10 Single-Well and Aquifer Tests

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10.1 Introduction

There are numerous examples of groundwater-flow problems whose solution requires a knowledge of the hydraulic characteristics of waterbearing layers. These characteristics were defined in Chapter 2. In drainage investigations, this knowledge is required for two purposes:
- To assess the net recharge to an aquifer in groundwater-balance studies (Chapter 16);
- To determine the long-term pumping rate and the well spacing for tubewell drainage (Chapter 22).

Performing an aquifer test is one of the most effective ways of determining the hydraulic characteristics. The procedure is simple: for a certain time and at a certain rate, water is pumped from a well in the aquifer, and the effect of this pumping on the watertable is regularly measured, in the pumped well itself and in a number of piezometers or observation wells in the vicinity.

Owing to the high costs of aquifer tests, the number that can be performed in most drainage studies has to be restricted. Nevertheless, one can perform an aquifer test without using observation wells, thereby cutting costs, although one must then accept a certain, sometimes appreciable, error. To distinguish such tests from normal aquifer tests, which are far more reliable, they are called single-well tests. In these tests, measurements are only taken inside the pumped well.

After a single-well or an aquifer test, the data collected during the test are substituted into an appropriate well-flow equation. In this chapter, we shall confine our discussions to the basic well-flow equations. For well-flow equations that cover a wider range of conditions, see Kruseman and De Ridder (1990).

10.2 Preparing for an Aquifer Test

10.2.1 Site Selection

Although, theoretically, any site that is easily accessible for manpower and equipment is suitable for a single-well or an aquifer test, a careful selection of the site will ensure better-quality data and will avoid unnecessary complications when the data are being analyzed. The factors to be kept in mind when selecting an appropriate site are:
- The hydrological conditions should be representative of the area;
- The watertable gradient should be small;
- The aquifer should extend in all directions over a relatively large distance (i.e. no recharge or barrier boundaries should occur in the vicinity of the test site);

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- The pumped water should be discharged outside the area affected by the pumping to prevent it from re-entering the aquifer.

If not all these conditions can be satisfied, techniques are available to compensate for any deviations.

10.2.2 Placement of the Pumped Well

At the site selected for the test, the well that is to be pumped is bored into the aquifer. Its diameter is generally between 0.10 and 0.30 m, depending on the type of pump that will be used; the type of pump depends on the desired discharge rate and the allowable maximum pumping lift.

After the well has been drilled, it must be fitted with a screen, the length of which

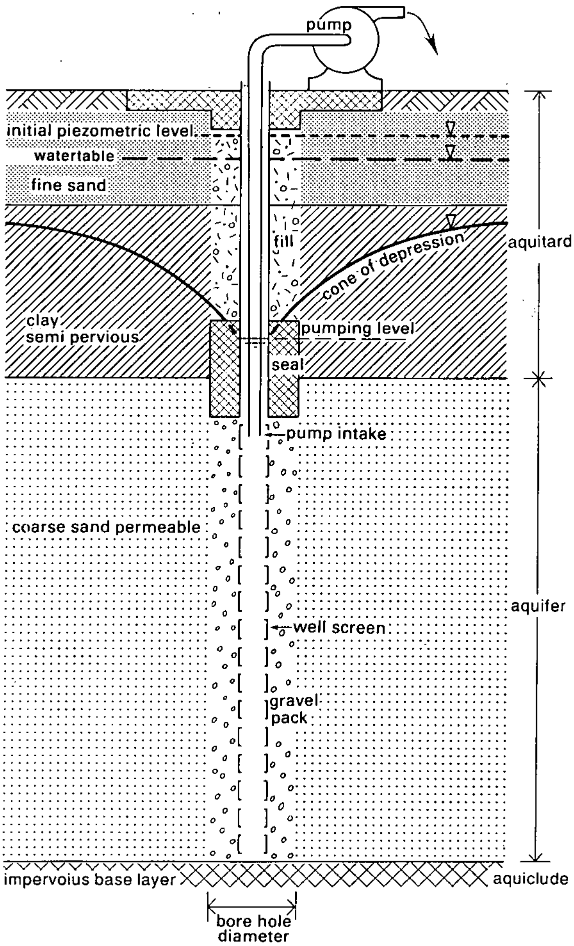

Figure 10.1 Fully-penetrating pumped well in a semi-confined aquifer

depends on the type of aquifer being tested. In unconfined aquifers, the bottom one-third to one-half of the aquifer should be screened to prevent the well screen from falling dry if appreciable drawdowns occur. In semi-confined (leaky) aquifers, the well should be screened over at least 70 to 80 per cent of the aquifer thickness. (If the watertable is expected to fall below the top of the aquifer during the test, that part of the aquifer should not be screened.) When such a well is pumped, the flow to the well will be essentially horizontal, and there will be no need to correct the drawdown data of any nearby observation wells. To prevent downward flow along the well from overlying layers, a seal of bentonite clay or very fine clayey sand may be required above the well screen (Figure 10.1).

Thick aquifers can only be partly screened, say their upper 50 m, because the cost of screening their full thickness would be prohibitive. In such partially-penetrating wells, vertical flow components will influence the drawdown within a radial distance from the well approximately equal to the thickness of the aquifer. As these vertical flow components are accompanied by a head loss, all drawdown data from wells sited within this radius must be corrected before they can be used to calculate the hydraulic characteristics. Figure 10.2 illustrates the flow to a fully-penetrating well (A) and to a partially-penetrating well (B).

In fine sandy or extensively laminated aquifers, the zone immediately surrounding the well screen can be made more permeable by removing the aquifer material and replacing it with an artificially-graded gravel pack (see Figure 10.1). The gravel pack will retain the aquifer material that would otherwise enter the well. Another advantage of a gravel pack is that it allows a somewhat larger slot size to be used in the well screen.

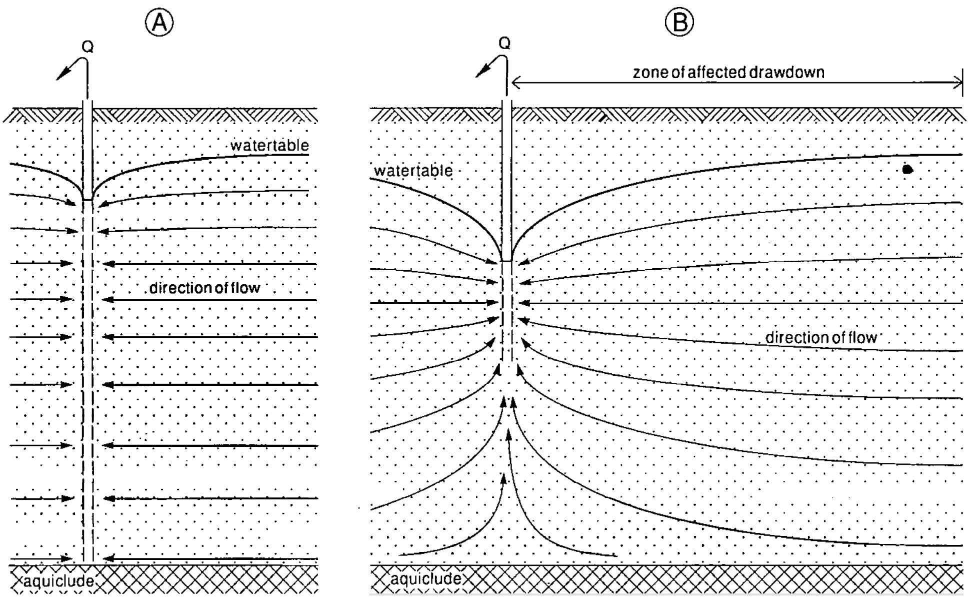

Figure 10.2 Groundwater flow to: A: A fully-penetrating well; B: A partially-penetrating well

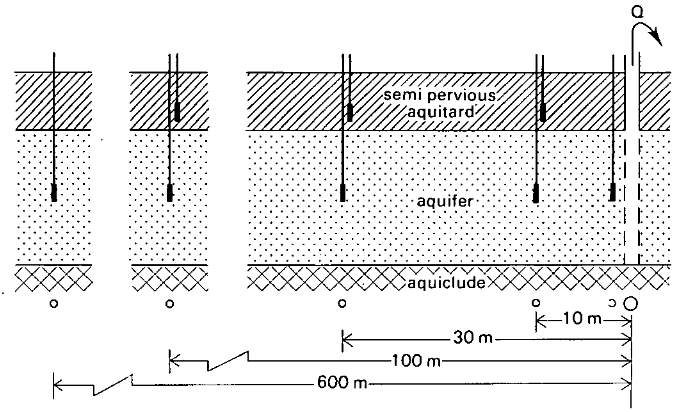

Figure 10.3 Example of the arrangement of observation wells in a semi-confined aquifer that is being tested by a fully-penetrating pumped well

10.2.3 Placement of Observation Wells

The observation wells need only be of small diameter, and each should be fitted with a screen, 1 to 2 m long, placed at about the same depth as the middle of the screen of the pumped well. Such an observation well is also called a piezometer.

Figure 10.3 shows an example of the arrangement of observation wells in a semi-confined aquifer that is being tested with a fully-penetrating well. Deep observation wells are placed in the aquifer and shallow ones are placed in the overlying semi-pervious layer. Other observation wells could be placed in the sandy material below the impervious base layer (aquiclude) to check whether that layer is indeed impervious.

In deciding how far from the pumped well one should place the observation wells, there are two factors to consider:

- The first is the non-homogeneity of aquifers; aquifers are almost always stratified to some degree. Care must be taken not to place an observation well in the least permeable part of the aquifer because the drawdown there will differ appreciably from that in the more permeable parts. This difference decreases as pumping continues, and is less significant at greater distances from the pumped well;
- The second factor is the degree of penetration of the screen of the pumped well. A short screen will have a noticeable effect on the drawdown near the screen because of the vertical flow components, so no observation wells should be placed too close to such a screen.

  This effect disappears at distances equal to one to three times the thickness of the aquifer. On the other hand, locating observation wells too far from the pumped well is not convenient either, because pumping must then be continued for a longer time to produce a sufficiently large drawdown at the most distant sites.

In unconfined aquifers, observation wells placed at distances of, say, 3, 10, 30, and

100 m from the pumped well will be appropriate in most cases. In confined and semi-confined aquifers, if thick and stratified, the distances must be greater, say, 100 to 300 m from the pumped well. For tests that last longer than one day, an extra observation well may be needed at a site that is not affected by the pumping. The water-level readings from that well can be used to check whether any natural changes occurred in the watertable during the pumping period. If so, the drawdown data produced by the pumping must be corrected accordingly.

When the pumped well and the observation wells are being drilled, samples of the pierced layers should be taken every one or two metres. A description of these samples will allow the type of aquifer (unconfined, confined, or semi-confined) to be defined. If possible, some of the wells should fully penetrate the aquifer to establish whether the impervious base layer is present throughout. After all the wells have been installed, they should be cleaned or pumped briefly to ensure that they function properly.

10.2.4 Arrangement and Number of Observation Wells

The number of observation wells depends on the amount and accuracy of information that is required and on the funds available for the test. The water-level data from one single observation well will allow the hydraulic characteristics to be calculated, but the data from two or more such wells will allow the test results to be analyzed in different ways. These different analyses provide a check on the accuracy of the results obtained from the test. Besides, since an aquifer is seldom homogeneous, it is always best to have as many observation wells as circumstances permit.

Figure 10.4 shows four different arrangements of observation wells and the pumped well. For drainage studies, arrangements A, B, or C will usually be appropriate.

10.3 Performing an Aquifer Test

An aquifer test relies heavily on three sets of measurements: those of time, head, and discharge.

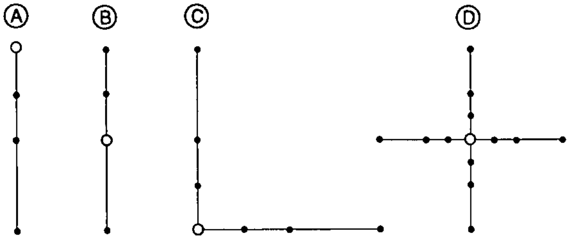

Figure 10.4 Different arrangements of observation wells:
o = pumped well; • = observation well

10.3.1 Time

The time measurements are started at the beginning of the test; they can be recorded either as 'time of day' or as 'time since the test started'. Because water levels are dropping fast during the first hour or two of the test, readings should first be taken at brief intervals. As pumping continues, water levels will drop less and less fast and the intervals between readings can gradually be lengthened. Since, in all the analysis procedures, the time is plotted on a logarithmic scale, it is recommended to have the same number of readings in each log cycle of time. Table 10.1 shows an example of the sequence in time for taking water-level measurements, based on ten readings in each log cycle and resulting in approximately equidistant plotting positions.

For observation wells far from the well and for those in aquitards above or below the aquifer, the brief time intervals in the first minutes of the test need not be adhered to.

10.3.2 Head

Before pumping starts, the water levels in all the wells should be measured from a chosen reference (e.g. the rim of the pipe).

Water-level measurements can be taken in various ways: with the wetted-tape method, mechanical sounder, electric water-level indicator, floating-level indicator or recorder, pressure gauge, or pressure logger. (For information on these devices, see Chapter 2.) Fairly accurate measurements can be made manually, but then the instant of each reading should be recorded with a chronometer. Experience has shown that it is possible to measure the depth to water within 2 mm.

For piezometers close to the well, the wetted-tape method cannot be used because of the rapid water-level changes, and the mechanical sounder is not suitable because of the noise of the pump. Although the pressure-gauge method is less accurate than the other methods (within 0.06 m), it is the most practical method of measuring water levels in a pumped well. It should not be used, however, in observation wells.

Most well-flow equations require drawdown data. Data on depth to the water level should therefore be converted to drawdown data. In other words, the initial depth

Table 10.1 Sequence in time for taking water-level measurements

Time (s)	Time (min)	Time (min)	Time (h)	Time (h)
10	2.5	20	2.5	22
20	3.0	25	3.0	27
30	4.0	30	4.0	33
40	5.0	40	5.0	42
50	6.5	50	7.0	53
60	8.0	65	8.5	67
80	10.0	80	11.0	83
100	13.0	90	13.0	108
120	16.0	120	17.0	133

to the water level prior to pumping must be subtracted from the depth to the water level during the test.

10.3.3 Discharge

The required discharge rate of the pump depends on many factors: the depth, diameter, and screen length of the pumped well; the type of aquifer; the actual hydraulic characteristics of the tested aquifer; and the distances of the observation wells.

The discharge rate is usually determined in the field. Several days before the test is to be conducted, the test well should be pumped for several hours. In most tests, a major portion of the drawdown occurs in the first few hours of pumping, so this preliminary testing will reveal the maximum expected drawdown in the well. Also, for aquifer tests, it will reveal whether the discharge rate is high enough to produce good measurable drawdowns – at least some decimetres – in all the observation wells.

To avoid unnecessary complications when the test is being analyzed, the discharge of the well should be kept constant. It should therefore be measured at least once every hour and, if necessary, adjusted.

There are various ways of measuring the discharge. If the outflow pipe is running full, accurate measurements can be made with a water meter of appropriate capacity. It can also be measured by recording the time required to fill a container of known volume, or, if the pumped water is conveyed through a channel or small ditch, by means of a flume or weir. For information on these devices, see Bos (1989) and Driscoll (1986).

The water delivered by the well should be prevented from returning to the aquifer. This can be done by conveying the water through a large-diameter pipe, say over a distance of 100 or 300 m, depending on the location of the piezometers, and then discharging it into a canal or natural channel. Preferably, the water should be discharged away from the line of piezometers. The pumped water can also be conveyed through a shallow ditch, but precautionary measures should be taken to seal the bottom of the ditch with clay or plastic sheets to prevent leakage.

10.3.4 Duration of the Test

The question of how long the test should run depends on the type of aquifer being tested. With all the effort and expense that is put into an aquifer test, it is not wise to economize on the time of pumping because this constitutes only a small fraction of the total cost. It is therefore advisable to continue the test until the water levels in the observation wells have stabilized (i.e. until the flow has reached a steady or pseudo-steady state).

Steady-state flow is independent of time (i.e. the water level, as observed in piezometers, does not change with time). It can occur, for instance, when there is equilibrium between the discharge of the pumped well and the recharge of the pumped aquifer from an overlying aquitard. Because real steady-state conditions seldom occur, it is said in practice that a steady state is reached when the changes in water level are negligibly small, or when the hydraulic gradient has become constant (pseudo steady-state).