AQUIFER PARAMETER ESTIMATION

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General

Darcy's law and continuity equation governs the groundwater movement. The storage coefficients and transmissivities of aquifers can be determined by pumping test of wells. Future decline in groundwater level with pumpage can be calculated with these aquifer characteristics. Various well flow equations have been developed for steady and unsteady flows, for various types of aquifers and for various boundary conditions. For practical application, most of the solutions are reduced to graphical or mathematical forms.

What is a Pumping Test

A pumping test is a field experiment in which a well is pumped at a controlled rate and water-level response (drawdown) is measured in one or more surrounding observation wells and optionally in the pumped well (control well) itself; response data from pumping tests are used to estimate the hydraulic properties of aquifers, evaluate well performance and identify aquifer boundaries. Aquifer test and aquifer performance test (APT) are alternate designations for a pumping test.

Principle of pumping test

Well having a screen in the aquifer to be tested, water is pumped during a certain period of time and at a certain rate. The effect of this pumping on the water table is measured in the pumped well and in some piezometers in the vicinity. The hydraulic characteristics of the aquifer are then found by substituting the drawdown measured in these piezometers, their distance from the pumped well and the well discharged.

Selection of Pumping Test Site

A careful selection of test site is necessary in order to prevent problems which one may otherwise encounter during the evaluation of pumping test data. In general, while selecting the site of an aquifer test, the following points should be kept in mind:

- The hydrogeological conditions of the site should not change over short distances and should be representative of the area under consideration
- The site should preferably not be near railroads or highways where passing trains and heavy traffic may produce measurable fluctuations of the piezometric surface of confined aquifers.
- The pumped water must be discharged in such a way that it does not return to the aquifer

- The gradient of water table or piezometric surface should be low
- The site should be accessible

Performance of a pumping test

The measurements to be taken during an actual pumping test fall into two groups namely measurement of the water level and measurement of the discharge rate. The most important part of an aquifer test is measuring the depth to the water in all piezometers and if possible, in the pumped well. Since water levels are dropping fast during the first one or two hours, reading should be taken at short intervals (Table 1). Time between readings being gradually increased as pumping continues. In a similar way, water level measurements in the piezometer should be taken at short intervals during the first few hours of the test, and then with lager interval (Table 2).

Table 1:-Range of time intervals between water level measurements in the pumped well

Time since pumping started	Time intervals
0 – 5 min	0.5 min
5 – 60 min	5 min
60 – 120 min	20 min
120 – shut down of the pump	6 m

Table 2:-Range of time interval between water level measurements in piezometer

Time since pumping started	Time intervals
0 – 2 min	10 sec
2 – 5 min	30 sec
5 – 15 min	1 min
15 – 50 min	5 min
50 – 100 min	10 min
100 min – 5 hrs	30 min
5 – 48 hrs	60 min
48 hrs – 6 days	3 times per day
6 days to shut down of the pump	1 time per day

The number of hours a well should be pumped depends on the type of aquifer to be tested. Better and more reliable results are obtained if pumping continues till the depression cone has reached a stabilized position i.e. the steady state flow condition at which the recharge to the aquifer equals the pumping rate. In general, the duration must be long enough to activate the hydraulic parameters to be estimated.In a confined aquifer the well should be pumped for 24 hrs, whereas in a semi-confined aquifer the duration of pumping should be within 24 to 48 hrs. In an unconfined aquifer a longer pumping period of three to seven days is required. After the pumping test is completed and all necessary data have been collected, the available data should be analyzed, as discussed below.

Pumping test data analysis method

The method of analyzing pumping test data depends upon whether steady or unsteady state flow conditions exist in infinitely extended (i.e., aquifer is of such wide extent that it can be assumed to be of infinite lateral extent) confined, unconfined, semi-confined or semi-unconfined aquifers. In this lecture note, the discussion is restricted to analyzing unsteady state flow in confined aquifers (Theis method)

Theis's method

The Theis (1935) solution is commonly applied to analyze problems involving transient flow to a well. It is a solution to the general flow equation for transient two-dimensional horizontal flow with homogeneous, isotropic K. Theis derived this solution by using research in the field of heat flow and noting the direct analogy between heat flow emanating from a long, straight wire and groundwater flow to a well.

According to Theis equation for unsteady state flow in a confined aquifer, the drawdown "s" measured in a piezometer at a distance r from the pumped well is written as

$$s = \frac{Q}{4\pi T} W(u) \tag{1}$$

Where W(u) is the well function and u is dimensionless parameter which is defined as

$$u = r^2 S / 4Tt \tag{2}$$

Where t = time in days since pumping started, S = dimensionless storage coefficient, T=Transmissivity in m^2/day

W(u) is the well function which is defined as

$$W(u) = -0.5772 - \ln u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!} + ... \tag{3}$$

The simplifying assumptions of the Theis solution are listed below.

- The aquifer is infinite in extent, with no constant head boundaries, no-flow bound-aries, or any other heterogeneity.
- The aquifer is homogeneous, with constant T and S over its infinite extent.
- The well does not induce additional leakage or recharge through the top and bottom of the aquifer.

- The well fully penetrates the aquifer, and there is only resistance to horizontal flow.

Procedure

- Prepare a normal type curve of Theis well function on double logarithmic paper by plotting values of W(u) against u (Figure 3).
- Plot values of s (y-axis) against r^2/t (x-axis) on another sheet of logarithmic paper of the same scale as that used for type curve (Figure 4).
- Place the observed data plot over the normal type curve and keeping the coordiante axes of both data plot and type curve parallel, locate the position of best match between the data plot and the type curve (Figure 5).
- Select an arbitrary match point on the overlapping portion of the two sheets of graph paper and determine the coordinates W(u), u, s and r^2/t for this match point.
- Compute T by substituting values of W(u), s and Q into Eq. (1)
- Compute S by substituting values of T, r^2/t and u into Eq. (2)

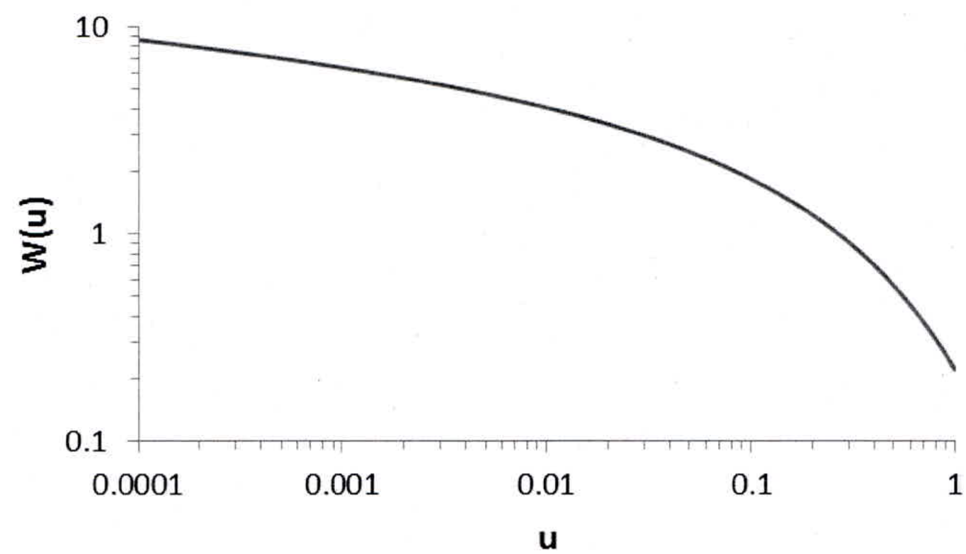

Figure 3: Relation between *W(u)* and *u*

(Source:http://nptel.ac.in/courses/105103026/module3/lec22/2.html)

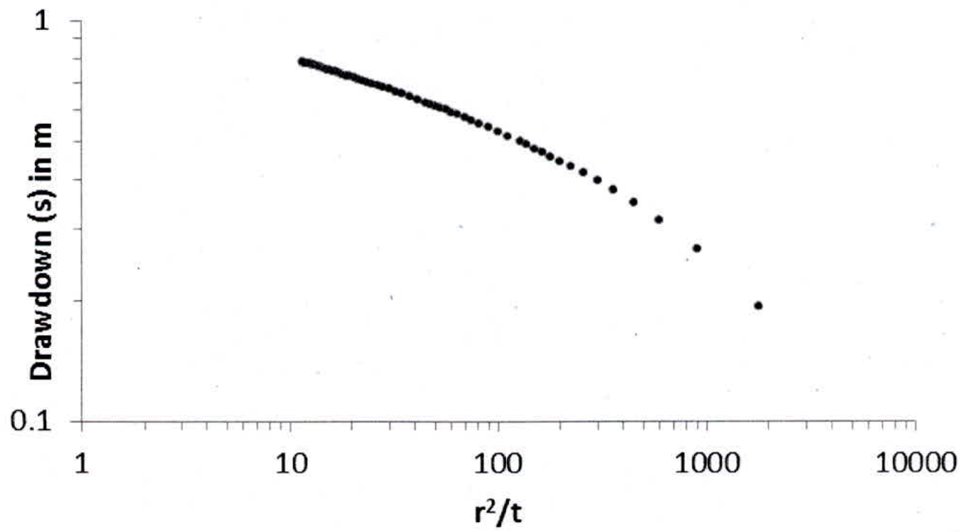

Figure 4: Relation between r2/t and S

(Source: http://nptel.ac.in/courses/105103026/module3/lec22/2.html)

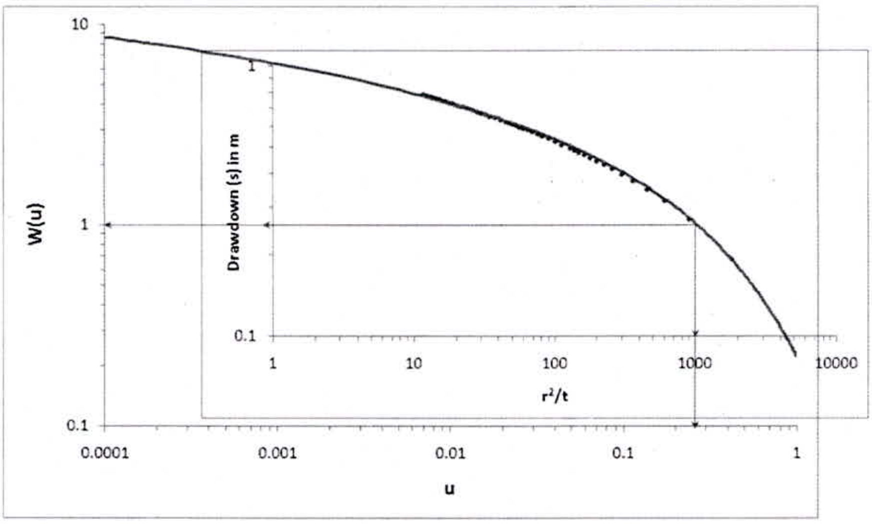

Figure 5: Superimposition of the relation between *W(u)* and *u*, and r^2/t and *S*

(Source: http://nptel.ac.in/courses/105103026/module3/lec22/2.html)

Theis's recovery method

The water level in pumping well and observation well will start rising after shut down of pump. The rise of the water level can be measured as residual drawdown s'' which is the difference between the original water level prior to pumping and the actual water level measured at a certain moment t'' since pumping stopped. After pumping has been shut down the water level will rise again to its original position.

The analysis of recovery test is based on principle of superposition. It is assumed that after the pump has shut down, the well continues to be pumped at same rate as earlier and that an imaginery recharge, equal to discharge cancel each other. The Theis recovery method is widely used for analysis of recovery tests. The transmissivity calculated through recovery test can be checked with data obtained during pumping test. This method has the advantage that the rate of recharge Q is constant and equal to the mean rate of discharge Q during pumping. This method should be used when in addition to conditions listed for Theis method, the values of u are small ($u < 0.01$), i.e. r is small and t'' is large.

The residual drawdown s'' during the recovery period is given by

$$s'' = \frac{Q}{4\pi T}\left(\ln\frac{4Tt}{r^2 S} - \ln\frac{4Tt''}{r^2 S''}\right)$$

where S″ = coefficient of storage during recovery (dimensionless), t″ = time in days since pumping stopped, r = distance from pumped well to observation well, or, if the pumped well itself is considered, $r = r_w$ = effective radius of pumped well.

When S and S″ are constant and equal, and $u = r^2 S''/4Tt''$ is less than 0.01 (this implies measurements for later recovery data), Eq. can be written as

$$s'' = \frac{2.3Q}{4\pi T}\log\frac{t}{t''}$$

Procedure

- Plot s'' vs t/t″on a semi- logarithmic paper (t/t″on logarithmic scale),
- Fit a straight line through the plotted points,
- **Determine the slope of this line $\Delta s''$, the residual drawdown difference per log cycle of t/t″, which is equal to 2.3Q/4πT. Therefore,**

$$\Delta s'' = \frac{2.3Q}{4\pi T}$$

- **Compute T by substituting values of Q and $\Delta s''$ in above Eq.**

AquiferTest Software

AquiferTest software can be used for analyzing pumping tests, where water is pumped from a well and the change in water level is measured inside one or more observation wells (or, in some cases, inside the pumping well itself). AquiferTest provides a flexible, user-friendly environment that will allow you to become more efficient in your aquifer testing projects. Data can be directly entered in AquiferTest via the keyboard, imported from a Microsoft Excel workbook file, or imported from any data logger file (in ASCII format). Test data can also be inserted from a Windows text editor, spreadsheet, or database by "cutting and pasting" through the clipboard. Various pumping test analysis methods are available for confined, unconfined, leaky-confined, fractured aquifers.

References:

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- Theis, C.V. (1935). The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage: Transactions of the American Geophysical Union, v. 16, p. 519-524.
- Website*: http://nptel.ac.in/courses/105103026/module3/lec22/2.html*