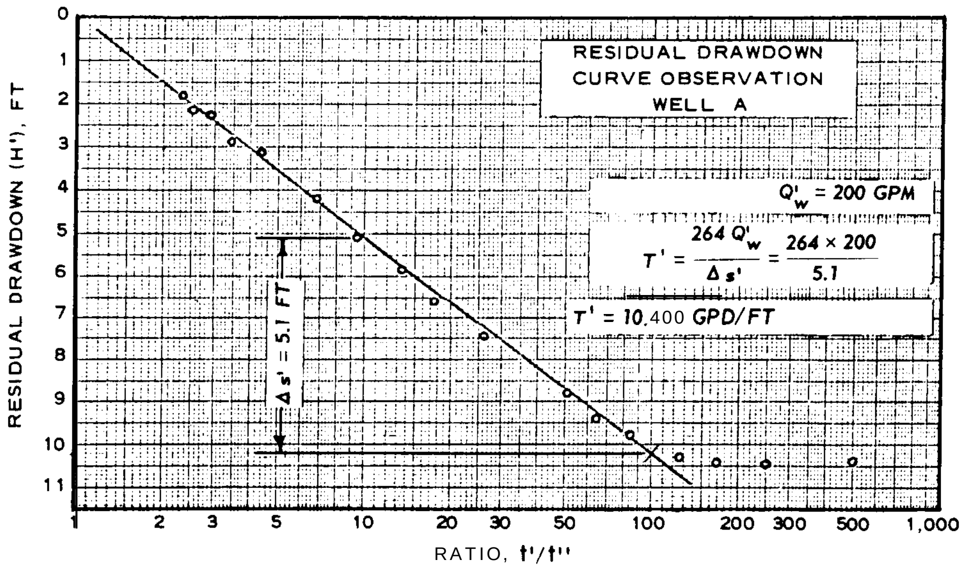
Figure C-15. Well-entrance loss versus pumping rate for a step-drawdown test.

(2) When the pump is turned off, the recovery of the groundwater levels is observed in the same manner as when the pump was turned on, as shown in figure C-16. The residual drawdown H' is plotted versus the ratio of log t'/t", where t' is the total elapsed time since the start of pumping, and t" is the elapsed time since the pump was stopped (fig. C-17). This plot should be a straight line and should intersect the zero



(Courtesy of UOP Johnson Division)

Figure C-16. Typical drawdown and recovery curves for a well pumped and then allowed to rebound.



(Courtesy of UOP Johnson Division)

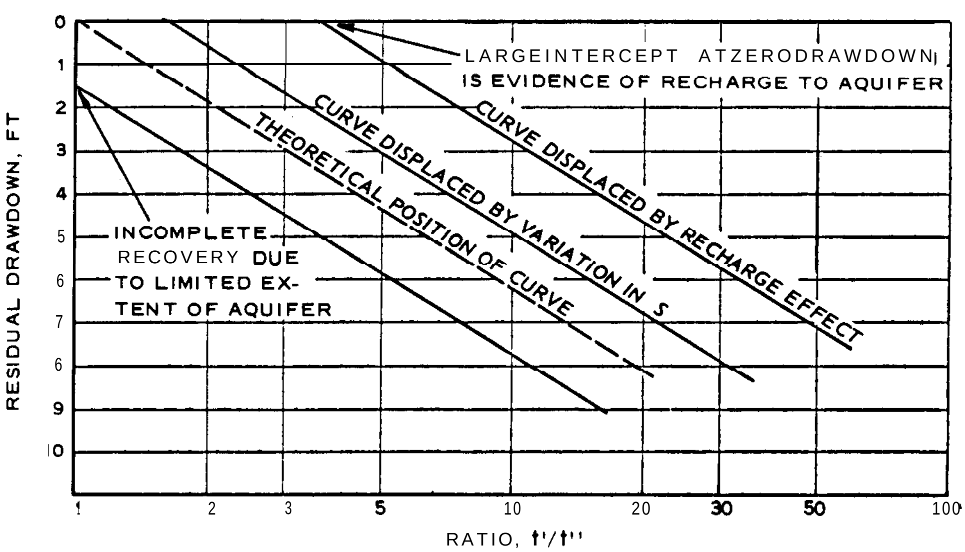
Figure C-l 7. Residual dmwdown versus t'/t" (time during recovery period increased toward the left).

residual drawdown at a ratio of t'/t" = 1 if there is normal recovery, as well as no recharge and no discontinuities in the aquifer within the zone of drawdown. The ratio t'/t" approaches one as the length of the recovery period is extended.

(3) The transmissibility of the aquifer can be calculated from the equation

$$T = \frac{264Q'_w}{\Delta s'} \qquad \text{(C-9)}$$

where Δs' = residual drawdown in feet per cycle of (log) t'/t" versus residual drawdown curve. Displacement of the residual drawdown versus (log) ratio t'/t" curve, as shown in figure C-18, indicates a variance with the assumed conditions.



(Courtesy of UOP Johnson Division)

Figure C-18. Displacement of residual dmwdown curve when aquifer conditions vary from theoretical conditions