

## Assessing the Duration of Pumping Test in Heterogeneous Aquifers

*Gholam Hossein Karami*

Department of Hydrogeology, Faculty of Earth Sciences,  
Shahrood University of Technology, P.O. Box 316 - 3619995161, Shahrood, Iran

**Abstract:** Aquifers are saturated permeable geological formations that can store and transmit significant quantities of groundwater. Most of real aquifers are heterogeneous and anisotropic. In such aquifers, the growth of cone of depression with increase of pumping period yields different values of aquifer parameters. To evaluate the effect of pumping period on aquifer parameters, values of transmissivity were determined from ever-longer longer portions of each pumping test data-set. Data-sets from a number of pumping test performed in anomaly No. 1 of Gole Gohar iron mine were employed. To determine the aquifer parameters by analysing the pumping test data-sets, AQUIFER WIN32 software were used. According to obtained results, the above-mentioned aquifer, which is a fractured rock aquifer, is very heterogeneous. Moreover, it is evident that the values of transmissivity determined from different durations of each pumping test vary considerably. In addition, it can be seen that at most pumping tests, there is a marked decrease in values of transmissivities. In longer duration of pumping test, which yields an average of transmissivity for a considerable portion of the aquifer, the values of transmissivity stabilize. In this study, a new and simple approach has been derived to assess the minimum pumping period in heterogeneous aquifers to determine relatively accurate values of the aquifer parameters. According to the obtained results in anomaly No. 1 of Gole Gohar iron mine and the degree of heterogeneity in this aquifer, it may be argued that the minimum required duration for pumping tests in heterogeneous aquifers is at least two or three days.

**Key words:** Pumping test • Pumping duration • Transmissivity • Heterogeneous aquifers

### INTRODUCTION

In order to specify the capability of aquifers for storing and transmitting groundwater, two aquifer parameters are widely used in groundwater hydraulics. These aquifer parameters are transmissivity and storage coefficient. Transmissivity is the rate of flow under a unit hydraulic gradient through a unit width of the aquifer. In the other words, transmissivity is the product of the average saturated thickness and average hydraulic conductivity of the aquifer. Transmissivity has the dimension of square length per time (e.g. square meter per day). Storage coefficient is volume of water that is released from storage or added into storage per unit surface of aquifer per unit change in hydraulic head. Storage coefficient is a dimensionless quantity [1].

The most reliable technique for assessing the aquifer parameters is by analysing pumping test data. It is because it reflects the response of a relatively large portion of the aquifers [1-3]. Pumping tests can provide fundamental information on the well performance,

aquifer hydraulic parameters (e.g. transmissivity and storage coefficient) and hydrogeological boundaries. Therefore, it may be concluded that pumping tests are the most important devices for investigation in the groundwater and environmental studies and assisting in groundwater pollution control [4]. Paillet and Reese [5] expressed that although it is difficult to determine the regionally averaged hydraulic properties of heterogeneous aquifers on the basis of logs and descriptions from a finite number of boreholes, in such aquifers pumping tests can provide useful estimates of hydraulic parameters.

In fractured aquifers due to their heterogeneity and anisotropy, the hydraulic parameters may vary considerably from one place to another. Therefore, during pumping test the cone of depression extends and encounters to new portion of aquifer in which the hydraulic parameters of aquifer are different. In such aquifers it is so important that pumping test lasts till the obtained hydraulic parameters act as representative values for whole aquifer.

In this paper, the most important purpose is to introduce a simple and practical method to assess the minimum time required for pumping tests particularly in fractured rocks which are highly heterogeneous and anisotropic.

## MATERIAL AND METHODS

In order to evaluate the duration of pumping tests, data obtained from some pumping tests performed in anomaly No. 1 of Gole Gohar iron mine were employed. These pumping tests were carried out in a fractured rock aquifer and their pumping periods are three days. To analyse pumping test data and determine the aquifer parameters, the methods of Theis [6] and Cooper-Jacob [7] straight line were used. In order to apply the above-mentioned methods, the AQUIFER WIN32 [8] software (a trademark of Environmental Simulations International Ltd.) has been used. This software facilitates either manual or automatic analysis of pumping test data.

Theis (1935) was the first to develop an analytical solution for unsteady flow in the aquifer. This solution was derived from an analogy between groundwater flow and heat conduction. The unsteady or Theis solution is written as:

$$s = \frac{Q}{4\pi T} \int_u^\infty \frac{e^{-u}}{u} du \quad (1)$$

$$s = \frac{Q}{4\pi T} W_{(u)} \quad (2)$$

$$W_{(u)} = [-0.5772 - \ln u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \dots] \quad (3)$$

$$u = \frac{r^2 S}{4Tt} \quad (4)$$

Where

s = the drawdown (m)

Q = the constant well discharge ( m<sup>3</sup>/day)

W<sub>(u)</sub> = well function

T = the transmissivity of the aquifer (m<sup>2</sup>/day)

S = the storage coefficient

t = the time since pumping started (day)

Theis (1935) described a graphical solution to determine the value of transmissivity and storage coefficient by means of Equations 2 and 4. A plot of the

value of W<sub>(u)</sub> versus the values of u on logarithmic paper (termed as type curve) is prepared. Also on another sheet of logarithmic paper at the same scale, values of drawdown versus r<sup>2</sup>/t are plotted. The data curve is superimposed on the type curve and, keeping the coordinate axes of the two graphs parallel, adjusted until most of the observed points fall on a segment of the type curve. Any point within the overlapping domains can be selected as a match point. Finally to calculate the transmissivity and the storage coefficient of the aquifer, the coordinates of the match point are substituted in Equation 2 and 4.

The Cooper-Jacob method is based on the Theis formula. It can be seen from Equation 4 that for small values of r and large values of t, u is small as the terms after the first two terms in Equation 3 become small and can be neglected. Therefore, the Theis formula for small values of u (u < 0.01) can be expressed by

$$s = \frac{Q}{4\pi T} (-0.5772 - \ln u) \quad (5)$$

After rewriting and changing to decimal logarithms, the equation simplifies to

$$s = \frac{2.3Q}{4\pi T} \log \frac{2.25Tt}{r^2 S} \quad (6)$$

In the Cooper-Jacob method, a plot of drawdowns versus the corresponding times on semi-log paper (time on logarithmic scale) gives a straight line. The straight line drawn through the plotted data is extended until it intercepts the time axis and the intercept gives the time t<sub>0</sub> (the notional time at zero drawdown).

## RESULTS AND DISCUSSION

The extent of cone of depression in a pumping test depends upon three factors including pumping rate, aquifer hydrodynamic parameters and pumping period. In unsteady state condition, the longer the pumping period, the greater is the extent of cone of depression. In heterogeneous aquifers, the growth of cone of depression with increase of pumping period yields different values of aquifer parameters. To evaluate the effect of pumping period on aquifer parameters, values of transmissivity were determined for incrementally longer portions of pumping test data in anomaly No. 1 of Gole Gohar iron mine. Figure 1 illustrates considerable variations in values of transmissivity calculated for different pumping periods in some pumping tests.

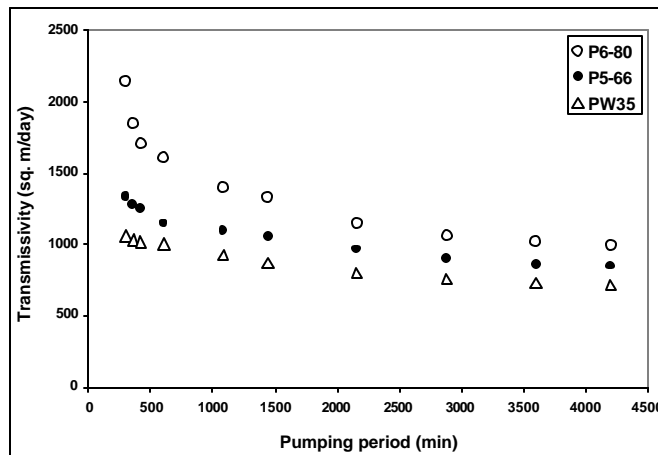


Fig. 1: Values of transmissivity determined in different pumping periods for 3 boreholes in Gole Gohar iron mine, anomaly No. 1

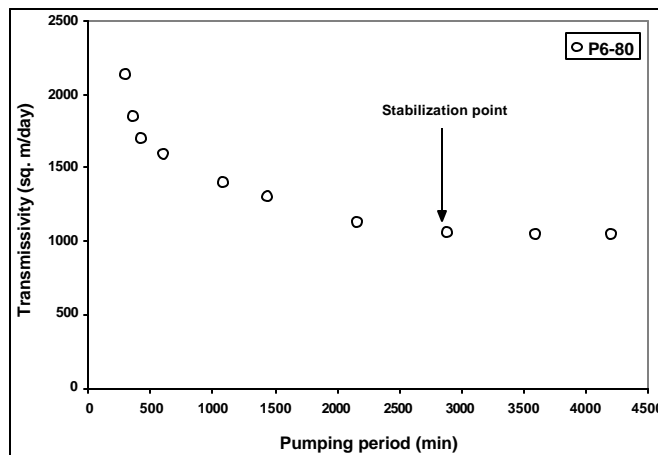


Fig. 2: Assessing pumping period using stabilization in value of transmissivity

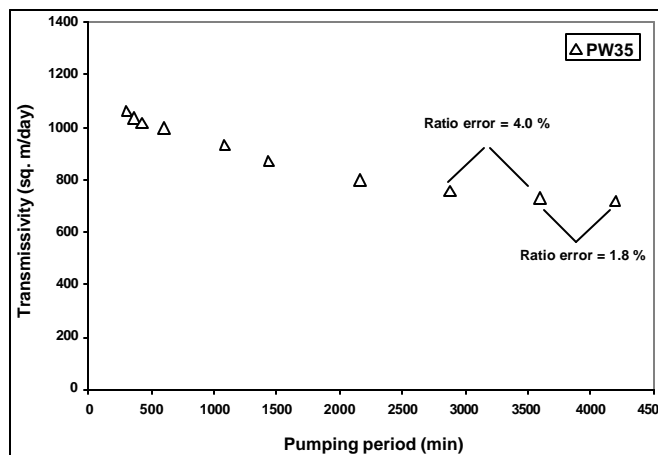


Fig. 3: Assessing pumping period using ratio error between two successive values of transmissivity

According to Figure 1, it is evident that the values of transmissivity determined from different durations of each pumping test vary considerably. Moreover, it is notable that at most pumping tests, there is a very sharp decrease in values of transmissivities. This is probably due to decrease in permeability of the aquifer surrounding boreholes. However, the expanding cone of depression may encounter zones with higher transmissivities than those most recently encountered. Such changes in values of transmissivity of the aquifer act in a scale which is not identical for different aquifers. In longer duration of pumping test which integrates the values of transmissivity for a considerable portion of the aquifer, the effect of scale will be neglected and the values of transmissivity tend to a relatively constant value. Therefore, it can be concluded that the longer duration of pumping test yield an average of the transmissivity of the whole of cone of depression in heterogeneous aquifers. However, the short period pumping tests display the hydraulic parameters of a small area around each borehole which may differ from those of whole aquifers.

**Assessing the Duration of Pumping Test:** As mentioned in the previous section, in heterogeneous aquifers, different durations of pumping test can yields different values of aquifer parameters. Therefore, it is necessary to assess the minimum duration for pumping tests in heterogeneous aquifers which in such duration the slight or smooth changes in average values of hydraulic parameters (e.g. transmissivity) are observed.

A new and practical approach has been derived to assess the minimum duration required for pumping test in heterogeneous aquifers to determine the accurate aquifer parameters. In this approach, the values of transmissivity are computed for ever-longer portions of pumping test data-set using *AQUIFER WIN32* software. The obtained values of transmissivity are plotted against time for different periods. When stabilisation occurs, the pumping test can be ended.

Figure 2 shows the variations of transmissivity against pumping period in borehole P6-80 which is located in anomaly No. 1 of Gole Gohar iron mine. In this pumping test at 2880 minutes since beginning of pumping test values of transmissivity were stabilised. Therefore, the minimum duration required for this pumping test is about 2880 minutes (i.e. 2 days). However, in some pumping tests, although the variations of transmissivity may reduce considerably over time, true stabilisation does not

occur. Figure 3 illustrates an example for the case in which true stabilisation does not take place. As can be seen from this Figure 3, variations observed in values of transmissivity for the short period of pumping test are relatively high while for the long periods of pumping test variations in the values of transmissivity have been considerably diminished. In such cases, based on the required precision, a ratio error (e.g. 1 to 5 percent) between two successive values of transmissivity may be accepted. In order to calculate the ratio error between two successive values of transmissivity, their difference is divided by their average and the obtained result multiplied by 100.

According to the obtained results in anomaly No. 1 of Gole Gohar iron mine, it may be concluded that pumping tests less than 2 days in duration should not be recommended. For such aquifers and in cases where high heterogeneity is suspected, tests may need to last for at least 5 days or more if meaningful results are to be obtained.

## CONCLUSION

The most reliable method for assessing the hydraulic parameters of aquifers is pumping test method. In heterogeneous aquifers, the values of hydraulic parameters obtained from analyzing the pumping test data depend upon the pumping period. Therefore, it is so important to assess an appropriate pumping period for such aquifers. A new and practical approach has been derived to assess the minimum duration required for pumping test in heterogeneous aquifers to determine the aquifer parameters. In this method, values of transmissivity are determined for incrementally longer portions of pumping test data. Thereafter, the values of obtained transmissivity are plotted against time for different periods. The minimum required pumping period is where stabilization occurs. However, in those pumping tests which true stabilisation does not occur, when ratio error between two successive values of transmissivity reached to acceptable value, pumping period can be determined. In such cases, based on the required accuracy, a ratio error (e.g. 1 to 5 percent) between two successive values of transmissivity can be taken into consideration. Therefore, where the discrepancy between two successive values of transmissivity becomes less than or equal to the selected ratio error, the pumping test can be ended.

## REFERENCES

1. Todd, D.K., 1980. Groundwater hydrology (2nd edn), John Wiley & sons, New York, pp: 539.
2. Walton, W.C., 1987. Groundwater pumping tests. Lewis Publishers, Inc. U.S.A., pp: 201.
3. Kruseman, G.P. and N.A. de Ridder, 1994. Analysis and evaluation of pumping test data (2nd edn), ILRI Publication, International Institute for Reclamation and development, Wagening, Netherlands, pp: 377.
4. Bardenhagen I., 2001. Pumping from discontinuous fracture networks. In: New Approaches Characterising Groundwater Flow, Seiler and Wohnlich (eds), Swets and Zeitlinger Lisse, pp: 805-810.
5. Paillet, F.L. and R.S. Reese, 2000. Integrating borehole logs and aquifer tests in aquifer characterization Ground Water, 38(5): 713-725.
6. 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 American Geophysical Union, 16: 519-524.
7. Cooper, H.H. and C.E. Jacob, 1946. A generalised graphical method for evaluating formation constants and summarising well field history, American Geophysics Union Transactions, 27: 526-534.
8. Aquifer win32 software. A trademark of Environmental Simulations International Ltd. Scientific Software Group. P.O. Box 708188, Sandy, Utah 84070.