11 Large-diameter wells

The standard methods of analysis all assume that storage in the well is negligible. This is not so in large-diameter wells, but methods have been devised that take the well storage into account.

For a large-diameter well that fully penetrates a confined aquifer, Papadopulos (1967) developed the method presented in Section 11.1.1.

For a large-diameter well that partially penetrates an unconfined anisotropic aquifer, Boulton and Streltsova (1976) developed the method presented in Section 11.2.1.

11.1 Confined aquifers, unsteady-state flow

11.1.1 Papadopulos's curve-fitting method

For unsteady-state flow to a fully penetrating, large-diameter well in a confined aquifer (Figure 11.1), Papadopulos (1967) gives the following drawdown equation

$$s = \frac{Q}{4\pi KD} F(u,\alpha,r/r_{ew}) \qquad (11.1)$$

where

$$u = \frac{r^2S}{4KDt}$$

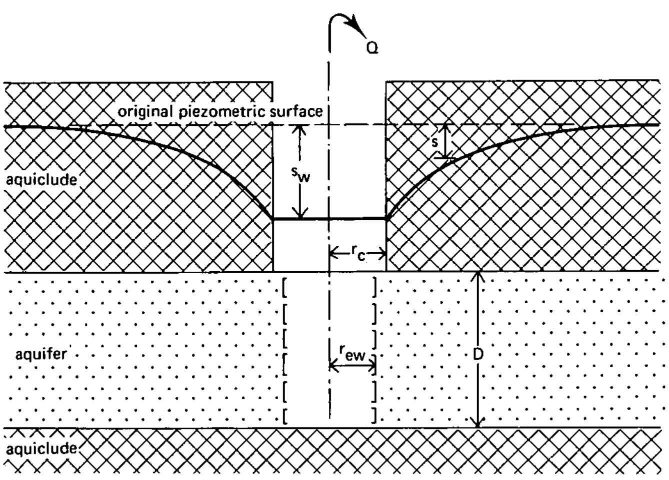

Figure 11.1 A confined aquifer pumped by a fully penetrating, large-diameter well

$$\alpha = \frac{r_{ew}^2 S}{r_c^2} \tag{11.2}$$

r_{ew} = effective radius of the well screen or open hole

r_c = radius of the unscreened part of the well over which the water level is changing

Numerical values of the function $F(u,\alpha,r/r_{ew})$ are given in Annex 11.1. These values can be plotted as families of type curves (Figure 11.2).

For long pumping times, i.e. when the drawdown response is no longer influenced by well storage effects, the function $F(u,\alpha,r/r_{ew})$ can be approximated by the Theis well function W(u) (Equation 3.5).

The assumptions and conditions underlying the Papadopulos curve-fitting method are:

- The assumptions listed at the beginning of Chapter 3, with the exception of the eighth assumption, which is replaced by:
  - The well diameter is not small; hence, storage in the well cannot be neglected;

The following condition is added:

- The flow to the well is in unsteady state.

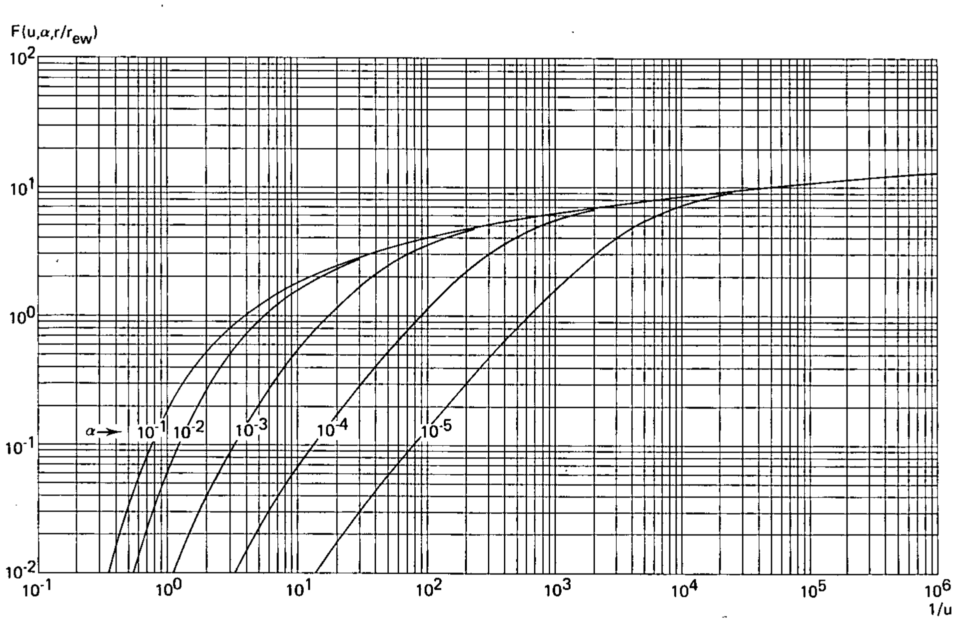

Figure 11.2 Family of Papadopulos's type curves for large-diameter wells: $F(u,\alpha,r/r_{ew})$ versus $1/u$ for different values of α ($r/r_{ew} = 20$)

Procedure 11.1

- For a single piezometer, i.e. for an estimated value of r/r_{ew}, plot a family of type curves $F(u,\alpha,r/r_{ew})$ versus $1/u$ for different values of α on log-log paper, using Annex 11.1;
- On another sheet of log-log paper of the same scale, plot the observed data curve s versus t;
- Match the observed data curve with one of the type curves and note the value of α of that type curve;
- Select an arbitrary matchpoint A on the superimposed sheets and note for this point the values of $F(u,\alpha,r/r_{ew})$, $1/u$, s, and t;
- Substitute the values of $F(u,\alpha,r/r_{ew})$ and s, together with the known value of Q, into Equation 11.1 and calculate KD;
- Calculate S by introducing the values of r, u, t, and KD into $u = r^2S/4KDt$, or by introducing the values of r_c, r_{ew}, and α into Equation 11.2.

Remarks

- If early-time drawdown data only are available, it will be difficult to obtain a unique match of the data curve and a type curve because the type curves differ only slightly in shape (Figure 11.2). The data curve can be matched equally well with more than one type curve. Moving from one type curve to another, however, results in a value of S which differs an order of magnitude. Hence, for early time, S determined by the Papadopulos curve-fitting method is of questionable reliability. The transmissivity, KD, is less sensitive to the choice of the type curve;
- Large-diameter wells are often only partially penetrating. For long pumping times ($t > DS/2K$), the effects of partial penetration reach their maximum and then remain constant. Analogous to Equation 10.7 (Section 10.2.2), the drawdown in a confined aquifer pumped by a partially penetrating, large-diameter well can be written as

$$s = \frac{Q}{4\pi KD}\left\{F(u,\alpha,r/r_{ew}) + f_s\left(\frac{r}{D},\frac{b}{D},\frac{d}{D},\frac{a}{D}\right)\right\}$$

where b, d, and a are the geometrical parameters shown in Figure 10.2.
For a particular well/piezometer configuration, f_s is constant and can be determined from Annex 8.1. For long pumping times, a log-log set of type curves of $\{F(u,\alpha,r/r_{ew}) + f_s\}$ versus $1/u$ for different values of α can be drawn and matched with the data curve. To obtain KD, Equation 11.1 is replaced by the above equation.

11.2 Unconfined aquifers, unsteady-state flow

11.2.1 Boulton-Streltsova's curve-fitting method

In Chapter 5, we discussed the typical S-shaped time-drawdown curve representing unsteady-state flow in an unconfined aquifer. For an unconfined anisotropic aquifer pumped by a partially penetrating, large-diameter well (Figure 11.3), Boulton and Streltsova (1976) developed a well function describing the first segment of the S-curve. In an abbreviated form, this can be written as

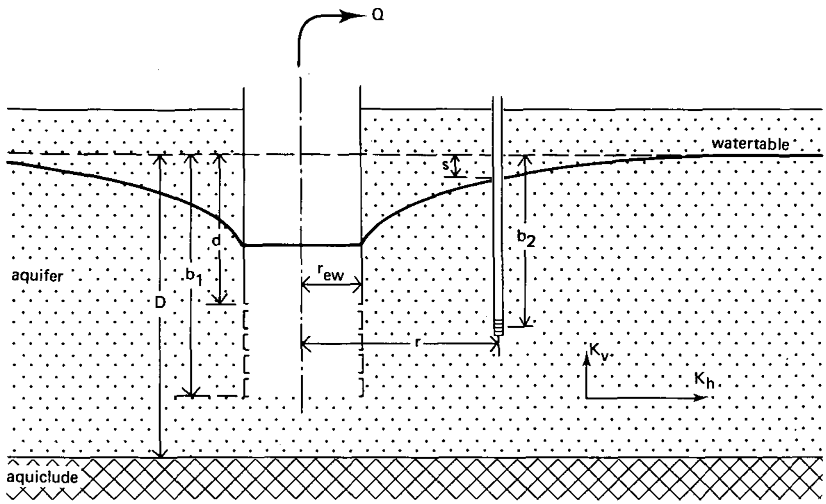

Figure 11.3 An unconfined anisotropic aquifer pumped by a partially penetrating, large-diameter well

$$s = \frac{Q}{4\pi K_h D} W\left(u_A, S_A, \beta, \frac{r}{r_{ew}}, \frac{b_1}{D}, \frac{d}{D}, \frac{b_2}{D}\right) \quad (11.3)$$

where

$$u_A = \frac{r^2 S_A}{4K_h Dt}$$

S_A = storativity of the compressible aquifer, assumed to be 10^{-3}

$$\beta = \left(\frac{r}{D}\right)^2 \frac{K_v}{K_h} \quad (11.4)$$

Because of the large number of parameters involved in this well function, only a selected range of parameter values are available with which $W(u_A,S_A,\beta,r/r_{ew},b_1/D,d/D,b_2/D)$ can be calculated for the construction of type A curves (Annex 11.2).

To analyze the late-time portion of the S-curve, the Boulton- Streltsova method applies the type B curves resulting from Streltsova's equation for a small-diameter well that partially penetrates an unconfined aquifer (Equation 10.17, Section 10.5.1). This is justified for sufficiently long pumping times when the effect of well storage is no longer pronounced.

The Boulton-Streltsova curve-fitting method can be used if the following assumptions and conditions are satisfied:

- The assumptions listed at the beginning of Chapter 3, with the exception of the first, third, sixth, seventh, and eighth assumptions, which are replaced by:
  - The aquifer is unconfined;
  - The aquifer is homogeneous, anisotropic, and of uniform thickness over the area influenced by the test;
  - The well does not penetrate the entire thickness of the aquifer;

• The well diameter is not small; hence, storage in the well cannot be neglected.

The following conditions are added:

- The flow to the well is in an unsteady state;
- $S_Y/S_A > 10$.

Procedure 11.2

- On log-log paper, draw the type A curves by plotting $W(u_A,S_A,\beta,r/r_{ew},b_1/D,d/D,b_2/D)$ versus $1/u_A$ for a range of values of $\sqrt{\beta}$, using the table in Annex 11.2 based on values of b_1/D, b_2/D, and r/r_{ew} nearest to the observed values;
- On the same sheet of log-log paper, draw the type B curves by plotting $W(u_B,\beta,b_1/D,b_2/D)$ versus $1/u_B$ for a range of values of $\sqrt{\beta}$, using the table in Annex 10.4 based on values of b_1/D and b_2/D nearest to the observed values;
- On another sheet of log-log paper of the same scale, plot s versus t for a single piezometer at r from the well;
- Match the early-time data curve with one of the type A curves and note the $\sqrt{\beta}$ value of that type curve;
- Select an arbitrary point A on the overlapping portion of the two sheets and note for this point the values of s, t, $1/u_A$, and $W(u_A,S_A,\beta,r/r_{ew},b_1/D,d/D,b_2/D)$;
- Substitute these values into Equation 11.3 and, with Q also known, calculate K_hD;
- Move the data curve until as many as possible of the late-time data fall on the type B curve with the same $\sqrt{\beta}$ value as the selected type A curve;
- Select an arbitrary point B on the superimposed curves and note for this point the values of s, t, $1/u_B$, and $W(u_B,\beta,b_1/D,b_2/D)$;
- Substitute these values into Equations 10.17 and 10.18 and, with Q, r, and b_1/D also known, calculate K_hD and S_Y. The two calculations of K_hD should give approximately the same result;
- From the K_hD value and the known initial saturated thickness of the aquifer D, calculate K_h;
- Substitute the numerical values of K_h, $\sqrt{\beta}$, D, and r into Equation 11.4 and calculate K_v;
- Repeat the procedure for each of the available piezometers. The results should be approximately the same.