

Groundwater in the Hydrologic Cycle

Groundwater constitutes one portion of the earth's water circulatory system known as the hydrologic cycle. Figure 1.8 illustrates some of the many facets involved in this cycle. Water-bearing formations of the earth's crust act as conduits for transmission and as reservoirs for storage of water. Water enters these formations from the ground surface or from bodies of surface water, after which it travels slowly for varying distances until it returns to the surface by action of natural flow, plants, or humans. The storage capacity of groundwater reservoirs combined with small flow rates provide large, extensively distributed sources of water supply. Groundwater emerging into surface streams channels aids in sustaining streamflow when surface runoff is low or nonexistent. Similarly, water pumped from wells represents the sole water source in many regions during much of every year.

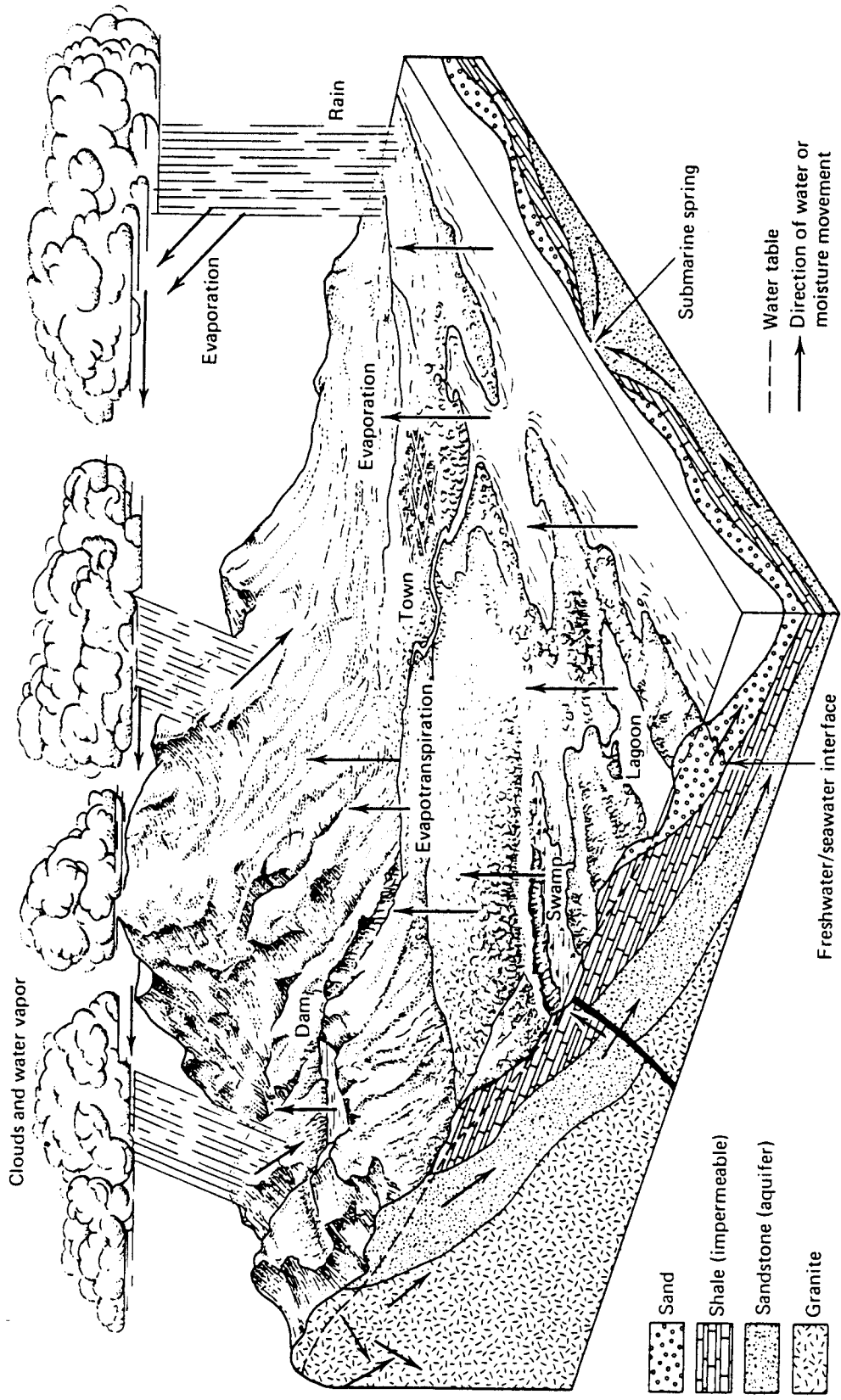


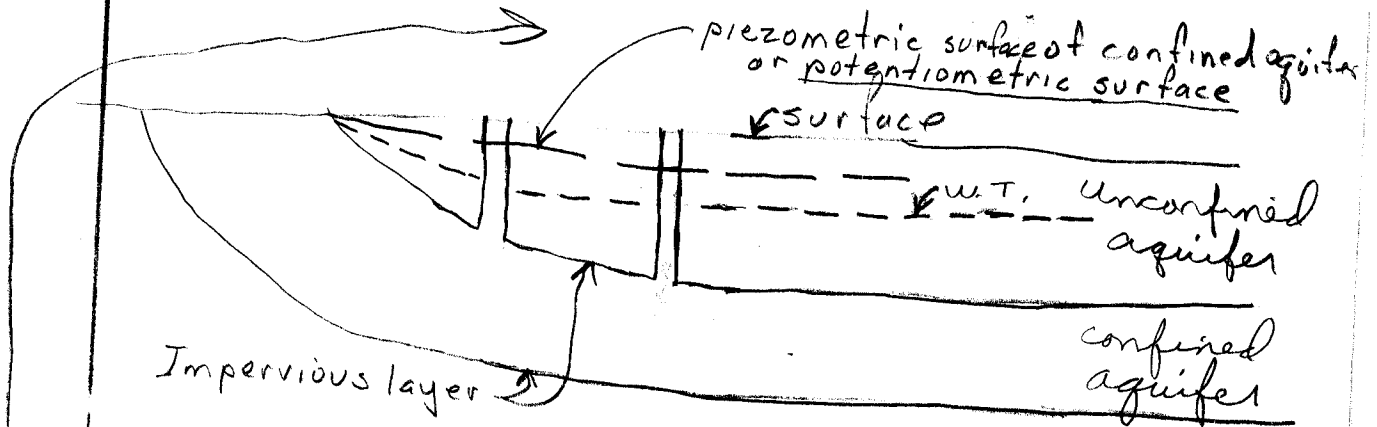
Fig. 1.8 Schematic diagram of the hydrologic cycle (courtesy Australian Water Resources Council).

Chapter 8

L-2

(12) ~~(11)~~

Aquifer - a subsurface reservoir that can produce water in significant amounts. Ability to store and transmit water.



Void spaces between the porous material must be interconnected in the medium to be an aquifer (to have the ability to produce water). That is, an aquifer must be permeable or have hydraulic conductivity.

Water in mediums that have voids that are not interconnected (not aquifers) is called fixed water.

A piezometer is a device which indicates the water-pressure head at a "point" in the aquifer.
 (go over pressure head) $h_p = \frac{p}{\gamma} + z$
 actually potential energy
 pressure head $\rightarrow \frac{p}{\gamma}$
 elev. head $\rightarrow z$

Bernoulli Eqn. $\frac{p}{\gamma} + z + \frac{V^2}{2g} = \text{Total Energy (constant)}$

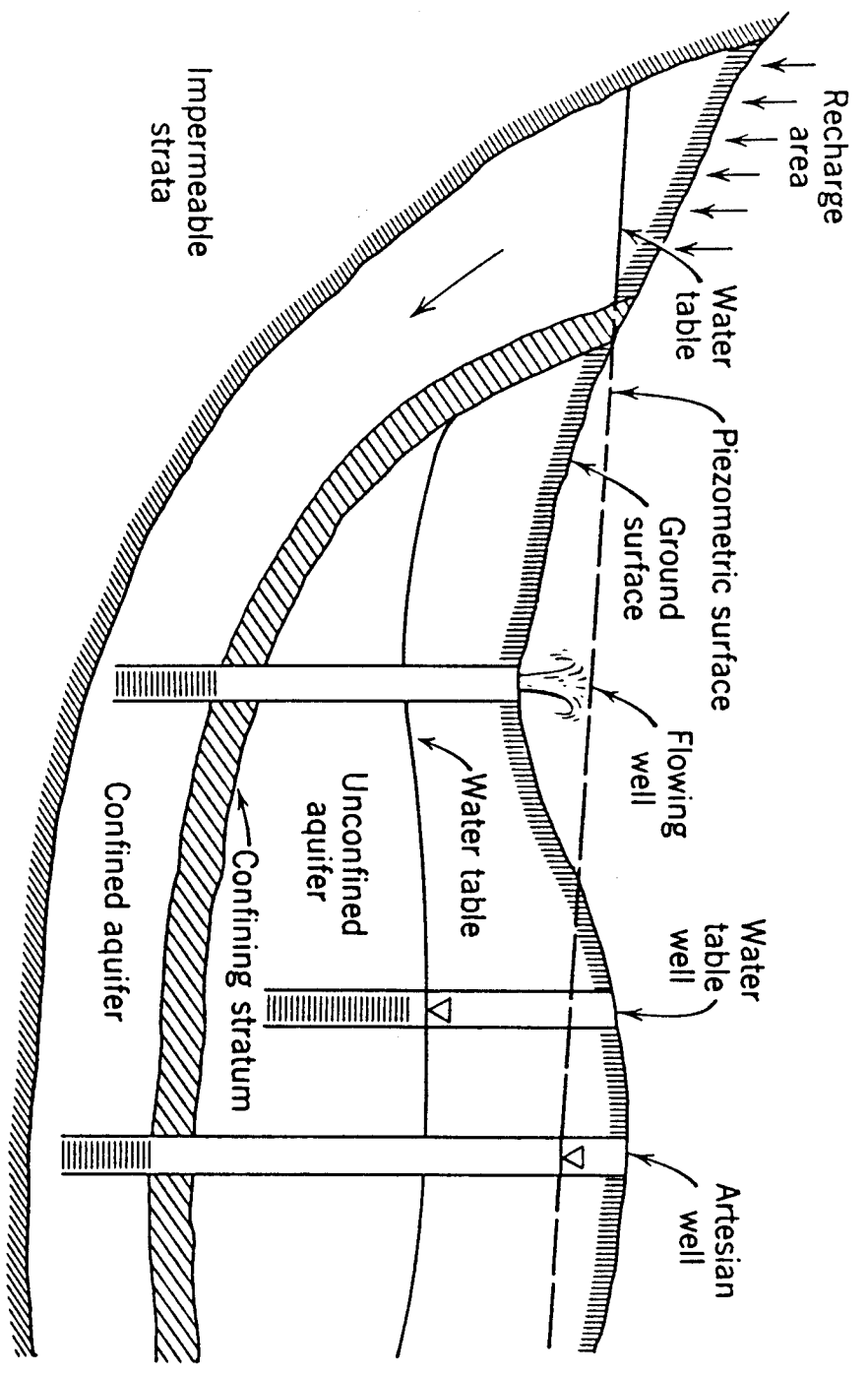


Fig. 2.11 Schematic cross section illustrating unconfined and confined aquifers.

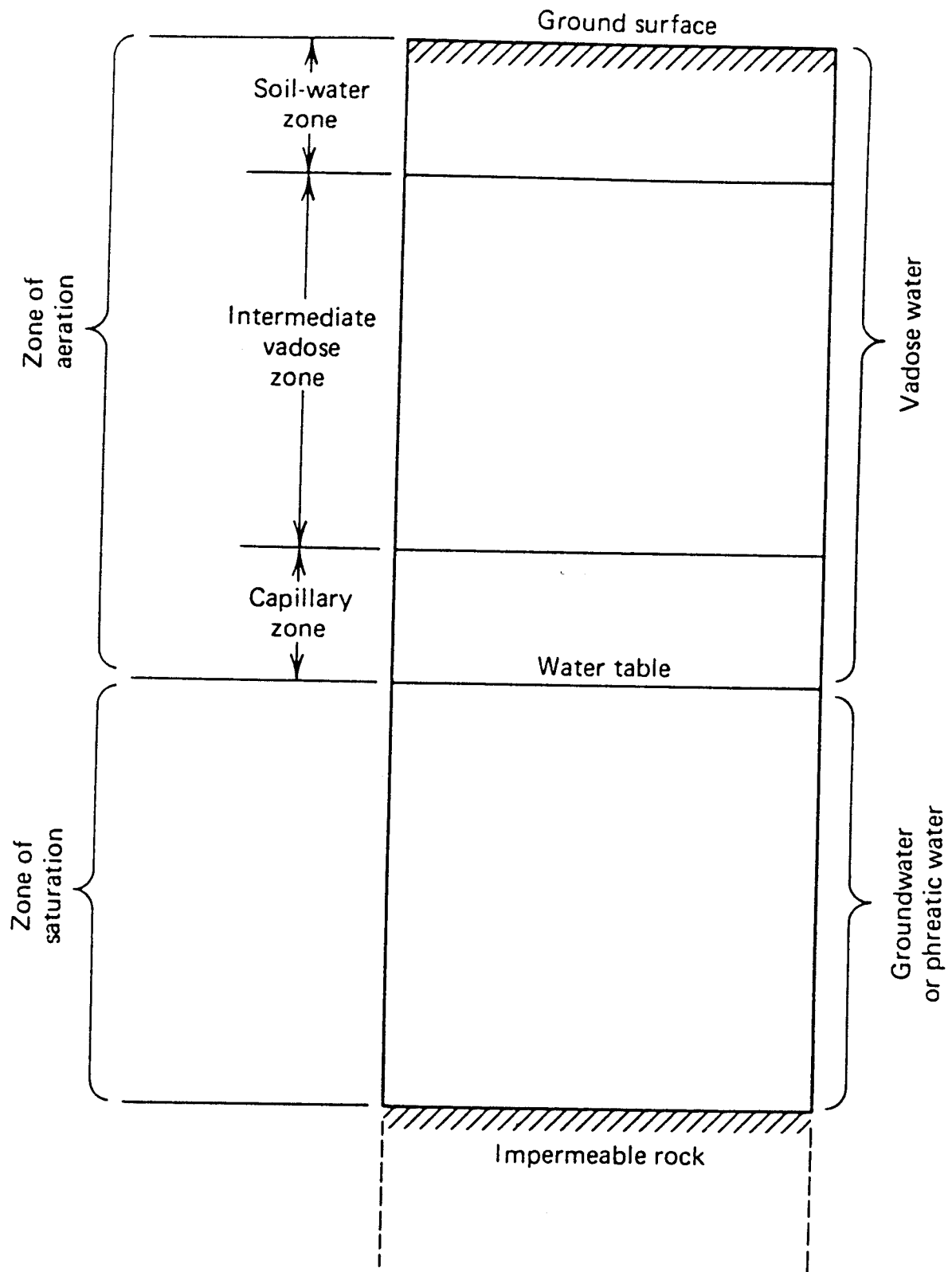
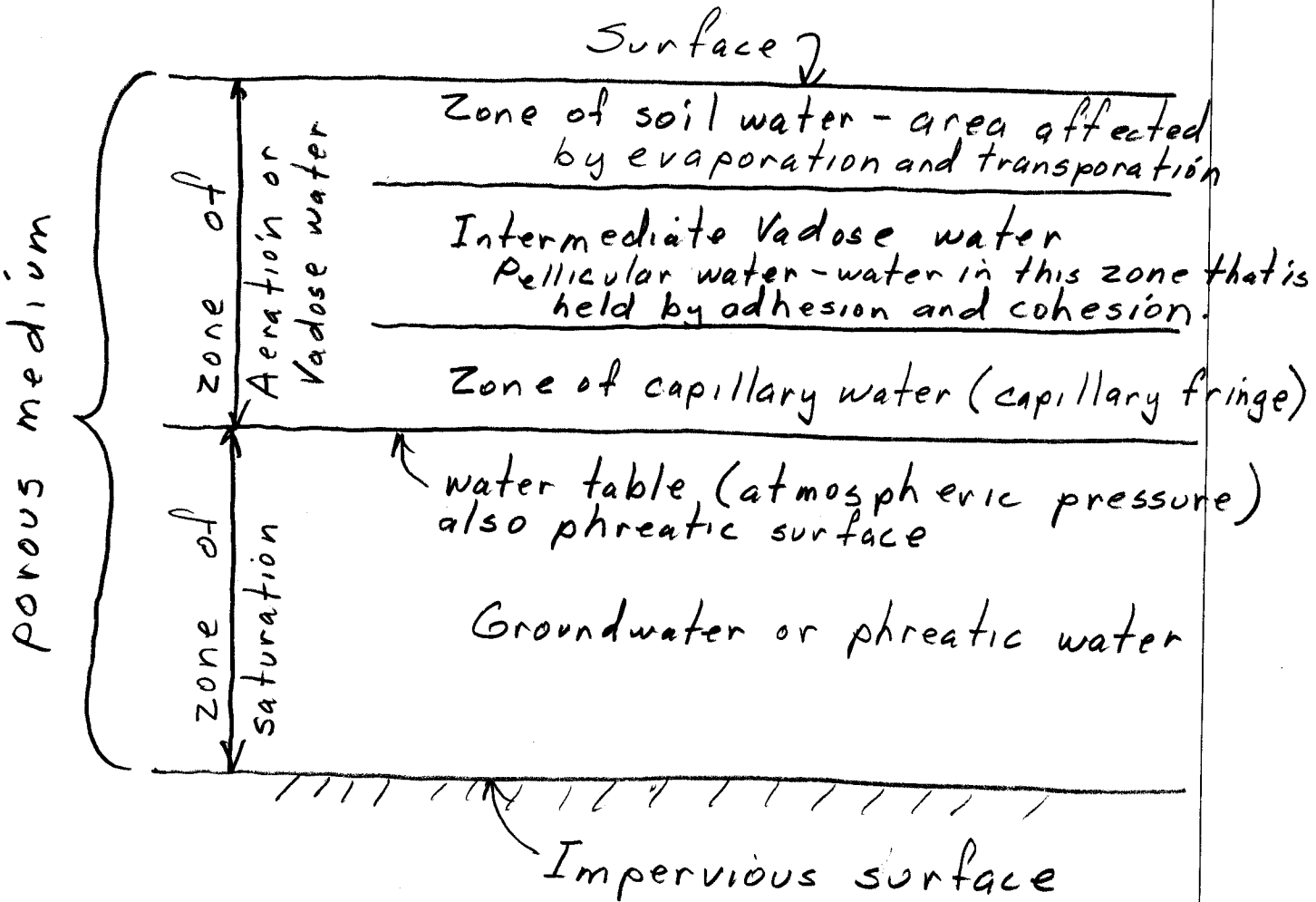


Fig. 2.5 Divisions of subsurface water.

Occurrence of Groundwater

Groundwater - that part of subsurface water that is below the level of saturation and under hydrostatic pressure.

42,381 50 SHEETS 3 SQUARE
42,382 100 SHEETS 3 SQUARE
42,383 200 SHEETS 3 SQUARE
42,384 300 SHEETS 3 SQUARE
NATIONAL
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Capillary Zone. The capillary zone (or capillary fringe) extends from the water table up to the limit of capillary rise of water. If a pore space could be idealized to represent a capillary tube, the capillary rise h_c (Fig. 2.7) can be derived from an equilibrium between surface tension of water and the weight of water raised. Thus,

$$h_c = \frac{2\tau}{r\gamma} \cos \lambda \quad (2.6)$$

where τ is surface tension, γ is the specific weight of water, r is the tube radius, and λ is the angle of contact between the meniscus

Capillary fringe - water is at pressure below atmospheric pressure. Water from this zone will not migrate to a well.

and the wall of the tube. For pure water in clean glass, $\lambda = 0$, and at 20°C $\tau = 0.074 \text{ g/cm}$ and $\gamma = 1 \text{ g/cm}^3$, so that the capillary rise approximates

$$h_c = \frac{0.15}{r} \quad (2.7)$$

It follows from Eq. 2.7 that the thickness of the capillary zone will vary inversely with the pore size of a soil or rock.

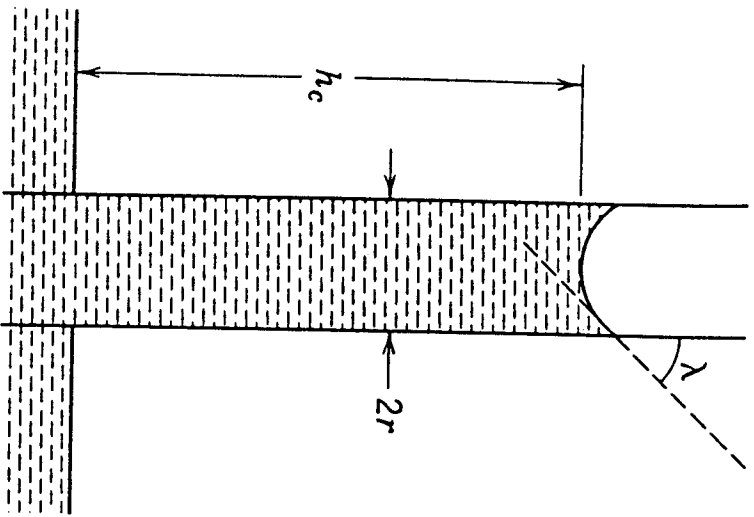


Fig. 2.7 Rise of water in a capillary tube.

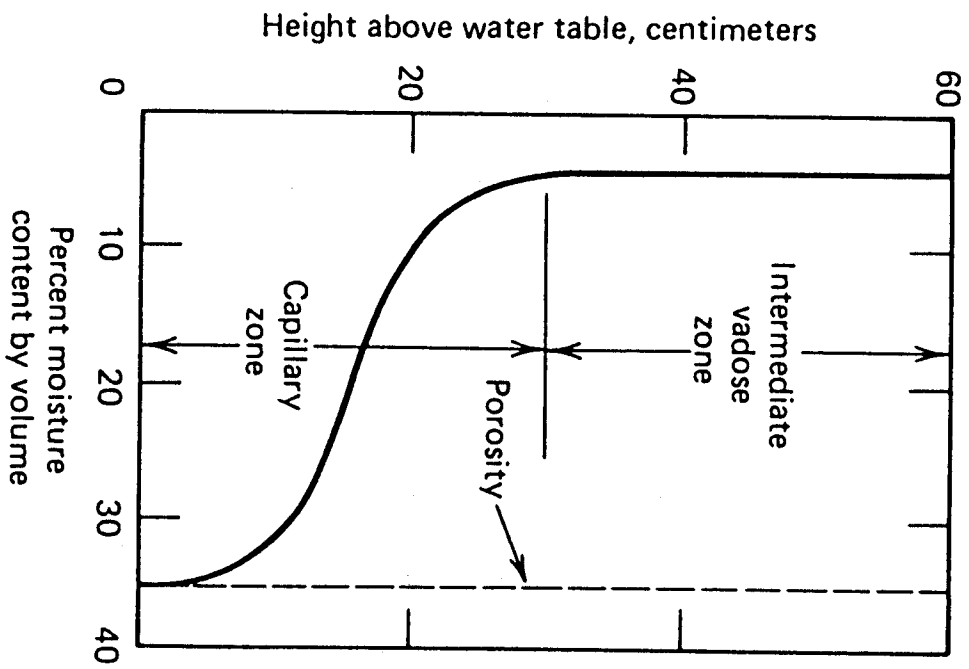


Fig. 2.8 Distribution of water in a coarse sand above the water table after drainage (after Prill³⁷).

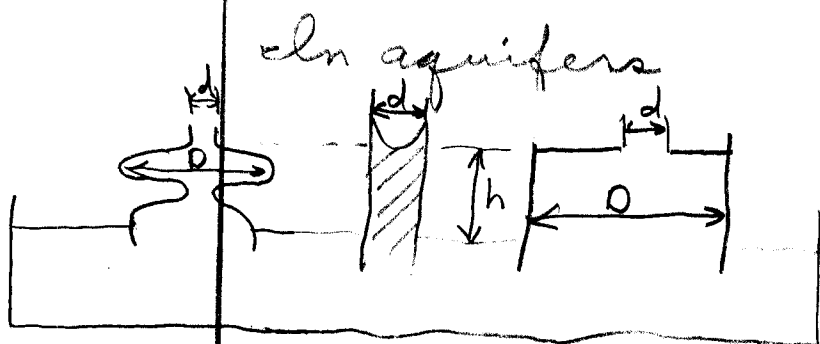
TABLE 2.4 Capillary Rise in Samples of Unconsolidated Materials (after Lohman²⁴)

Material	Grain Size, mm	Capillary Rise, cm
Fine gravel	5-2	2.5
Very coarse sand	2-1	6.5
Coarse sand	1-0.5	13.5
Medium sand	0.5-0.2	24.6
Fine sand	0.2-0.1	42.8
Silt	0.1-0.05	105.5
Silt	0.05-0.02	200 ^a

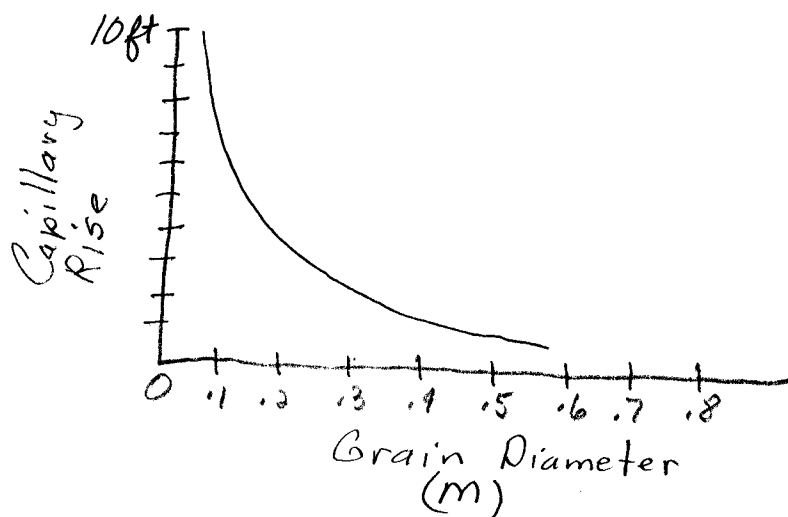
Sand on a beach is held by surface tension

NOTE: Capillary rise measured after 72 days; all samples have virtually the same porosity of 41 percent.

^aStill rising after 72 days.



first, water will not rise in the super cap. tube (because D is too large). But if the water table rises above h , the water will stay in the large tube because d is then controlling.



Neutron Probe for measuring the capillary rise in the ground. Fast neutrons are emitted. Hydrogen captures the fast neutrons and emit gamma rays. Relationship between neutrons emitted and the gamma rays received gives the limits of the capillary zone.

(see page 49 of Charbeneau text)

$$S_y = \text{Specific Yield} = \frac{\text{Vol. of water drained by gravity}}{\text{total rock volume}}$$

$$S_R = \text{Specific Retention} = \frac{\text{Vol. of water retained against gravity}}{\text{total rock volume}}$$

Specific Retention is water held by the adhesive and cohesive forces and this amount of water is constant.

Specific Yield is also constant

*

$$S_y + S_R = \text{Porosity } (n)$$

When grain sizes are large then S_y is large and (S_R is small) also,
when grain sizes are small then S_y is small and (S_R is large).

**TABLE 2.5 Representative Values
of Specific Yield (after Johnson 18)**

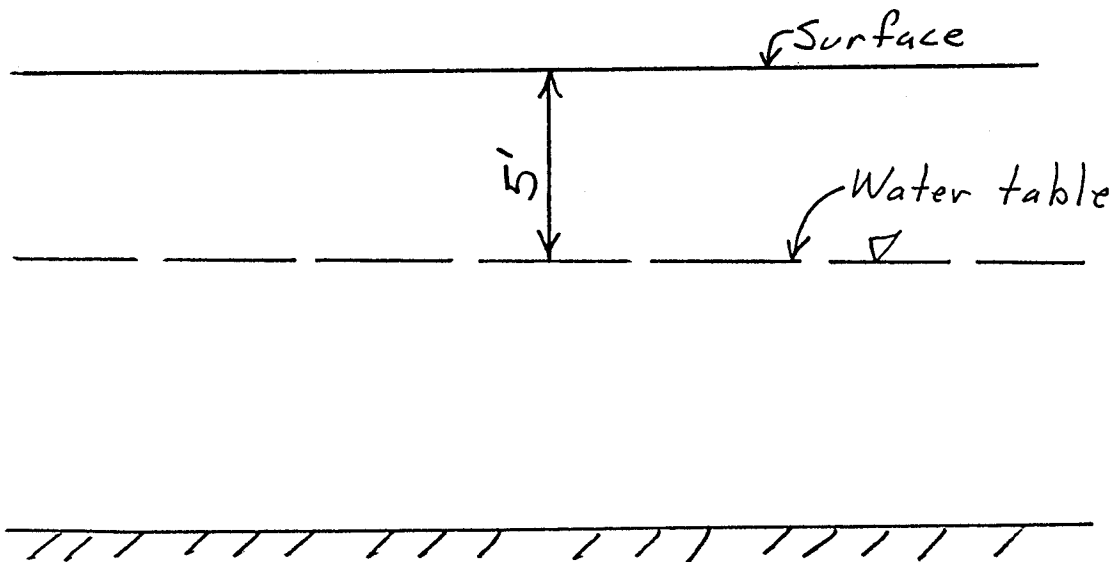
Material	Specific Yield, percent
Gravel, coarse	23
Gravel, medium	24
Gravel, fine	25
Sand, coarse	27
Sand, medium	28
Sand, fine	23
Silt	8
Clay	3
Sandstone, fine-grained	21
Sandstone, medium-grained	27
Limestone	14
Dune sand	38
Loess	18
Peat	44
Schist	26
Siltstone	12
Till, predominantly silt	6
Till, predominantly sand	16
Till, predominantly gravel	16
Tuff	21

*Good then
see notes*

Example

~~Problems 6-9 are 15 points each (Open Books and Notes).~~

~~4~~ An area has not had rainfall for a sufficiently long time so that it can be assumed that there is no bound water in the soil above the water table. The porous material has a porosity of 15% and a specific retention of 5%. If a uniform rainfall of 4 inches occurs, how much will the water table rise? Assume that there is no runoff (see sketch below). *Disregard capillary rise.*



~~TEST #1~~

7. ~~$$n = \frac{\text{volume of voids}}{\text{total volume}} = \frac{1^3}{2^3}$$~~

~~$$n = \frac{1}{8} = 12.5\% \text{ or } 12.5\%$$~~

Example

~~7.~~ specific retention = $\frac{\text{max. volume of water retained}}{\text{total volume}}$

$S_r = 5\% \text{ or } .05$ & $S_y = n - S_r = .10$

total volume = $5' \times 1' \times 1' = 5 \text{ ft}^3$

$.05 = \frac{\text{max. volume of water retained}}{5}$

max. volume of water retained = $.25 \text{ ft}^3$
= $3 \text{ in} \cdot \text{ft}^2$

Precipitation = 4 inches

- water retained = 3 inches

water available } 1 inch
to water table }

Water table rise = $1 \text{ in} / S_y$

= $1 / .10 = 10 \text{ inches}$

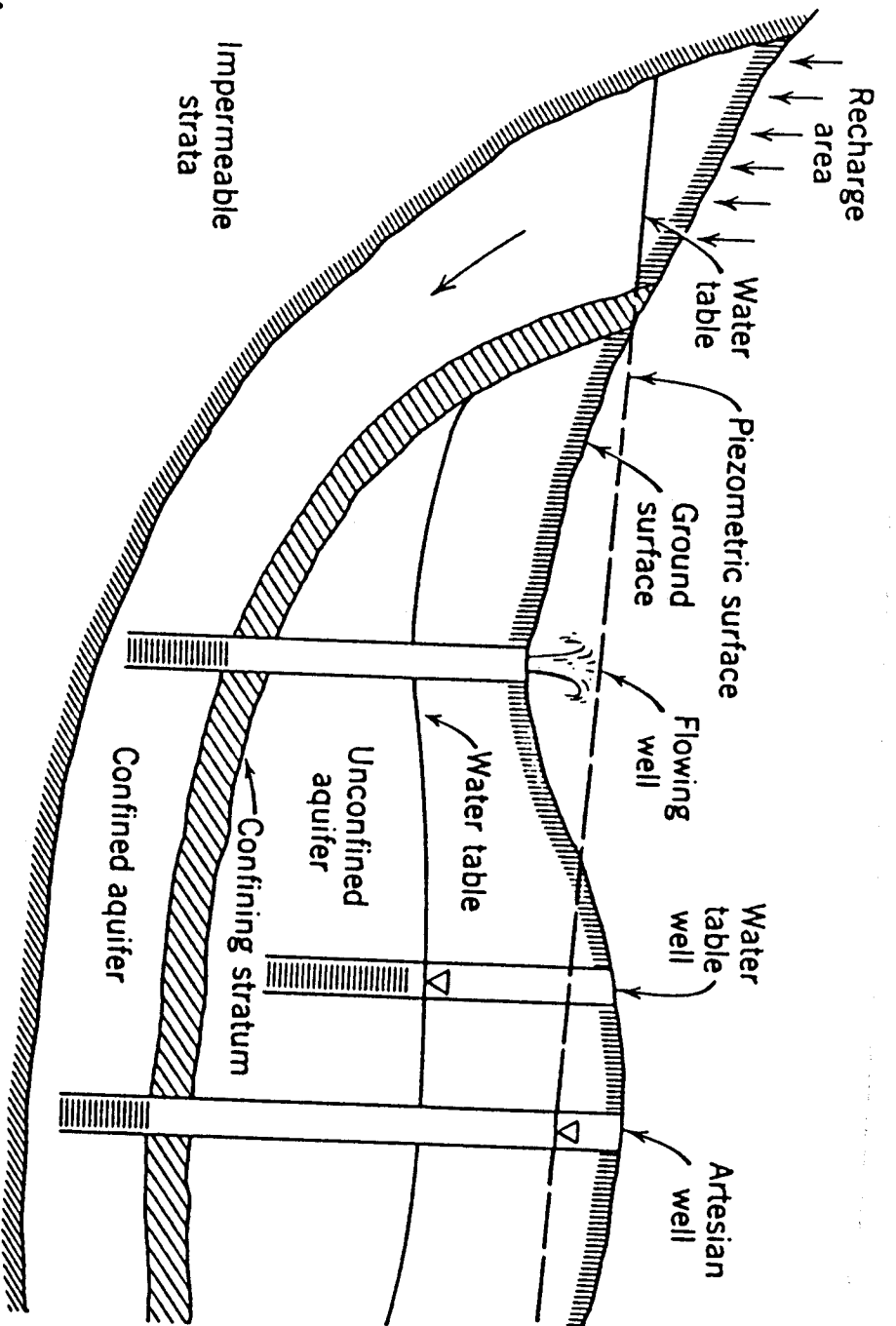


Fig. 2.11 Schematic cross section illustrating unconfined and confined aquifers.

Aquifers may be classed as unconfined or confined, depending on the presence or absence of a water table, while a leaky aquifer represents a combination of the two types.

Unconfined Aquifer. An unconfined aquifer is one in which a water table varies in undulating form and in slope, depending on areas of recharge and discharge, pumpage from wells, and permeability. Rises and falls in the water table correspond to changes in the volume of water in storage within an aquifer.

Confined Aquifers. Confined aquifers, also known as *artesian** or pressure aquifers, occur where groundwater is confined under pressure greater than atmospheric by overlying relatively impermeable strata. In a well penetrating such an aquifer, the water level will rise above the bottom of the confining bed, as shown by the artesian and flowing wells of Fig. 2.11.

A region supplying water to a confined aquifer is known as a recharge area; water may also enter by leakage through a confining bed (see below). Rises and falls of water in wells penetrating confined aquifers result primarily from changes in pressure rather than changes in storage volumes. Hence, confined aquifers display only small changes in storage and serve primarily as conduits for conveying water from recharge areas to locations of natural or artificial discharge.

The piezometric surface, or potentiometric surface, of a confined aquifer is an imaginary surface coinciding with the hydrostatic pressure level of the water in the aquifer (Fig. 2.11). The water level in a well penetrating a confined aquifer defines the elevation of the piezometric surface at that point. Should the piezometric surface lie above ground surface, a flowing well results. Contour maps and profiles of the piezometric surface can be prepared from well data similar to those for the water table in an unconfined aquifer. It should be noted that a confined aquifer becomes an unconfined aquifer when the piezometric surface falls below the bottom of the upper confining bed. Also, quite commonly an unconfined aquifer exists above a confined one, as shown in Fig. 2.11.

Leaky Aquifer. Aquifers that are completely confined or unconfined occur less frequently than do leaky, or semiconfined, aquifers.

L-4

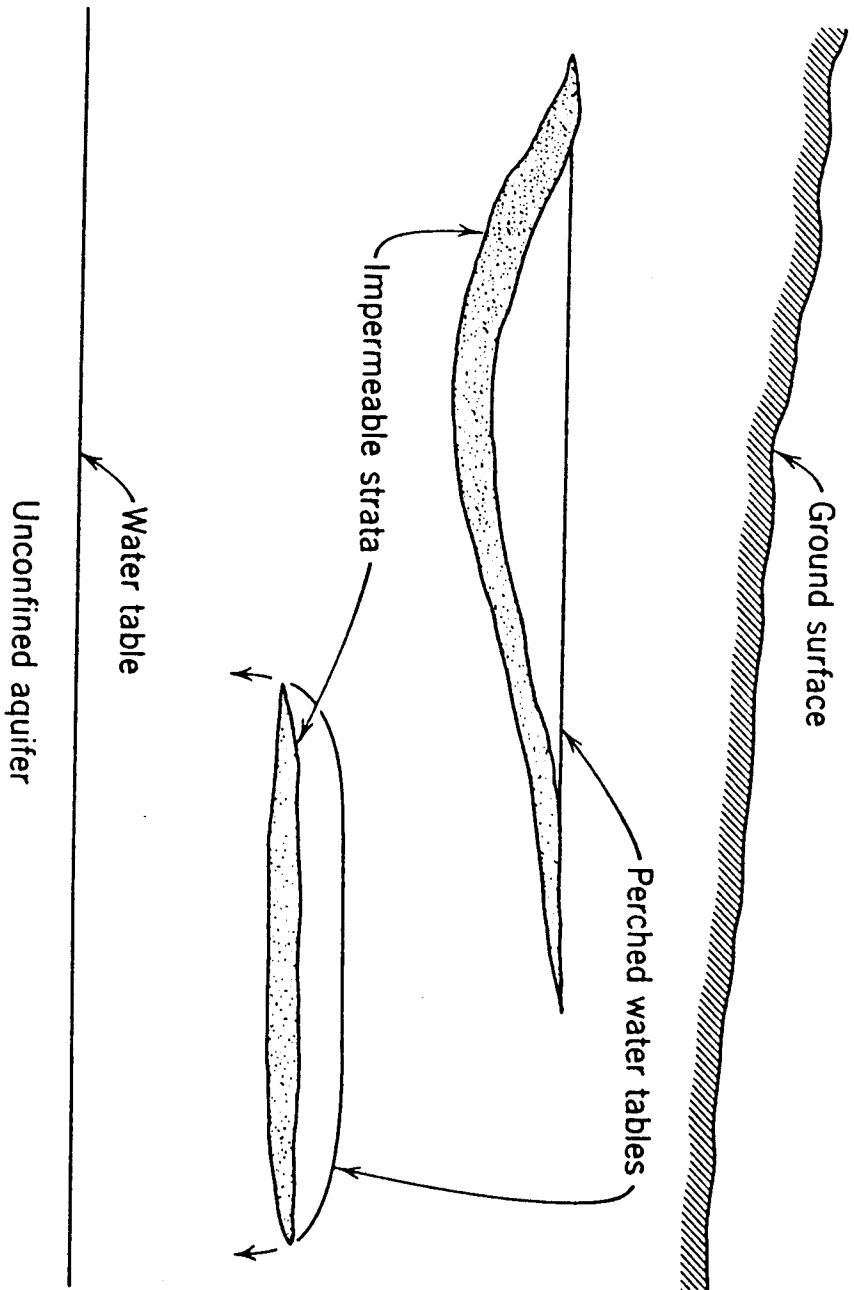


Fig. 2.12 Sketch of perched water tables.

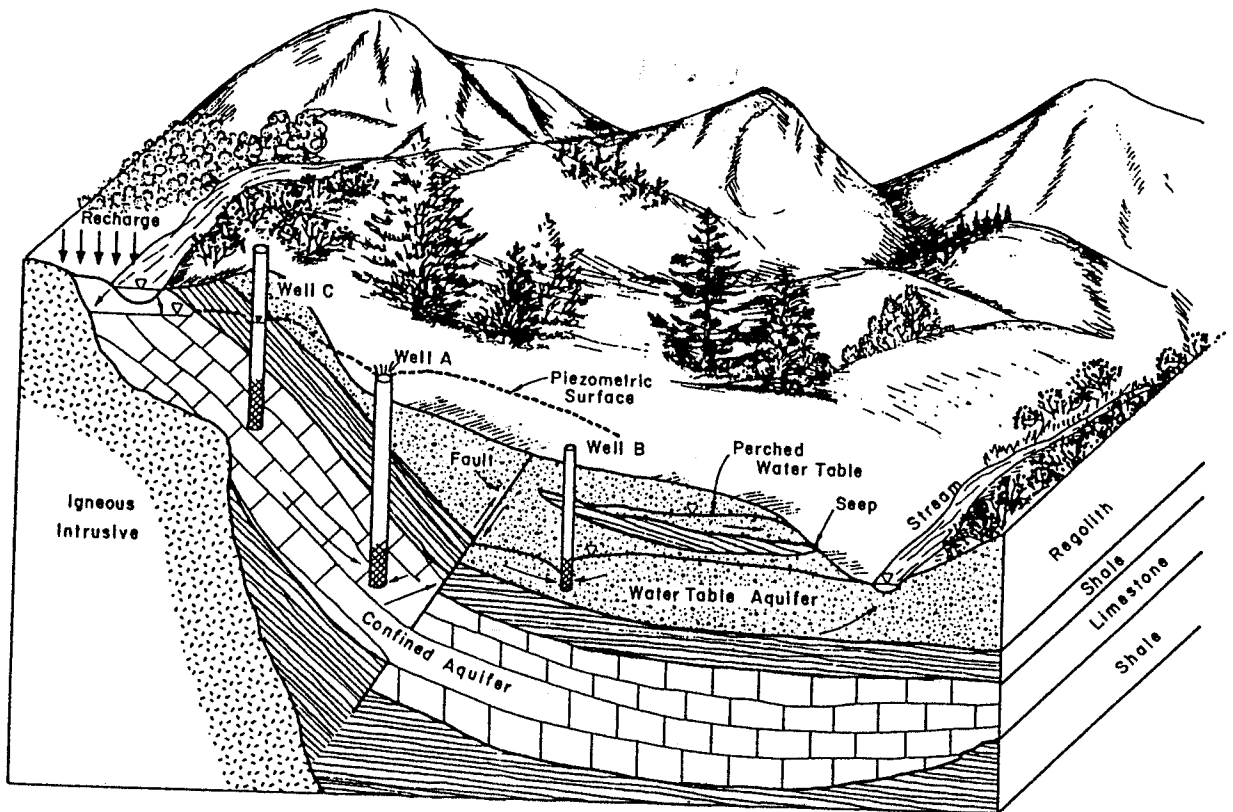


Figure 1-4. Example of ground-water occurrence.

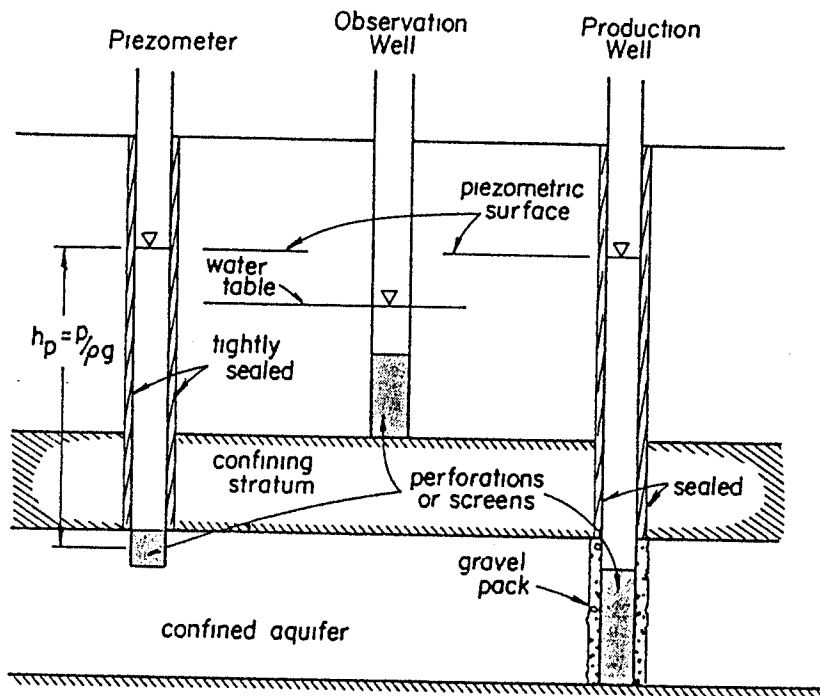


Figure 1-5. Common facilities for observing water levels in aquifers.

L-4

A piezometer is a device which indicates the water-pressure head h_p at a "point" in the aquifer (Fig. 1-5). The piezometer consists of a casing, perforated near the terminal point only, that is installed in such a way that the casing fits tightly against the geologic formation. A common method of installation is to place the casing in a drilled hole, backfilling the annulus between the casing and the wall of the bore hole with clay. The height to which water rises in the piezometer is the water-pressure head at the terminal point of the piezometer.

The observation well of Fig. 1-5 is a perforated casing simply placed in a bore hole with no attempt to provide a seal between the casing and the aquifer. In the case shown, the observation well properly indicates the water table position. Should the observation well penetrate into the underlying confined aquifer, however, the observed water level would be meaningless. This is true because the water level would reflect neither the water table nor the piezometric surface elevation, but a combination of the two since the well bore provides a flow conduit between the two aquifers.

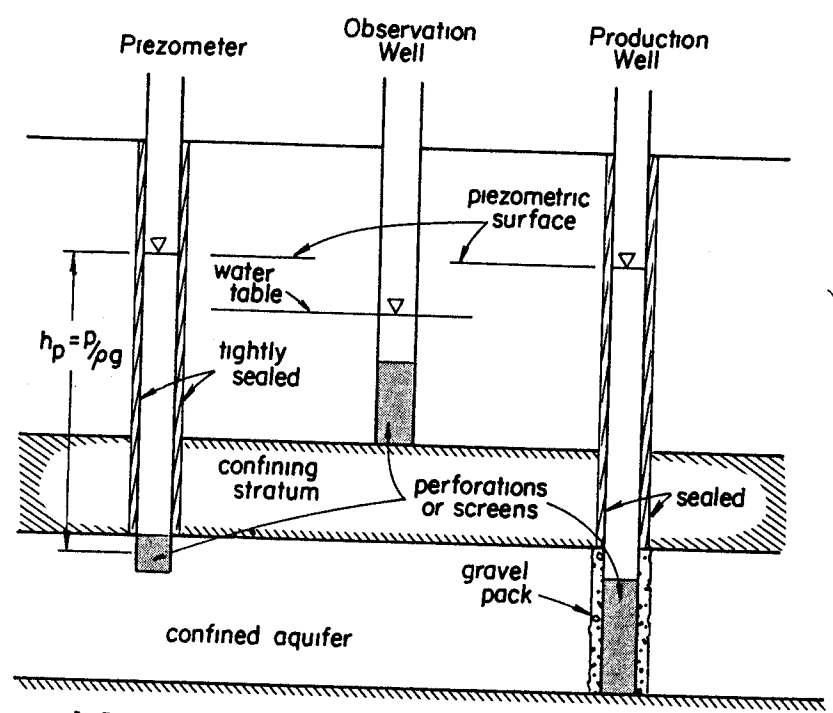
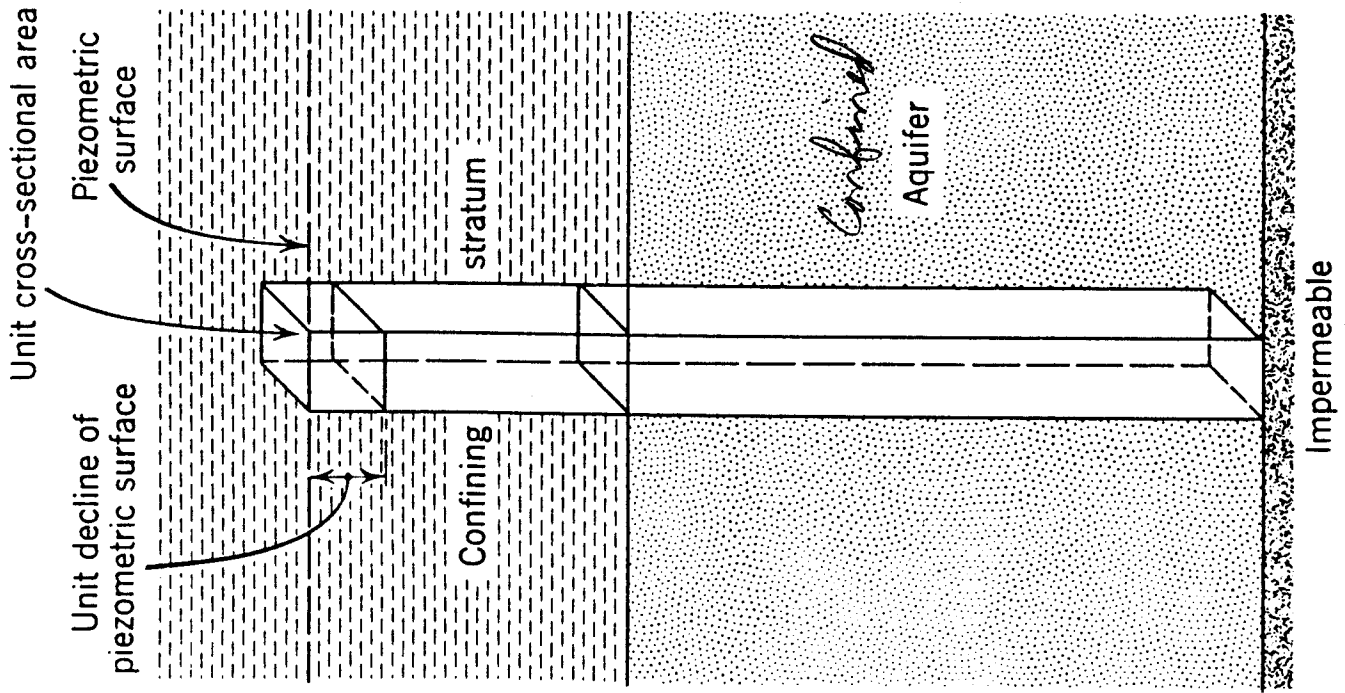


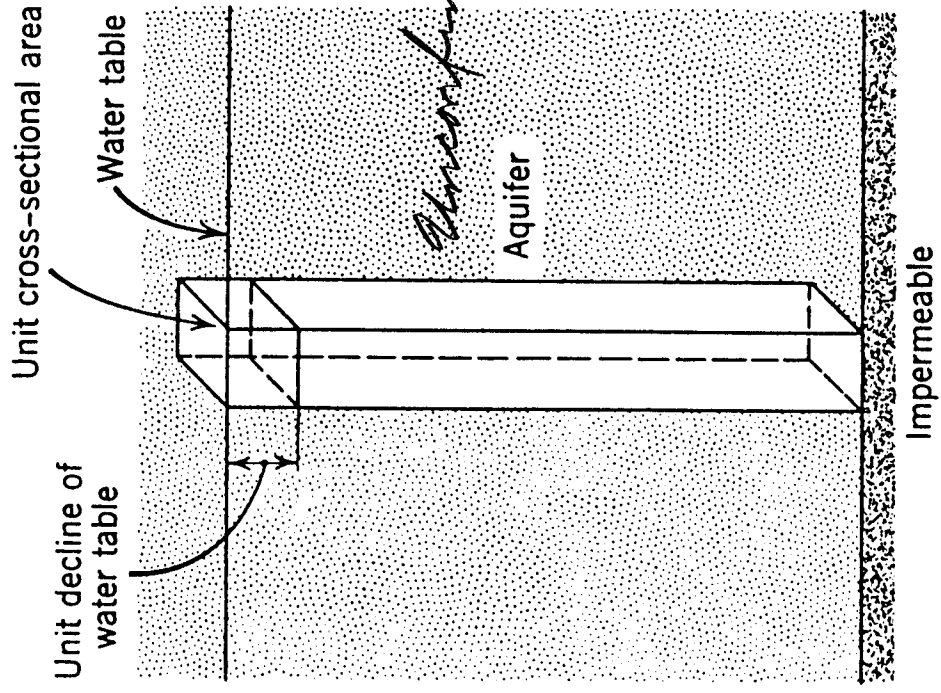
Figure 1-5. Common facilities for observing water levels in aquifers.

The production well on the right side of Figure 1-5 can function as an observation well in the confined aquifer, because the annulus is sealed in the confining layer. The production well is not a piezometer, strictly speaking, because the well screen extends over an appreciable fraction of the aquifer. Thus, the water level indicates an average water-pressure head over the screened interval. The water levels in the production well and in the piezometer will be identical only under special conditions, one of which is no flow of water in the aquifer.

Read Chapter 3

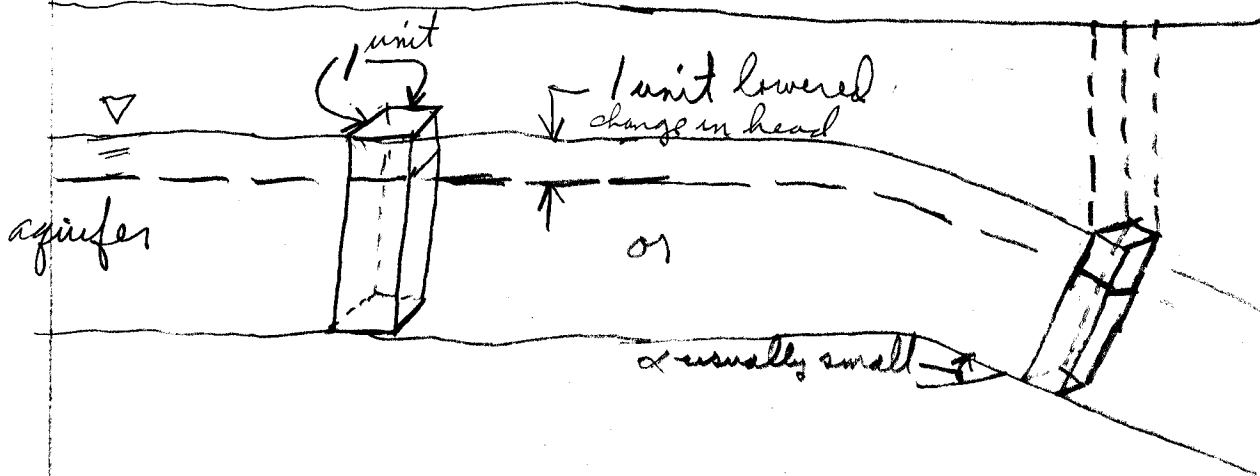


(a)



(b)

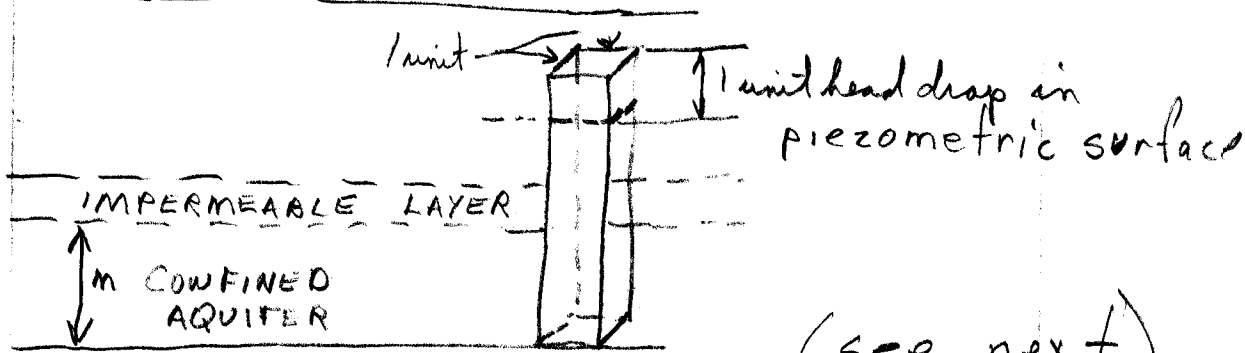
WATER TABLE AQUIFER (UNCONFINED)



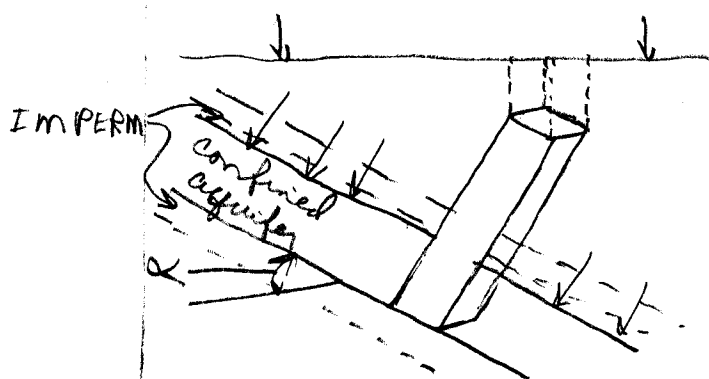
S = storage coefficient = is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head normal to that surface.

note { The storage coefficient for an unconfined aquifer corresponds to its specific yield.

Confined Aquifer



(see next page)



Values of coefficient of Storage

$$S = 0.00005 \text{ to } 0.005 \left\{ \begin{array}{l} \text{Confined} \\ \text{aquifer} \end{array} \right.$$

$$S = 0.05 \text{ to } 0.30 \left\{ \begin{array}{l} \text{water table or} \\ \text{unconfined} \\ \text{aquifer} \end{array} \right.$$

2.2 STORAGE IN CONFINED AQUIFERS

Confined aquifers, by definition, remain completely saturated. Water released from storage in a confined aquifer is not, therefore, derived from drainage of the voids as is the case in unconfined aquifers. In confined aquifers water is released or taken into storage as the result of changes in pore volume due to aquifer compressibility and changes in water density associated with a change in pore-water pressure. The capacity of confined aquifers to release water from storage is markedly different from that for unconfined aquifers, therefore.