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# DURATION OF TEST PUMPING

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| | |
|---|---|
| $A$ | cross-section of the well casing |
| $b$ | aquifer thickness |
| $\beta$ | hydraulic diffusivity$(\frac{T}{\emptyset})$ |
| $E$ | the error |
| $K_z$ | vertical permeability |
| $K_r$ | radial hydraulic conductivity |
| $Q$ | rate of well discharge |
| $Q(t)$ | withdrawal rate at time t |
| $R_r$ | radial distance of the recharge boundary from the pumping well |
| $R_e$ | radius of influence |
| $r_f$ | radial distance of the farthest observation point |
| $r_o$ | radius of the well |
| $r$ | radial distance of the observation well |
| $s_o$ | drawdown in the bore hole |
| $s, s'$ | drawdown in the piezometer |
| $t', t, t_o$ | time |
| $T$ | transmissivity |
| $t_p$ | time of pumping during which the initial disturbances affects the drawdown |
| $u$ | non-dimensional well function factor |
| $V(t)$ | water volume drawn from the bore hole at time t |
| $W(u)$ | Theis well function |
| $\emptyset$ | storativity |
| $\emptyset_y$ | specific field |

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# ABSTRACT

The duration of the pumping test is largely influenced by the discharge rate, radial distances of the osbservation points ,aquifer parameters and boundary conditions. Plots have been presented for determining the time during which the initial disturbances persist during a pumping test. An equation has been suggested to compute the travel time of the radius of influence when a pumping test is conducted near a recharge boundary. Based on the actual pumping test data certain guidelines and index drawdowns have been provided which would help in deciding the maximum duration of pumping in a confined aquifer for reliable estimation of aquifer properties.

## 1.0 INTRODUCTION

Pumping test is one of the most useful means of determining the aquifer parameters of the water bearing formations and confining beds. However, the pumping tests are frequently subject to criticism because they are of short duration. The question how long a pumping test should be carried out, frequently goes unanswered. Only in few cases it has been possible to compare the results of short duration test with that of a long duration one. The reason for this is the non-availability of long term data. Even where long duration pumping test data exist other variables such as boundary conditions operate on the system, which at times prohibit comparison of results.

In the present report, an attempt has been made to establish guidelines to decide the minimum and maximum durations of the test pumping. It has also been attempted to identify the parameters which may influence the decisions regarding the length of the pumping test.

## 2.0 REVIEW

The duration of an aquifer test is governed by many factors such as type of aquifer, boundary conditions, accuracy required, availability of funds, equipment, manpower etc. A very few guidelines and thumb rules are available at present for deciding the duration of an aquifer test. Reeder(1957) published the results of a detailed study of the sand and gravel aquifer based upon data collected from 1948 through 1955. To determine the hydraulic characteristics of the aquifer, he made use of three tests. These tests followed the usual porocedures of pumping one well continuously for two or three days at a constant rate while making water level measurements in nearby wells and in the pumped well during and after the period of pumping. The transmissivity and storativity were found to be of the order of 50,000 gpd per foot and 0.10 respectively. Subsequently the analysis of long term (18 years)data shows that Reeder's estimates of the hydraulic characteristics of the alluvial aquifer in the Animas Valley, New Mexico was conservative and about 18 percent low for the transmissivity and 25-80 percent high for storativity. Summers (1967) has compared long term and short term pumping test results. He concludes on the basis of observation that the individual piece of short term data may be in error or subject to local interpretation and therefore no special emphasis should be given to a specific piece of short term data.

Experience in an area can be a critical factor in reaching reasonable conclusions about the parameters. The duration of any pumping test is determined by the adequacy of the data available to construct time-drawdown or distance drawdown plots. The semi-logarithmic time drawdown plot is preferred because the deviation of the field data from the interpretative model is better emphasized (USDI,1981). These deviations due to the experimental well or to the heterogenity of the aquifer and to the presence of certain boundaries nearby, decide for the use of the particular portion of the time-drawdown plot for determination of the hydrogeological parameters. The delimitation of the deviations on time-drawdown plot is necessary both to establish the computation time interval and to obtain additional information about the characteristics of the tested aquifer.

It is the Initial effect' of the experimental well that determines the deviation of the experimental data from the theoretical straightline plot of the time drawdowngraph. This is due to the fact that the theory considers the well as a line source and consequently it starts from the assumption that at the beginning of the pumping the rate of discharge from the well is instantaneously stabilized. But in reality the wells have a certain radius and at the beginning of the pumping, a part of the pumped water comes directly from the well bore storage. For this reason, the time-drawdown plot appears in initial portion as a curve and only after a certain time it can be approximated to a straightline. The initial portion of this plot may also be influenced partly key well imperfectioins as well as the resistance of its adjacent areas (skin effect) to the flow. The error E that affects hydrogeological parameter computations owing to the ommission of the well bore storage effect has been quantified by the relation(Gheorghe,1978).

$$E = \frac{V(t)}{Q(t)} = \frac{As_o}{Q(t)}$$

where,

$A$ is the cross-section of the well casing,

$V(t)$ is the water volume drawn from the bore hole at time t,

$s_o$ is the drawdown in the bore hole, and

$Q(t)$ is the withdrawal rate.

The time at which the error becomes negligible depends upon the radius of the well and the withdrawal rate. However, this error due to initial effect decreases with time as the storage in the well diminishes. Bocever, et al (1965) have stated that admissible error should be less than about 5 percent ( $E < 0.05$).

Another criterion which gives the time $t_o$ during which the initial effect of well storage is dominant is given by (Forkasiewiez,1969)

$$t_o = \frac{25 r_o^2}{T}$$

where,

$r_o$ is the radius of the well, and

$T$ is the transmissivity of the aquifer.

In the above equation it is recommended that the pumping period should be equal to at least $10t_o$ in order to obtain a straightline semilog for time-drawdown data (Gheorghe,1978).

The initial effect is equally manifested in the piezometers placed in the immediate vicinity of the pumping well. When this is the case the initial period ($t_o$) is computed by the relation.

$$t_o = \frac{12.5\ r_o^2}{T} \left( \frac{s_o + s'}{s'} \right)$$

where,

$s_o$ and $s'$ are the drawdowns in the borewell and the piezometer respectively.

The following guidelines have been proposed to decide the length of pumping in different aquifers:

(i) Confined aquifer: The test data can be plotted on semi-log paper as time-drawdown and distance-drawdown plots. These plots are straight lines and therefore can be used to determine the maximum duration of pumping test.

In time-drawdown plot on semi-log paper the plotted points for each observation well fall initially on a curve which, with time, approximate a straight line within the limit of plotting . The straightline plot will be attained earliest for the pumping well, than for nearby observation wells. When three or more drawdowns, measured at hourly intervals in the most distant observation well, fall on the straightline the pumping may be discontinued. Because under continued pumping the resulting drawdown will fall on a prolongation of the straight line unless a boundary is encountered. The time for approximate straight line plotting conditions to be reached may range from 2 hours to as much as 3 weeks, but usually a satisfactory test can be completed within 48 hours of pumping (USDI,1981). According to Nilsson(1983 ) the pumping test will give a sufficient amount of data within about 5 hours of pumping of a well in sedimentary deposits and within 20 hours for a well in fractured bed rock.

When three or more observation wells (including pumping well) are available, a distance-drawdown graph is made as a check before pumping is stopped.

In partially penetrating pumping and observation wells, the preliminary estimates of T and $\emptyset$ should be made from the time-drawdown plots during pumping. In such case the test ideally should be continued until the value of : $u = \frac{r^2\emptyset}{4Tt}$ , estimated for each hole is less than $0.1 \frac{r^2}{b}$ where T and $\emptyset$ are the transmissivity and storativity respectively. r and b are the radial distance of the observation point and aquifer thickness respectively, and t is the time.

If the time-drawdown plot does not appear to approach the straight line condition even after 24 hours past the minimum pumping time, the pumping may be stopped and recovery observations be made.

ii) Unconfined aquifer : The most significant theoretical advancement in testing unconfined systems has been made by Boulton. Boulton (1954a) presented type curves for unsteady flow, assuming negligible dewatering of the aquifer, release from storage, and termination of flow lines on the water table.

Before the analytical work described the effects of vertical flow and delayed yield in unconfined flow to wells, it was common practice to pump ' long enough' such that the effects become negligible and respose approaches that of a simple artesian model. However, no criteria existed for judging how long is ' long enough'. With analytical solutions now available, some criteria exist for judging the length of time required for effectively attaining an artesian response in an unconfined aquifer.

According to Boulton (1954a) and Hantush (1949) vertical flow components in unconfined aquifer significantly affect the response when

$$t < \frac{5\, b\, \emptyset_y}{K_z} \quad , \text{ in region } \quad 0 < \frac{r}{b} < 0.2 \qquad \ldots(1)$$

where,

b is the aquifer thickness, $\emptyset_y$ is specific yield, and $K_z$ is the vertical permeability.

Equation (1) is derived analytically and it is assumed that unsteady radial and vertical flow components exists in the vicinity of the fully penetrating well, specific yield is constant in time and space and drawdown is negligible compared with aquifer thickness. Equation(1) produces a rather startling revelation (Stallman,1976) of the pumping time required for approaching artesian type flow. For b = 30.48 m, (100 ft.), $\emptyset_y = 0.2$ , and $K_z = 3.048$ m per day (10 feet/day), the response is affected by vertical flow for as long as t = 10 days near the pumped well.

Electrical analog studies (Stallman,1965) showed vertical flow components to be, significant for

$$t < r^2 \emptyset / T$$

or

$$t < 9b\, \emptyset / K_z \text{ in the region}$$

$$\left(\frac{r}{b}\right) \left(\frac{K_z}{K_r}\right)^{1/2} < 3 \qquad \ldots(2)$$

where,

$K_r$ and $K_z$ are the hydraulic conductivity to radial and vertical flow respectively.

Criteria such as equations 1 and 2 are not now available from type curves for delayed yield. However, a dimensionless plot of column drainage (Stallman,1967) has shown that about 70 percent of the ultimate drainage due to lowering the water table will be attained at

$$t = \frac{100_y s_o}{K_z} \qquad \ldots(3)$$

Thus, for $K_z$ = 3.048 m/day ( 10 ft./day)

$s_o$ = 3.048 m (10 ft.) , and

$0_y$ = 0.2, the delayed yield will be pronounced for at least

t = 2 days.

If the pumping time in a test of an unconfined aquifer can be extended long enough to surpass the time requirements evident from eqs. 1, 2&3, equations of radial artesian flow can be employed for data analysis, provided the control well fully penetrate the aquifer. If the control well partially penetrates the aquifer, equations accounting for partial penetration (Hantush, 1961a,d; 1964a, Stallman, 1965) must be employed, or one is restricted further to using data in the region

$$r > 1.5\, b \left(\frac{K_r}{K_z}\right)^{1/2} \qquad \ldots(4)$$

Use of type curves for predicting response at a test site and the liberal use of criteria like equation(1) - (4) for design purposes are necessary to reduce the prospect of failure to achieve the test objective the accurate measurement of the hydraulic properties of the aquifer etc.

The following recommendations have been made by USDI (1981) for adopting the minimum time of pumping based on the predominant aquifer material for unconfined aquifers.

| Predominant aquifer material | Minimum pumping time in hours |
|---|---|
| Silt and Clay | 170 |
| Fine sand | 30 |
| Medium sand and coarse material | 4 |

In the case of bounded aquifers, test should be continued till the effect of the boundary becomes apparent. However, the quantitative estimation of time duration in such situations only can be made on the basis of nature of the boundaries ( recharging or discharging) and their lateral distances from the point of excitation.

## 3.0 PROBLEM DEFINITION

Generally the groundwater hydrologist is faced with the problem of 'how long' a pumping test should be carried out at a specific site. The question is best answered only by a skillful and experienced hydrogeologists who are well versed with the subsurface geology of the area under study. But for an inexperienced hydrogeologist who has little idea about the subsurface geology of the test site it is generally not possible to arrive at any conclusive decisions about how long a pumping test should be carried out at a particular site. For such field personnel it is required that some guidelines and thumb rules should be made available for their ready use in the field so that they can decide the approximate length of the test to be carried out which in turn reduces the cost and other requirements for such tests.

# 4.0 METHODOLOGY

The equation describing the unsteady hydraulic response in a confined aquifer resulting from constant discharge from a pumping well is written as (Theis,1935).

$$s = \frac{Q}{4 \pi t} W(u) \qquad \text{...(5)}$$

in which

W(u) is the Theis well function and is given by

$$W(u) = - 0.5722 - \ln u - \sum_{n=1}^{\infty} \frac{(-)^n u^n}{n.n!} \qquad \text{...(6)}$$

where

$$u = \frac{r^2 \emptyset}{4Tt} \qquad \text{....(7)}$$

s = drawdown measured in the observation well (L),

r = radial distance of the observation well (L),

Q = constant rate of discharge ($L^3/T$),

t = time since start of pumping (T),

T = transmissivity ($L^2/ T$), and

$\emptyset$ = storativity

Theis unsteady equation is applicable to a homogeneous istoropic and infinite aquifer of constant thickness. The pumping and observation wells should be fully penetrating.

For the value of $u < 0.01$, the term $\sum^{\infty} (-1)^n U^n/n.n!$ in the equation (6) becomes insignificant (Cooper and Jacob, 1946) i.e. for larger values of time the error introduced by neglecting the higher order terms in equation (6) is negligible. Let $t_p$ be the time since start of pumping upto which the value of u is greater than 0.01. Substituting $t = t_p$ and $u = 0.01$ in equation (7) the time $t_p$ can be estimated for given combination of T, $\emptyset$ and r using the relation

$$t_p \doteq \frac{r^2 \phi}{4T(0.01)} \qquad \ldots(8)$$

This theoretical value of $t_p$ is the time till which the drawdown cannnot be used in Jacob's straight line method for computation of the aquifer parameters. Fig.1 shows the plot of $t_p$ vs. observation well distance for various values of $\beta$, the hydraulic diffusivity. Using these plots it is possible to determine the time $t_p$ by knowing the approximate value of the hydraulic diffusivity at a test site. Once the value of $t_p$ is determined the minimum time of pumping should be at least $10t_p$ so that a straightline can be fitted through the plotted points. Figure 2 shows the plot of $t_{min}$(i.e. $10t_p$) vs. observation well distance for various $\beta$ values. Fig.3 shows the plot of $\beta$ vs. $t_p$ for different values of observation well distances.

In certain situations the initial disturbance in the field drawdown may not continue for long time till the value of u becomes less than or equal to 0.01 as assumed by Jacob (1946). For instance Fig.4 shows the time-drawdown plot on a semi-log paper of an actual field data (CGWB,1984) for two observation points located at a distance $r_1$= 99.9 and $r_2$ = 199.8 m respectively. From the figure it is seen that the data points fall on a straightline after about 150 minutes of pumping for which the values of u are calculated to be 0.027 and 0.075 respectively for $r_1$ and $r_2$. According to Jacob's assumption the initial disturbances should have continued upto time 400 and 1100 minutes respectively for observation wells $r_1$ and $r_2$. Therefore, in such situations the theoretical upper limit of $t_p$ upto which the disturbances exist in drawdown itself may be the maximum time of pumping required to get a straightline plot on a semi-log graph,therefore it is always worthwhile to plot the data on semilong paper during test itself.

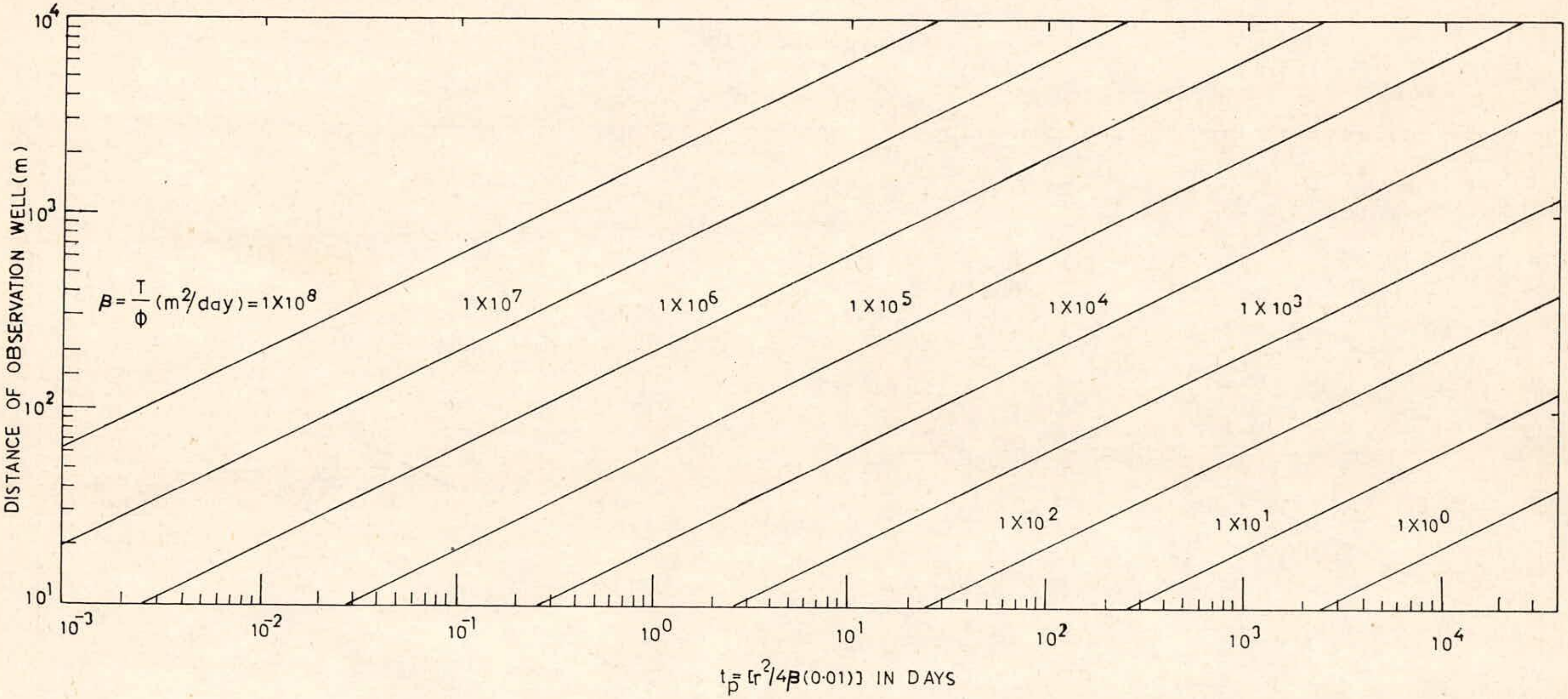

FIG. 1. PLOT OF OBSERVATION WELL DISTANCE Vs. tp FOR DIFFERENT VALUES OF $\beta$

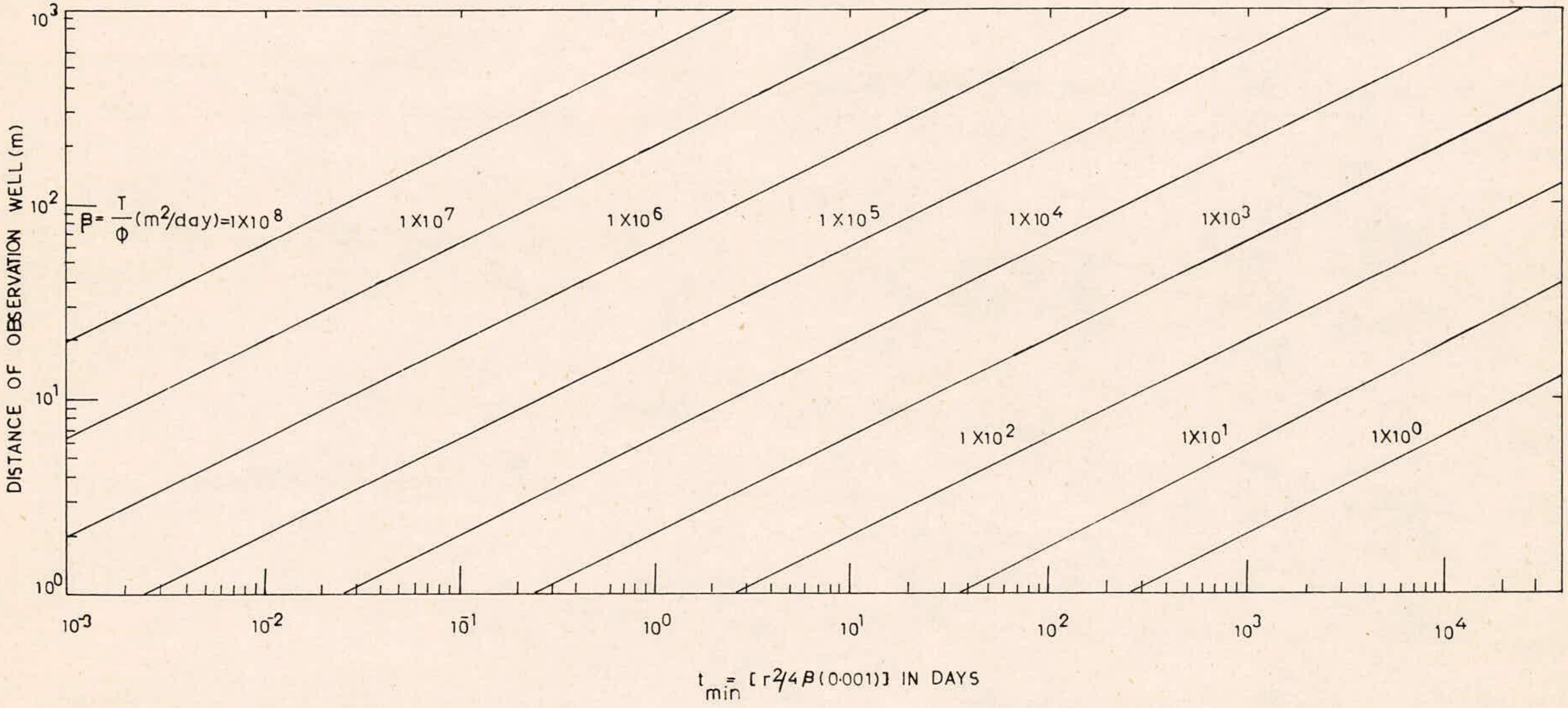

FIG. 2. PLOT OF DISTANCE OF OBSERVATION WELL Vs. $t_{min}$ FOR DIFFERENT VALUES OF $\beta$

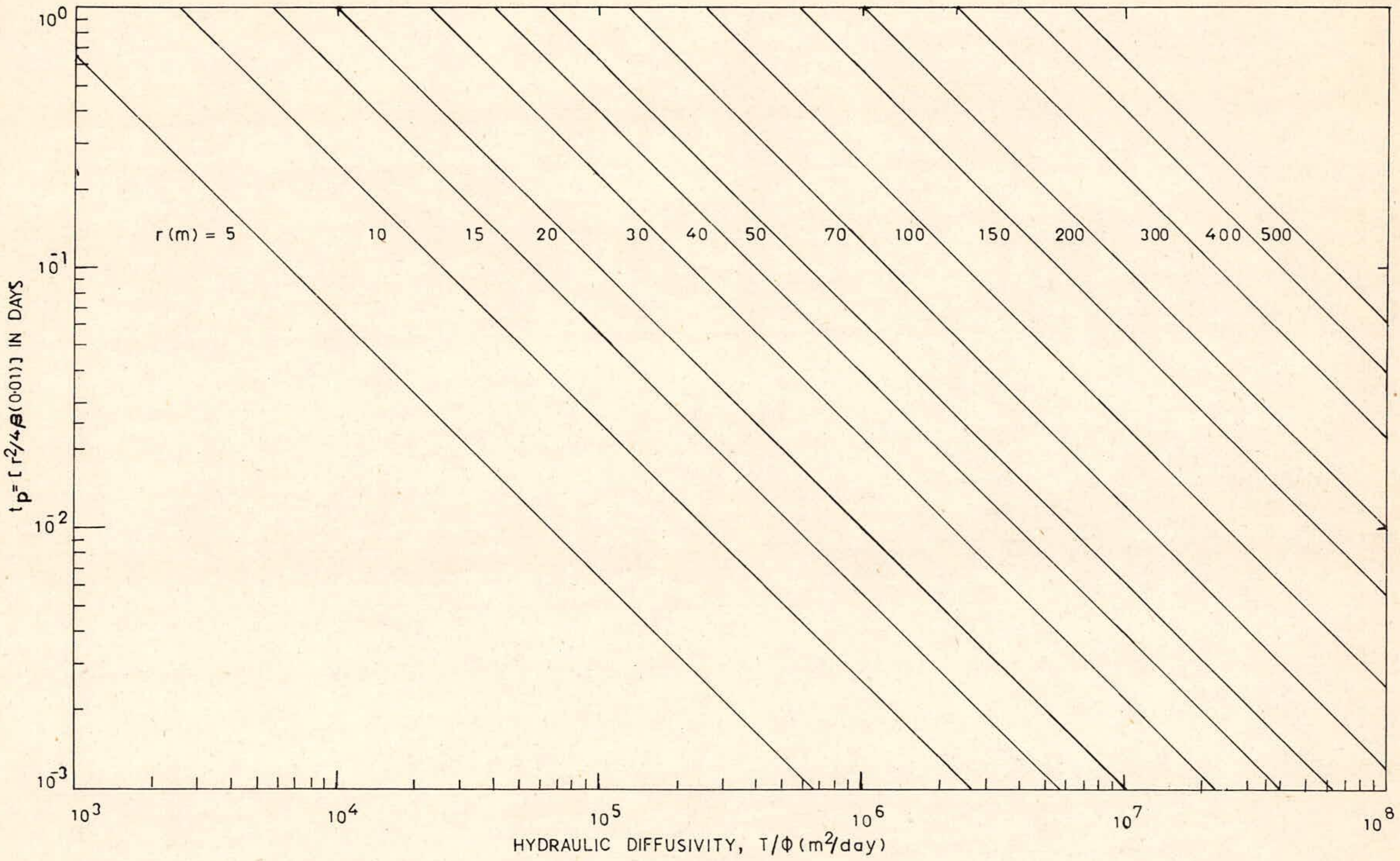

FIG. 3. PLOT OF $t_p$-Vs HYDRAULIC DIFFUSIVITY FOR DIFFERENT OBSERVATION WELL DISTANCES

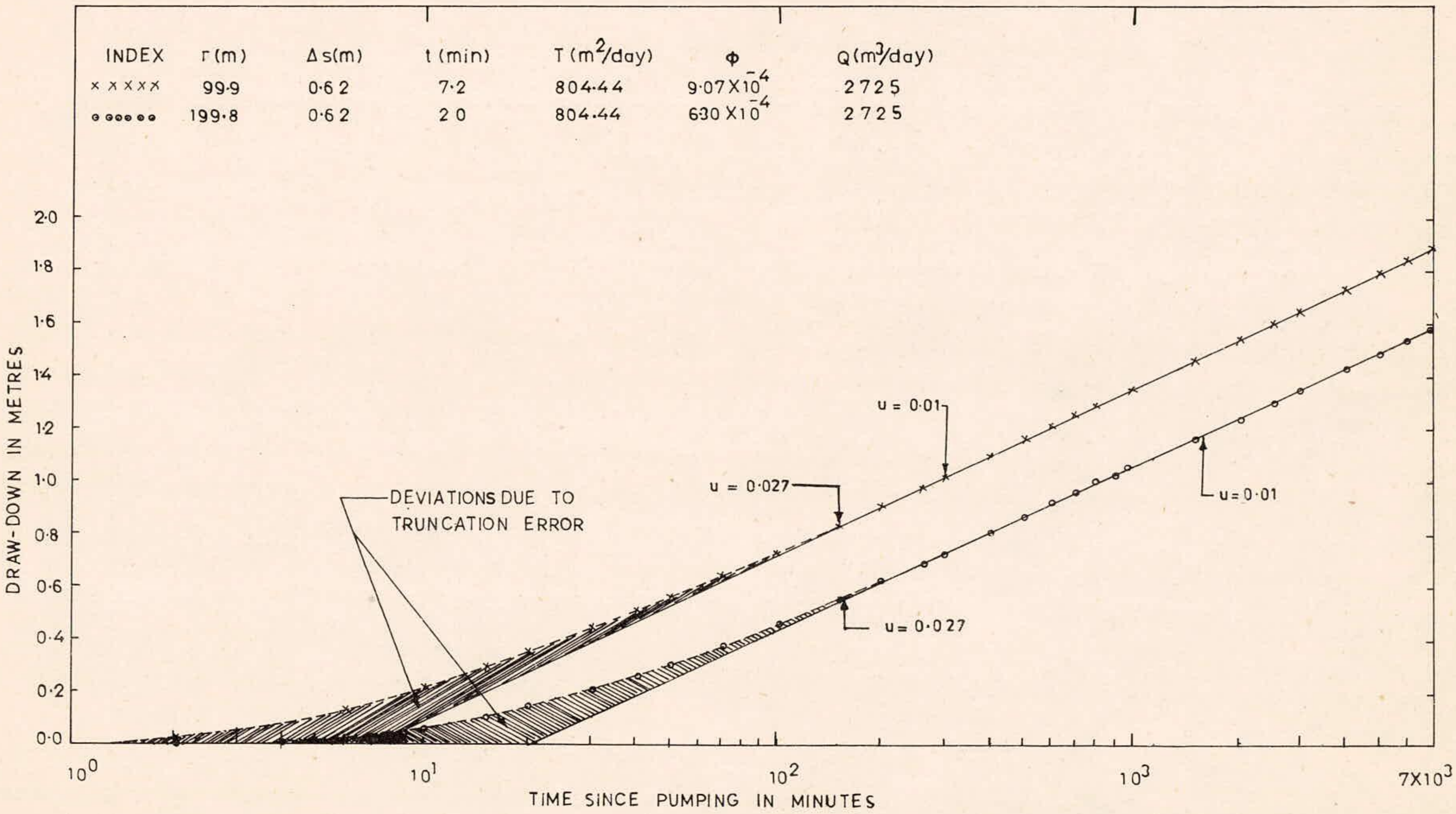

FIG. 4 - TIME - DRAWDOWN PLOT FOR A PUMPING TEST

If there is a recharge boundary at a radial distance of $R_r$ from the well in which a pump test is to be conducted then the maximum duration of pumping can be calculated as follows:

Let $r_f$ be the radial distance of the farthest observation point from the pumping well. When a negligible drawdown of 0.01 - 0.02 m is experienced at this farthest point the corresponding time t' be measured. It can be assumed that at this time t' the radius of influence has reached up to the distance $r_f$. The relation between the travel time and the radius of influence $R_e$ under continuous pumping is given by (Bear, 1979)

$$t' = \frac{R_e^2}{2.25(T/\emptyset)}$$

When for the first time the negligible drawdown is experienced at the farthest observation point the radius of influence at that time t' is equal to $r_f$, therefore from the above equation

$$t' = \frac{r_f^2}{2.25(T/\emptyset)} \quad \text{....(9)}$$

Pumping should be continued till the radius of influence reaches the recharge boundary. Let $t_p$ be the time at which the radius of influence reaches the recharge boundary $R_r$. Therefore,

$$t_p = \frac{R^2_r}{2.25(T/\emptyset)} \quad \text{...(10)}$$

From equations (9) and (10) $t_p$ is given by

$$t_p = \frac{R_r^2}{r_f^2}.t' \quad \text{.... (11)}$$

Therefore from equation (11) the time $t_p$ can be calculated by knowing the time $t'$, $R_r$ and $r_f$.

Table 1 shows the maximum drawdown that has been experienced during various pump tests. It can be seen from the table that the maximum drawdowns are of the order of 0.25-1.50 m corresponding to a discharge rate of 1000 $m^3$/day. The duration of pumping test would be governed by the pumping rate and distance of the observation wells. Based on the results of the pump test data it is suggested that the pump test should be stopped when a certain drawdown is experienced at a particular observation point. The actual drawdowns for aquifer of very low, low, medium and high transmissivity at various distance of the observation points are given in Tables 2 and 3 for Ø equal to 0.001 and 0.0001 respectively. Based on these tables the index drawdowns for various distances of the observation points are given in Tables 4 and 5 for Ø equal to 0.0001 and 0.001 respectively . However, to make use of the Tables 4 and 5 it is necessary to know the approximate transmissivity and storativity values of the aquifer in advance.

Tables 6 and 7 show the radius of influence calculated using the index drawdown for Ø equal to 0.0001 and 0.001 respectively.

## 5.0 CONCLUSIONS

The maximum duration of pumping test depends upon the radial distances of the observation points, the rate of discharge, the aquifer properties and boundary conditions. Therefore, it is generally not possible to decide the duration of pumping test in advance. However, if the rough estimates of the aquifer properties and observation well distances are known it could be possible to estimate the maximum duration of pumping test under given set of geological conditions.

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TABLE - 1 : MAXIMUM DRAWDOWN OBSERVED AT VARIOUS OBSERVATION POINTS DURING CONDUCTED PUMPING TESTS

| S. No. | Location of pumping test | Pumping rate $m^3$/day | Distance of observation well (m) | Duration of the conducted pumping test (min) | Describing of the type of aquifer | Average estimated values of T, and Ø ($m^2$/day) | Maximum drawdown recorded (m) | Corresponding drawdown when Ø=1000 $m^3$/day (m) |
|---|---|---|---|---|---|---|---|---|
| 1. | Mathana Haryana India (CGWB, 1982) | 2725 | 99.9 | 7000 | Confined | 822.0<br>$6.00 \times 10^{-4}$ | 1.860 | 0.683 |
| | | | 199.8 | | | | 1.570 | 0.576 |
| 2. | Oude Korendijk The Netherlands (Kruseman and De Ridder, 1970) | 788 | 30.0 | 830 | Confined | 400.0<br>$2.00 \times 10^{-4}$ | 1.088 | 1.380 |
| | | | 90.0 | | | | 0.716 | 0.910 |
| | | | 215.0 | | | | 0.250 | 0.320 |
| 3. | U.S.G.S. (Todd, 1959) | 2725 | 66.96 | 240 | Confined | 1120.0<br>$1.90 \times 10^{-4}$ | 1.119 | 0.410 |
| 4. | Progresul U.S.S.R. (Gheorghe, 1978) | 984 | 266.00 | 4275 | Confined | 597.0<br>$1.10 \times 10^{-4}$ | 0.860 | 0.874 |
| 5. | U.S.A. (Walton, 1978) | 8175 | 91.44 | 1440 | Confined | 4449.0<br>$4.70 \times 10^{-4}$ | 1.160 | 0.142 |
| 6. | U.S.A. (McElwee, 1980) | 8784 | 585.00 | 720 | Confined | 1698.0<br>$9.86 \times 10^{-4}$ | 0.751 | 0.085 |
| 7. | India (Sharma and Chawla, 1977) | 4176 | 19.20 | 210 | Confined | 2213.0<br>$6.88 \times 10^{-4}$ | 1.100 | 0.263 |
| 8. | U.S.A. (Lohman, 1979) | 2717 | 60.96 | 240 | Confined | 426.0<br>$2.00 \times 10^{-4}$ | 1.119 | 0.412 |
| | | | 121.92 | | | | 0.878 | 0.323 |
| | | | 243.84 | | | | 0.648 | 0.237 |
| 9. | Ganeshpur U.P. India (GWC, 1979) | 863 | 32.73 | 330 | Confined | 1010.0<br>$2.00 \times 10^{-4}$ | 0.400 | 0.460 |
| 10. | Patulsarai West Bengal India Bhattacharya et. al, 1986 | 3288 | 61.00 | 1440 | Confined | 986.0<br>$6.43 \times 10^{-4}$ | 1.870 | 0.569 |
| | | | 366.00 | | | | 0.910 | 0.277 |

## TABLE 2.

### COMPARISON OF DRAWDOWN AT VARIOUS DISTANCES FOR THE SAME DURATION OF PUMPING ( 12h) FOR Ø =0.001

| r (m) | T ($m^2$/day) = | 100 - 200 | 200 - 600 | 600 - 1500 | 1500 - 2500 |
|---|---|---|---|---|---|
| | Q ($m^3$/day) = | 500 | 1000 | 2000 | 3000 |
| 10 | | 2.795 - 1.535 | 1.535 - 1.169 | 1.169 - 1.032 | 1.032 - 0.978 |
| 25 | | 2.07 - 1.171 | 1.171 - 0.926 | 0.926 - 0.838 | 0.838 - 0.804 |
| 50 | | 1.519 - 0.896 | 0.896 - 0.743 | 0.743 - 0.692 | 0.692 - 0.672 |
| 100 | | 0.982 - 0.625 | 0.625 - 0.560 | 0.560 - 0.544 | 0.544 - 0.540 |
| 200 | | 0.487 - 0.363 | 0.363 - 0. 379 | 0.379 - 0.398 | 0.398 - 0.408 |

## TABLE-3

### COMPARISON OF DRAWDOWN AT VARIOUS DISTANCES FOR THE SAME DURATION OF PUMPING (12 h) FOR $\phi=0.0001$

| r (m) | T ($m^2$/day = | 100 - 200 | 200 - 600 | 600 - 1500 | 1500 - 2500 |
|---|---|---|---|---|---|
| | Q ($m^3$/day) = | 500 | 1000 | 2000 | 3000 |
| 10 | | 3.711 - 1.994 | 1.994 - 1.475 | 1.475 - 1.276 | 1.276 - 1.200 |
| 25 | | 2.982 - 1.629 | 1.629 - 1.232 | 1.232 - 1.082 | 1.082 - 1.023 |
| 50 | | 2.430 - 1.353 | 1.353 - 1.048 | 1.048 - 0.936 | 0.936 - 0.891 |
| 100 | | 1.880 - 1.078 | 1.078 - 0.864 | 0.864 - 0.788 | 0.788 - 0.759 |
| 200 | | 1.335 - 0.804 | 0.804 - 0.680 | 0.680 - 0.642 | 0.642 - 0.627 |

# TABLE-4

## INDEX DRAWDOWN AT VARIOUS OBSERVATION POINTS ADOPTED FROM TABLE - 3 FOR $\phi=0.0001$

| r (m) | T ($m^2$/day) = | 100 - 200 | 200 - 600 | 600 - 1500 | 1500-2500 |
|---|---|---|---|---|---|
| | Q ($m^3$/day) = | 500 | 1000 | 2000 | 3000 |
| 10 | | 3.5 - 2.0 | 2.0 - 1.5 | 1.5 - 1.3 | 1.3 - 1.2 |
| 25 | | 3.0 - 1.6 | 1.6 - 1.2 | 1.2 - 1.1 | 1.1 - 1.0 |
| 50 | | 2.5 - 1.4 | 1.4 - 1.1 | 1.1 - 1.0 | 1.0 - 0.9 |
| 100 | | 2.0 - 1.1 | 1.1 - 0.9 | 0.9 - 0.8 | 0.8 - 0.7 |
| 200 | | 1.3 - 0.8 | 0.8 - 0.7 | 0.7 - 0.6 | 0.6 - 0.6 |

## TABLE - 5

### INDEX DRAWDOWN AT VARIOUS OBSERVATION POINTS ADOPTED FROM TABLE - 2 FOR $\phi = 0.001$

| r (m) | T ($m^2$/day) = | 100 - 200 | 200 - 600 | 600 - 1500 | 1500 - 2500 |
|---|---|---|---|---|---|
| | Q ($m^3$/day) = | 500 | 1000 | 2000 | 3000 |
| 10 | | 2.5 - 1.5 | 1.5 - 1.2 | 1.2 - 1.0 | 1.0 - 0.9 |
| 25 | | 2.0 - 1.2 | 1.2 - 0.9 | 0.9 - 0.8 | 0.8 - 0.8 |
| 50 | | 1.5 - 0.9 | 0.9 - 0.7 | 0.7 - 0.7 | 0.7 - 0.6 |
| 100 | | 1.0 - 0.6 | 0.6 - 0.5 | 0.5 - 0.5 | 0.5 - 0.5 |
| 200 | | 0.5 - 0.4 | 0.4 - 0.3 | 0.3 - 0.3 | 0.3 - 0.4 |

## TABLE - 6

### RADIUS OF INFLUENCE IN METRES CALCULATED AT VARIOUS OBSERVATION POINTS USING INDEX DRAWDOWNS FOR $\phi = 0.0001$

| r (m) | T ($m^2$/day) = | 100 - 200 | 200 - 600 | 600 - 1500 | 1500 - 2500 |
|---|---|---|---|---|---|
| | Q ($m^3$/day) = | 500 | 1000 | 2000 | 3000 |
| 10 | | 813 - 1524 | 1524 - 2857 | 2857 - 4576 | 4576 - 5355 |
| 25 | | 1084 - 1394 | 1394 - 2305 | 2305 - 4458 | 4458 - 4698 |
| 50 | | 1157 - 1687 | 1687 - 3162 | 3162 - 5566 | 5566 - 5566 |
| 100 | | 1235 - 1587 | 1587 - 2975 | 2975 - 4337 | 4337 - 3906 |
| 200 | | 1024 - 1494 | 1494 - 2800 | 2800 - 3380 | 3380 - 4628 |

## TABLE - 7

RADIUS OF INFLUENCE IN METRES CALCULATED AT VARIOUS OBSERVATION POINTS USING INDEX DRAWDOWNS FOR Ø = 0.001

| r (m) | T ($m^2$/day) = | 100 - 200 | 200 - 600 | 600 - 1500 | 1500 - 2500 |
|---|---|---|---|---|---|
|  | Q ($m^3$/day) = | 500 | 1000 | 2000 | 3000 |
| 10 |  | 231 - 434 | 434 - 922 | 922 - 1113 | 1113 - 1113 |
| 25 |  | 308 - 510 | 510 - 744 | 744 - 1084 | 1084 - 1649 |
| 50 |  | 329 - 480 | 480 - 700 | 700 - 1354 | 1354 - 1157 |
| 100 |  | 351 - 452 | 452 - 659 | 659 - 1055 | 1055 - 1371 |
| 200 |  | 375 - 547 | 547 - 620 | 620 - 822 | 822 - 962 |