



A REVIEW ON DRAWDOWN AND RECUPERATION PATTERN

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Abstract

Drawdown and recuperation pattern of wells are much dependent on the aquifer parameters. Analysis of drawdown and recuperation pattern of wells is necessary for the determination of various aquifer parameters. The levels at which water stands in a well before pumping is called static water level. When a well is being pumped, the water level in the well lowers. In general case initial contribution of water from the well mostly comes from the well storage. It is only after sometime that the aquifer starts contributing to pumpage. The time gap between the onset of pumping and the beginning of an appreciable flow of water from the aquifer to the well depends mainly on the transmissivity of the aquifer. The linear relationship between drawdown and time implies that the water is pumped mostly from storage. Thus time drawdown curves were initially linear, but later with the beginning of the contribution from the aquifer; they gradually become non-linear.

Key words: drawdown, aquifer parameters, transmissivity of the aquifer, pumpage, static water level

I. INTRODUCTION

Drawdown and recuperation pattern of wells are much dependent on the aquifer parameters. Analysis of drawdown and recuperation pattern of wells is necessary for the determination of various aquifer parameters. The levels at which water stands in a well before pumping is called static water level. When a well is being pumped, the water level in the well lowers. In general case initial contribution of water from the well mostly comes from the well storage. It is only after sometime that the aquifer starts contributing to pumpage. The time gap between the onset of pumping and the beginning of an appreciable flow of water from the aquifer to the well depends mainly on the transmissivity of the aquifer. The linear relationship between drawdown and time implies that the water is pumped mostly from storage. Thus time drawdown curves were initially linear, but later with the beginning of the contribution from the aquifer; they gradually become non-linear.

When the pump is stopped, at the end of the pumping test, the water level in the well starts rising. This is referred to as recovery of the ground water level. Recovery rate is high at the beginning of the recuperation due to steep hydraulic gradient. It is gradually reduces as the static water level approaches.

II. DRAWDOWN AND RECUPERATION PATTERN

Hilton *et al.* (1967) presented a solution for the change in water level in a well of finite diameter after a known volume of water is suddenly injected or withdrawn. A set of type curves computed from the solution permits a determination of the transmissivity of the aquifer.

Papadopulos and Coope (1967) analyzed the drawdown in a well of large diameter. Their purpose was to present an exact solution of the drawdown in and around the well of finite diameter taking into consideration the effect of water stored in it. Under some conditions, the solution may be

useful in analyzing pumping from a pond. A set of type curves computed from the solution permits the determination of transmissivity of the aquifer by analysis of drawdown observed in the pumped well.

Neumann (1975) analyzed the pumping test data from unconfined aquifers considering delayed gravity response. He developed two methods of analysis, one based on matching of field data with theoretical type curves and the other based on semi logarithmic relationship between drawdown and time. Owing to the reversible nature of the delayed response process as represented by the analytical model, he used the recovery test data to determine the aquifer transmissivity.

Bintley (1979) determined aquifer coefficients from multiple well effects at Fernandina beach in Florida. A water level recorder was used to record the change in water level following shut down and start up. Pumping rates of the well ranged from 400,000 to 590,000 cubic feet per day. Distance from the pumped wells to the observation wells ranged from 660 to 7920 feet. Analysis of water level data was further complicated because the wells were neither turned off nor restarted simultaneously. The Copper-Jacob graphical method based on the principle of super position and using the value of specific drawdown or specific recovery (S/Q) and the weighted logarithmic mean of the distance squared divided by the time (r^2/t), was applied to determine the aquifer coefficients for the upper water bearing zone of the aquifer. A transmissivity of 30,000 feet squared per day and a storage coefficient of between 2.5×10^{-4} and 4.0×10^{-4} were computed.

Baker and Herbert (1982) conducted study on pumping test in a patchy aquifer and developed an evaluation describing the long time behavior of draw down so that Jacob's method can be employed to estimate the regional transmissivity from draw down measured at any point in aquifer. These equation shows that an average storage coefficient should be calculated from draw down measured outside of the aquifer discontinuity. The result of the study support the hypothesis that the average transmissivity of the heterogeneous aquifer can be calculated from the rates of draw down observed after a long period of pumping.

Norris (1983) conducted and analyzed aquifer tests and well field performance at Scioto River valley, Ohio. Values of drawdown measured in the observation wells at the end of constant rate pumping periods, usually of 3 days duration, were used to determine line source distance and aquifer transmissivity based on 13 aquifer infiltration rate at 11 sites, aquifer transmissivity ranged from 17,000 to 40,000 square feet per day and the saturation infiltration range ranged from 0.06 to 0.19 million gallons per day per acre along a 7 mile reach of the Scioto river in south central Ohio.

Walthall and Ingram (1984) determined the aquifer parameters using the multiple piezometers. The study was being carried to evaluate the North Merseyside Permian-Triassic sand stone aquifer with particular reference to saline intrusions and water resources. The study had included a full range of hydrological investigations of which the behavior of observation boreholes has formed an important part in addition to water levels, these observation boreholes had been used to assess the regional permeability of the aquifer, variations of hydraulic properties over the aerial extent of the aquifer and for hydrological sampling. The use of multiple piezometers proved to be the only way of obtaining sensible results for field pumping tests and has given storage coefficients for both confined and unconfined sections of the aquifer.

Rushton (1985) studied the interference due to neighboring wells during pumping test. An important finding of the analysis is that the distance between the test and interfering wells has a small effect during both pumping and recovery face

Butt and McElwee (1985) conducted convolution and sensitivity analysis on variable rate pumping tests to evaluate aquifer parameters. They used the convolution and sensitivity analysis to obtain 'best fit' of the aquifer parameters in the least square sense from a pumping with variable pumping rate. It can also be used to analyze the residual drawdown data obtained during the recovery period. The method is used to analyze the drawdown and recovery data conjunctively. The method developed by them was straightforward, quick, inexpensive and is always objective.

Boonstra (1989) developed a computer program names SATEM for the determination of aquifer parameters in consolidated aquifers. In order to run the program some limiting conditions are there to be satisfied:

- Discharge should not be less than $100\text{m}^3/\text{day}$
- Minimum pumping hour should be 8 hours

This program is only applicable to tube wells.

Ballukraya and Sharma (1991) suggested a method for estimating storativity using residual drawdown measurement from an observation well in confined aquifer. An equation derived from Cooper Jacob is suggested for estimating storativity using residual drawdown measurement from an observation well. It may be pointed out that in cases where Cooper Jacob straight line method can be applied, the proposed method can be safely employed.

Avci (1992) developed a procedure that analysis step drawdown test with pumping stage of unequal time duration was formulated and developed in the computer program.

This method is applicable the confined aquifer where the water level drawdown is governed by Theis' well function. A least square fit error analysis is used in the determination of aquifer properties and the well loss component of the drawdown. The method considers the time dependency of the aquifer loss coefficient during the collection of step drawdown data without requiring equal pumping stage duration.

Chapuis (1992) studies proposed a graphical representation for visualizing and quantifying difference between Cooper – Jacob's solution and Theis solution. The graph of drawdown versus log time may be divided into three zones, the early one being influenced by storativity, pumping well pipe capacity and skin effects and the intermediate one by the transmissivity and storativity of the aquifer. The solution can be used when Cooper – Jacob's approximation and values does not require curve matching. Early data can be used, however to obtain a better estimate of storativity and transmissivity from drawdown data of observation wells.

Szekely (1993) conducted studies for estimation of unsteady vertically heterogeneous aquifers exhibit three dimensional flow patterns around pumping wells that partially penetrate the formations. A quasi, a mixed and a weighted three dimensional model are applied to approximate the three dimensional, unsteady drawdown in vertical pumping and observation wells. Case of confined, semi confined and unconfined flow conditions are considered and numerical examples are used to quantify the numerical error of the methods, introduced by the vertical homogeneity of the aquifer.

Helweg (1994) proposed General Well Function (GWF) to replace Jacob's step drawdown equation. Jacob's equation requires preselected discharge duration and does not incorporate time as an independent variable. The General Well Function not only corrects for this weakness but appears to better predict drawdown that extent beyond the test data. The GWF assumes that both formation and well losses increases over time.

Kawecki (1995) conducted step drawdown test to evaluate the well performance. This method is restricted to confined aquifer and determines the total well losses as a function of discharge with linear and nonlinear components. This method is valid for any stepped pumping pattern and any observed fluctuation in discharge during a step are simply accommodated as additional steps.

Chung and Quazar (1995) made a study on Theis solution under aquifer parameters uncertainty. This study showed that drawdown is almost inversely proportional to transmissivity and also find that there is no correlation between transmissivity and storativity.

Bhadouria and Seth (1996) conducted a study on time drawdown and recovery trends of open wells and they found that flow of water to well is dependent on rate of pumping. They also found specific gravity of well at different well depth and uneven variation in specific capacity shows the heterogeneous formation within the well depth. The recovery trends are dissimilar because the wells are

located in different well logs in the case this case study the rate of pumping 5 liters per second had exceeded the rate of inflow. Hence determination of specific capacity at this rate was not feasible.

Xunhong and Jerry (1997) used Hantush solution for simultaneous determination properties using Taylor series and non-linear least square method. The main limitation of this case is that the construction characteristics of the well should be known and also will should be located within a radial distance 1.5 times the thickness of aquifer. The error between determined and true parameter values was less than 0.1% depending on the quality of the field data.

Moench (1999) proved that on the basis of a pumping test in an unconfined aquifer, it is possible to derive values of horizontal and vertical hydraulic conductivities, specific storage, and specific yield using analytical methods. However, because it is a time consuming process and the difficulty to obtain accurate fits of theoretical curves to observed drawdown data, numerical modeling makes it possible to eliminate some of the simplifications and assumptions on which the analytical solutions are based (Lebbe et.al., 1992). Moench recommended the composite analysis of pumping test data and grouping of corresponding time drawdown data for parameterization as opposed to the analyses of individual drawdown curves.

Hvilshoj et al. (2000) demonstrated that it is possible to determine horizontal and vertical hydraulic conductivities, specific yield, and specific storage based on a pumping test of a partially penetrating well. Also, from the analyses of the Vejen unconfined aquifer in found to be in accordance with the horizontal hydraulic conductivity determined by the pumping tests of partially penetrating wells. However, pumping tests of fully penetrating wells are the most common, and analyses of such tests yield values of transmissivity, storage coefficient, and leakage factor

Chen et al. (2003) showed from the contours of relative errors (REs) for, K_z , S , and S_y that the areas immediately above and below the pumping well screen are poor locations for an observation well. Shallow locations with distances of 15 m or closer to the pumping well seem to be poor choices for obtaining reliable K_z and S values. Favorable locations for S_y are often in the shallow part of the aquifer and a certain distance from the pumping well. At least two observation wells are needed for locations good for S_y if the flexibility of K_h is considered; otherwise, three wells are preferred over a vertical profile. Although REs for K_h are small over the entire vertical profile, a deep observation well generates a slightly larger error. Therefore, constructing observation wells in the depth interval opposite the pumping well screen is likely to generate good quality data because the REs for K_r , K_z , and S are usually small.

Raman, (2006) had been achieved from the analysis of pumping system, by the use of Aquifer Test and comparing the results with those obtained by linking MODFLOW with WinPest. To authenticate his results, we made use of the Neuman (1975) method set in Aquifer Test to calculate dimensional drawdown for each observation well, for which dimensional drawdown computed by WTAQare compared to affirm the values obtained for the T , S , K_h , K_v , and S_y of the aquifer. Under consistent assumptions, analytical drawdown curves derived by WTAQ (by using values for all hydraulic parameters that were calculated by Aquifer Test), should be super-imposable on those obtained using Aquifer Test

III. AQUIFER PARAMETER EVALUATION

Evaluation of hydraulic properties of aquifer and those of adjoining formation layers is an important aspect of any scheme of ground water resources assessment. Knowledge of aquifer parameters gives an idea of regarding an aquifer's water transmitting and storage capacity. Hydraulic properties of aquifer and associated layers can be determined by a pumping test. It involves abstraction of water from a well at controlled rate and observing the changes in the water level in pumped well or in one or more observation well. Pumping test can also be conducted to obtain information of yield and drawdown of wells for proper selection and positioning of pumps.

Sayed (1982) developed two programs for pumping test analysis by least square method using Jacob's modification of Theis equation. Two programs are given for the direct computation of transmissivity and storativity from time drawdown and distance drawdown data. The programs also calculate drawdown at various times and distance using the computed transmissivity and storativity.

Norris (1983) conducted aquifer test at 11 sites to determine the hydraulic properties. The values of drawdown are measured from the observation wells at the end of constant rate pumping periods, usually of three days duration were used to determine line- source distance and aquifer transmissivity. Results of the best assess the characteristics of aquifer system. Another purpose is to compare the performance of production well with prediction of yield and drawdown based on aquifer and stream infiltration characteristics determined from the test.

Franke (1987) developed a procedure for the analysis of aquifer test using the Theis non equilibrium solution. A classical dimensional analysis of the Theis non equilibrium radial flow problem in a confined aquifer requires three dimensionless parameters for representation. A type curve based on three dimensional parameters is developed that can be employed to analyze the aquifer test data by curve matching procedure. The shape of the proposed curve gives the approximate estimate for field parameters T and S.

Johns *et al* (1992) conducted studies to estimate aquifer properties by nonlinear least square analysis of pump test data developed for different aquifer models viz. Theis model, Equipotential model, Boundary model, Confined leaky model and Water table aquitard model. More than one aquifer model was found to match the pump test response with the same residual least square error and the well site hydrogeological information. The fitting routine employed in the pump test analysis were found to be enhance the interpretation by conventional method allowing parameter estimates to be defined for tests which may only weakly exhibit the long term aquifer behavior. This study illustrate that least square routine cannot replace the judgments of hydro geologist in interpreting pump test data particularly in assessing the validity of alternative aquifer model.

Mishra and Guyonet (1992) developed a simple method for computing transmissivity and storativity of the analysis from observation well response during constant head aquifer test. Objectives of this is to develop and demonstrate a procedure for interpreting the observation well data when the head at the test well is kept constant and considered as a fully penetrating well in confined, homogeneous and isotropic aquifer which is of infinite lateral extent, both the test well and observation wells are assumed to have negligible bore hole storage or skin effect. The proposed methodology is based on the approximate solution developed using the Boltzmann transformation technique.

Sen (1992) developed a simplified conceptual model for ground water flow pattern around an extended well leading to an analytic solution with type curve which can be used in determining the aquifer parameters from the field measurement of time drawdown data. It is observed that extended well type curve merge with Theis curve and consequently Jacob straight line method becomes applicable. The application of methodology to actual field data did not show any complication. Parameters estimation becomes reliable if length of the extended well is known.

Srivasthava and Guzman (1994) proposed slope matching techniques which obtain the parameter values without using any tables or iterative procedure. It is shown that the slope of the drawdown with respect to the logarithm of time result in the most accurate prediction of aquifer parameters. The methods are then applied to some field data and the results are compared with published data and are found to work reasonably well for field application.

Jio and Zheng (1995) conducted studies for different characteristics of aquifer parameters using the concepts of two ways coordinate and one way coordinate. An upstream observation well can produced information on storativity and both upstream and downstream, but it can produce little information on transmissivity downstream. These characteristics of aquifer parameters have important implication on pumping test designs and interpretations.

Li and Derek (1995) proposed a modified method for the aquifer parameter estimation procedure. In this the parameters are evaluated by a modified Gauss-Newton method, which is applied to transient ground water flow. Three different approaches of evaluating the sensitivity coefficient matrix are examined including influence coefficient, sensitivity equations and variational approaches. The performance of each of the techniques is evaluated by applying a common synthetic data set.

Banton and Bangoy (1996) developed a new method to determine the transmissivity and storage coefficient from recovery data. The method requires from observation from a minimum of two points. The results obtained are close to those using the Theis' or Jacob's methods applied to drawdown data during the pumping period.

Bergelson *et al.* (1998) conducted studies to determine hydraulic parameters of the aquifer around the Sea of Galilee. Water level fluctuations were used to calculate specific storage values which differs in the lower and upper aquifer. Depletion curves were used to calculate transmissivity in the lower and upper aquifers respectively. Age indicators were used to calculate the hydraulic conductivity, those obtained by radio carbon data. The pumping test provides values which are too high because of leakage from adjacent formation during the test. This technique is more adaptable than that of conventional pumping test.

Heidari and Ranjithan (1998) developed a method Genetic Algorithm is combined with Truncated Newton research technique to estimate ground water parameters for a confined steady state groundwater model. Use of prior information about the parameter is shown to be important in estimating correct or near correct values on the regional scale. Results from estimated parameters depend on the level of noise in the hydraulic head data and the initial values in the Truncated Newton research technique.

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