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the same piece of rock by mounting the cube in the permeameter in different orientations.

Ideally, the fluid passed through the sample should be groundwater from that formation, and no other fluid should come into contact with the samples from the time they are part of the aquifer until the time the tests are finished. This is because groundwater is not pure water: it contains dissolved materials in various proportions and concentrations. The groundwater and the aquifer will be in approximate chemical equilibrium; if water with different dissolved material is introduced into the rock, the minerals in the rock may change. This is most likely to happen when clay minerals (present in many sedimentary rocks) are involved; the clay particles may swell or shrink as the water chemistry is changed, thereby altering the dimensions of the pores and hence the rock properties. (Even the action of drying samples for a porosity test can cause large changes, and sophisticated drying techniques may have to be used.) Values of permeability differing by a factor of a hundred or more can be measured on the same rock sample using different test fluids; if natural formation water (or a solution with the same dissolved constituents) is used for all measurements and preparation, the possibility of error is greatly reduced.

When dealing with 'clean' rocks (those containing negligible amounts of clay) the choice of test fluid is less critical, and distilled water or even a gas can be used for permeability measurements. Gas measurements are quick, as small gas flows can be measured accurately, whereas small liquid flows may have to be collected for a long time to obtain a measurable volume; however, allowances must be made for changes in gas volume caused by expansion and for the fact that gas molecules 'slip' through small-pore channels more easily than do liquid molecules. Gas techniques are also available for the measurement of porosity.

Laboratory tests offer the possibility of making accurate measurements under carefully controlled conditions on samples of precisely known geometry, but the samples are inevitably small. To test more representative volumes we must leave the laboratory and move 'into the field'.

Field measurements

One of the most effective and frequently used methods of measuring aquifer properties is the **field pumping test**. We saw in Chapter 6 that when water is pumped from a well, a cone of depression is formed in the potentiometric surface. The steepness of the cone depends on the hydraulic gradient, which in turn depends on the pumping rate and on the transmissivity and storage coefficient of the aquifer. The storage

coefficient relates the volume of the cone to the total quantity of water pumped out; the smaller the storage coefficient, the larger the cone must be for any given quantity of water abstracted. Knowing these relationships it follows, in the absence of complicating factors, that if we pump water from a well and observe the way the cone of depression expands, then we should be able to deduce the transmissivity and storage coefficient of the aquifer. This is the principle of the pumping test, but the phrase 'in the absence of complicating factors' must be kept in mind.

The usual procedure for a test is that water is pumped from one well – called the **production well** or **pumped well** – at a constant rate, which is carefully controlled and measured. The resulting change in the potentiometric surface is monitored by measuring the change in head in one or more **observation wells** near the pumped well. (Provided that the density of the groundwater is constant, the change in water level in a well is an accurate representation of the change in head.) A possible arrangement of wells for a test is shown in Figure 10.5. The longer pumping

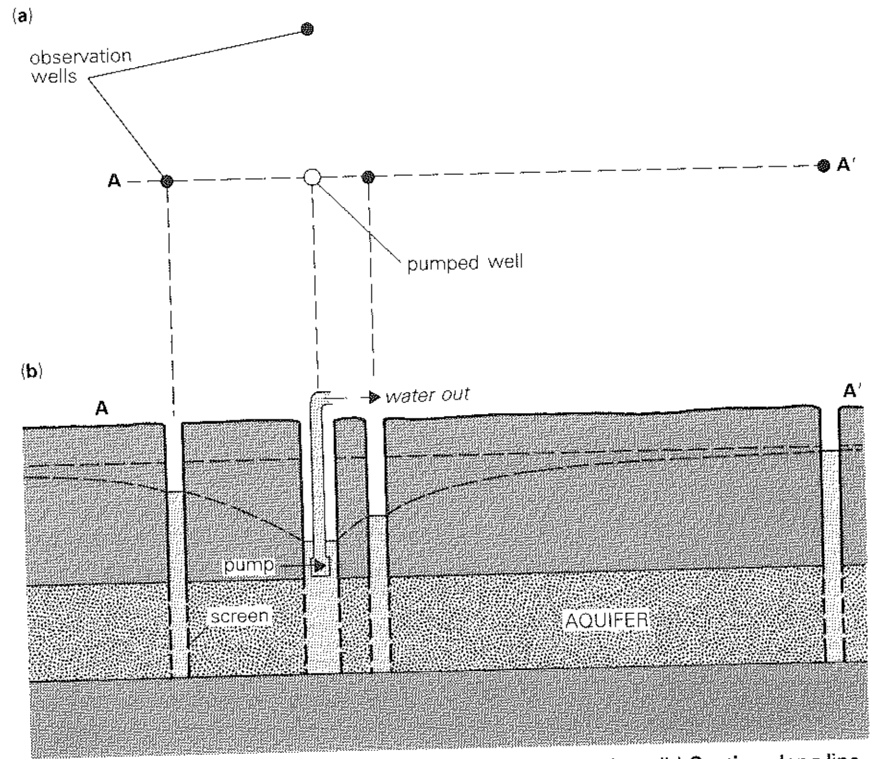

Figure 10.5 Idealised layout for a pumping test (a) Plan view. (b) Section along line A–A'.