SAND2008-3715P

Groundwater Flow and Transport Class:

Introduction to General Hydrogeology

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,
for the United States Department of Energy's National Nuclear Security Administration
under contract DE-AC04-94AL85000.

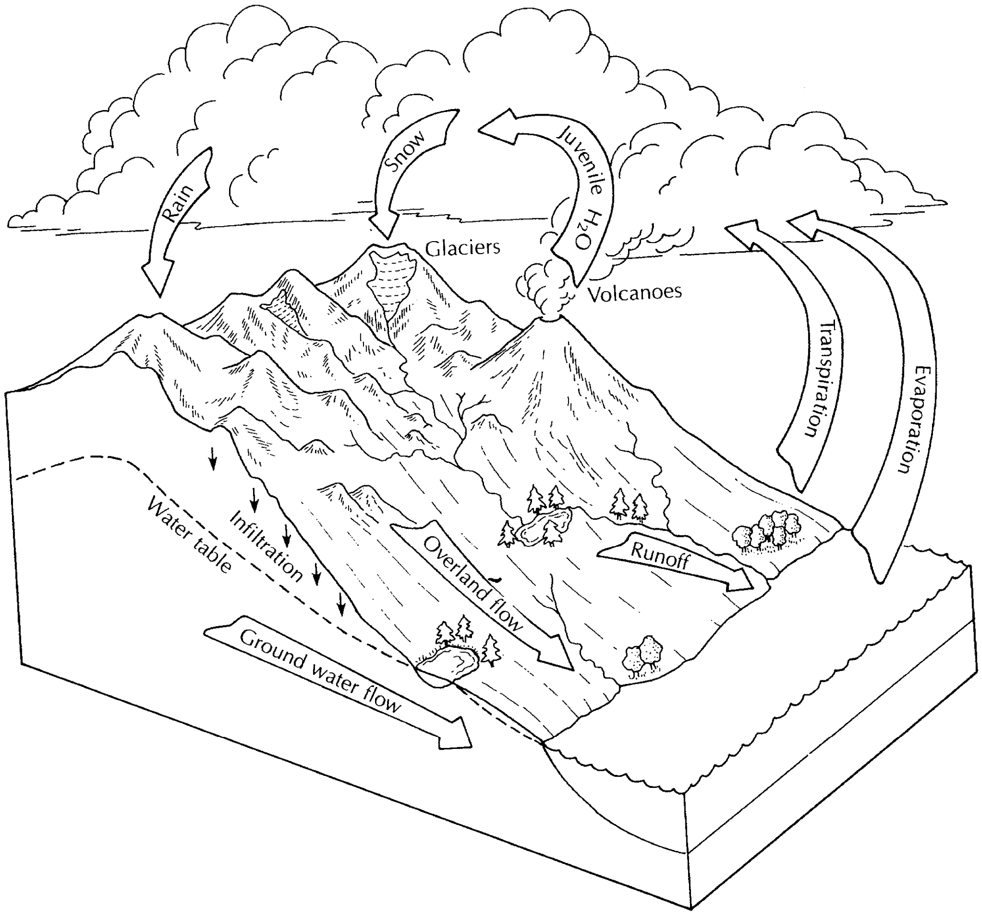
Welcome

- Introduction of instructors and students
- Introduction to Sandia National Laboratories
- Orientation to facilities
- Groundrules for visitors to Sandia National Laboratories
- Discussion of professional roles and responsibilities of students in Iraq
- Discussion of objectives for class

Objectives

- Provide an overview of the major principles of groundwater flow and groundwater flow systems
- Present the mathematical basis for quantifying groundwater flow and well hydraulics
- Introduce the concepts of groundwater contamination and the processes of contaminant transport in groundwater
- Provide technical background for well construction, groundwater monitoring, and groundwater sampling
- Provide an overview of radionuclide sources, contamination, and transport processes in groundwater
- Discuss real-world applications of hydrogeologic principles of flow and transport to radionuclide contamination of groundwater

Water Cycle



Rain
Snow
Juvenile H_2O
Glaciers
Volcanoes
Transpiration
Evaporation
Water table
Infiltration
Overland flow
Runoff
Ground water flow

Water Cycle

Parameter	Surface area $(km^2) \times 10^6$	Volume $(km^3) \times 10^6$	Volume (%)	Equivalent depth (m)*	Residence time
Oceans and seas	361	1370	94	2500	~4000 years
Lakes and reservoirs	1.55	0.13	<0.01	0.25	~10 years
Swamps	<0.1	<0.01	<0.01	0.007	1–10 years
River channels	<0.1	<0.01	<0.01	0.003	~2 weeks
Soil moisture	130	0.07	<0.01	0.13	2 weeks–1 year
Groundwater	130	60	4	120	2 weeks–10,000 years
Icecaps and glaciers	17.8	30	2	60	10–1000 years
Atmospheric water	504	0.01	<0.01	0.025	~10 days
Biospheric water	<0.1	<0.01	<0.01	0.001	~1 week

SOURCE: Nace, 1971.

*Computed as though storage were uniformly distributed over the entire surface of the earth.

Groundwater as a Resource

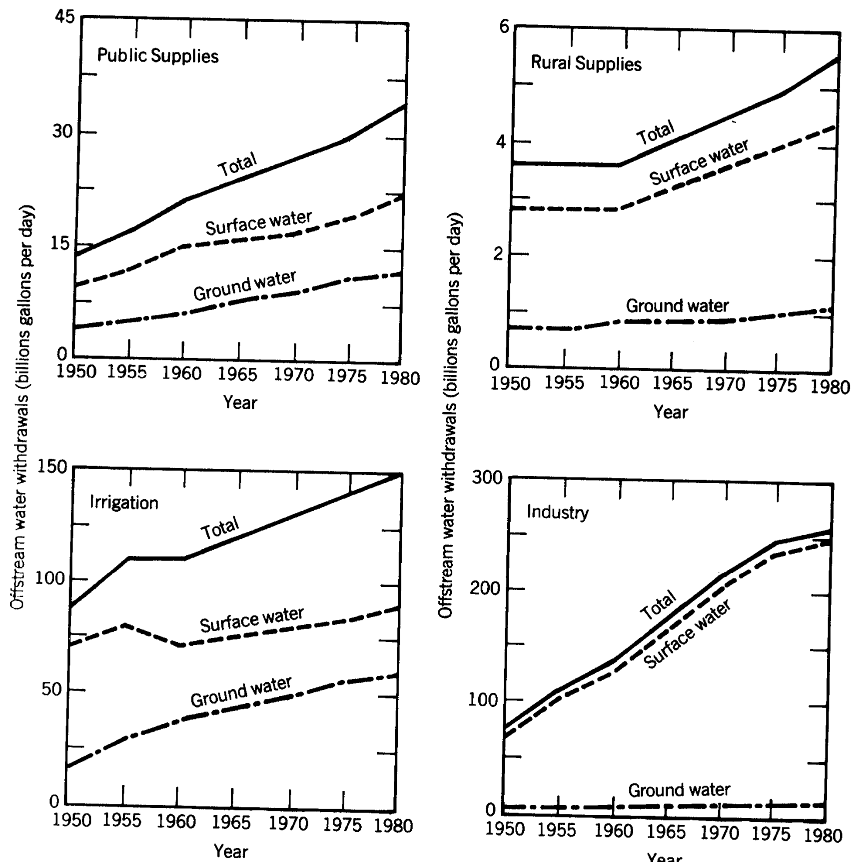


Figure 6.3
Trends in water withdrawals for public supplies, rural supplies, irrigation, and self-supplied industry. 1950–1980 (from Solley and others, 1983).

Groundwater as a Resource

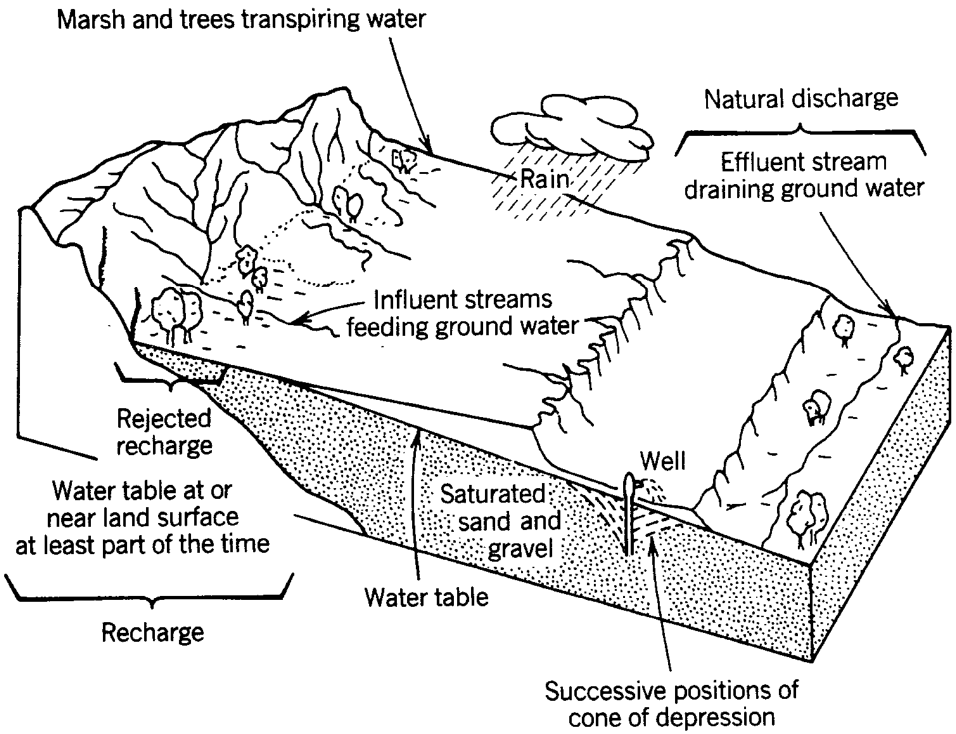


Figure 6.1
Factors controlling the response of a ground water basin to discharge by wells (from Theis, 1940). Reprinted with permission of The American Society of Civil Engineers.

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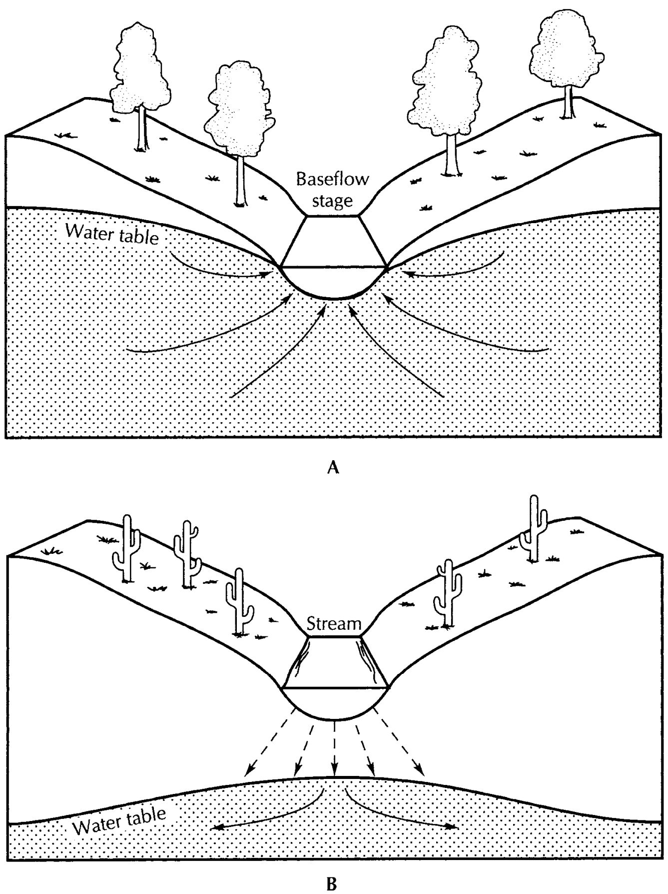
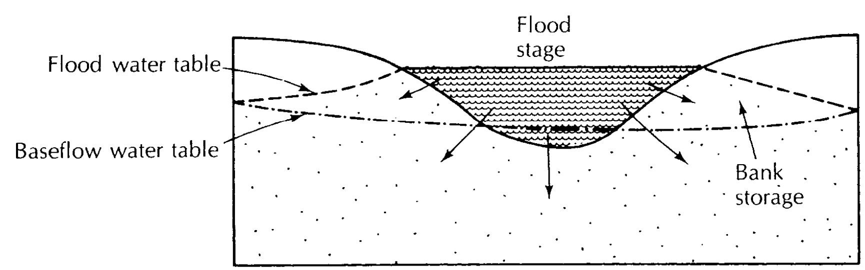
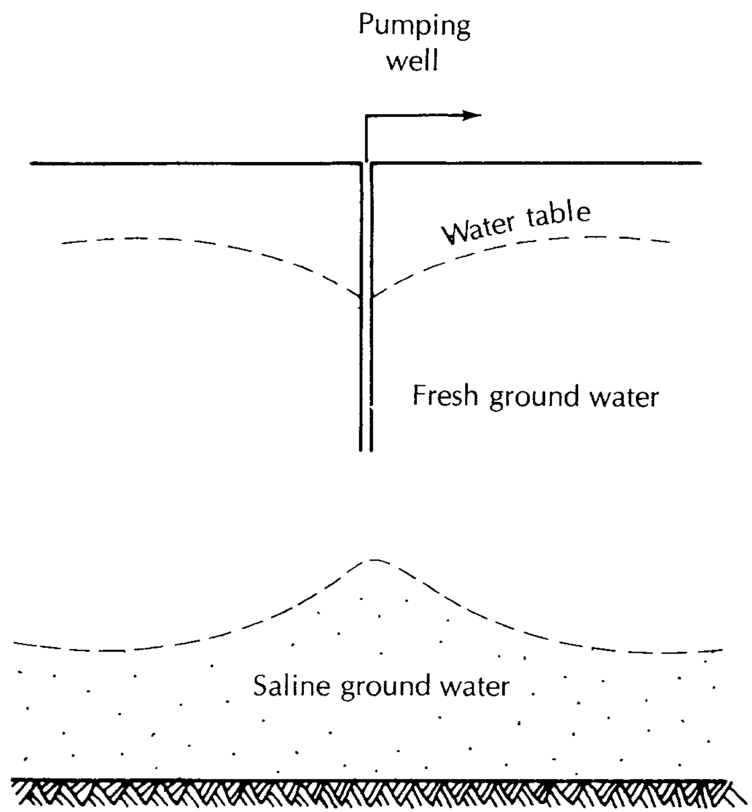
Groundwater as a Resource





Groundwater as a Resource

- **Limitations on groundwater utilization as a resource:**
  - **Storage capacity of the groundwater system**
  - **Slow recharge of the system**
  - **Degradation of water quality with continued extraction**
  - **Interaction with surface water resources (stream and spring flow)**
  - **Subsidence**



Groundwater as a Resource

- Qanats developed as a method of groundwater extraction in ancient Persia
- Energy saving technology for accessing groundwater resource is still used in Middle East and Central Asia

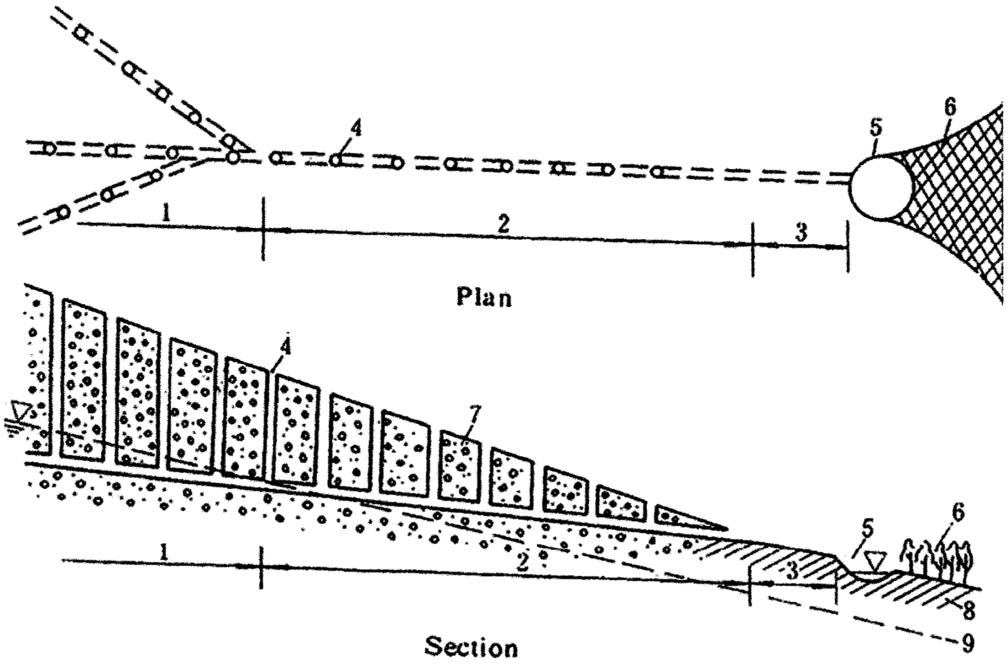
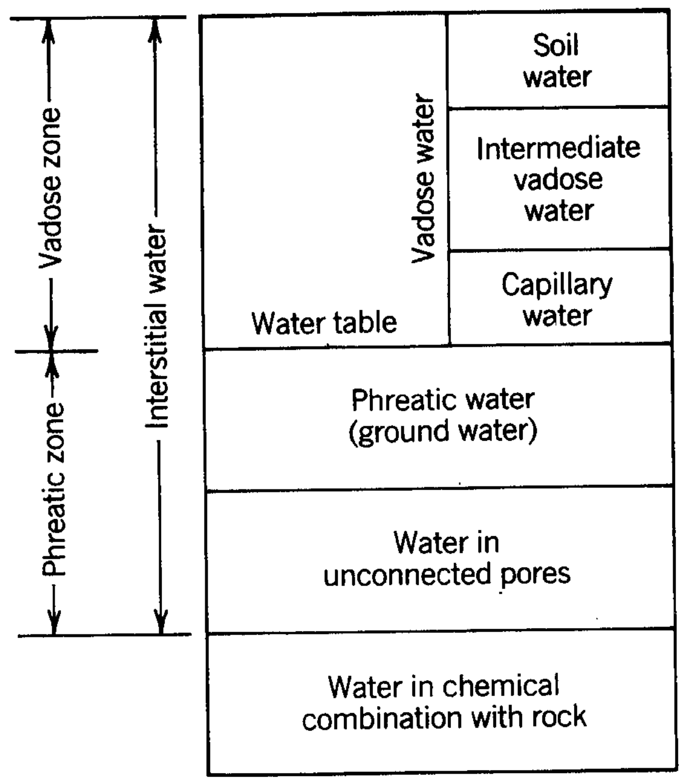


Figure 1. General Schematic for a Qanat.

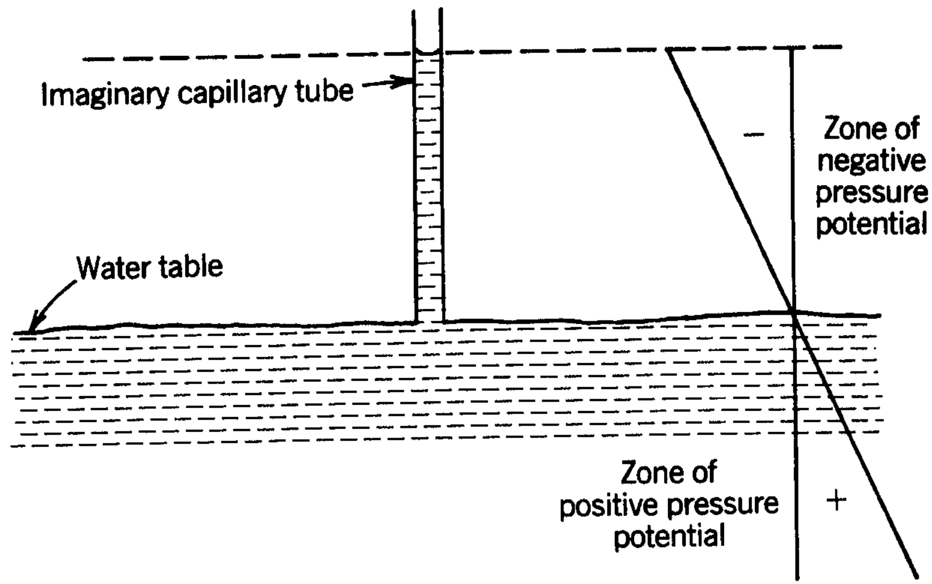
Groundwater Regimes

- Water movement is primarily vertical in the vadose zone
- Thickness of the vadose zone varies considerably depending on climate and location in the groundwater flow system
- Groundwater flow in the phreatic zone tends to be primarily horizontal in high-permeability layers and vertical in low-permeability layers



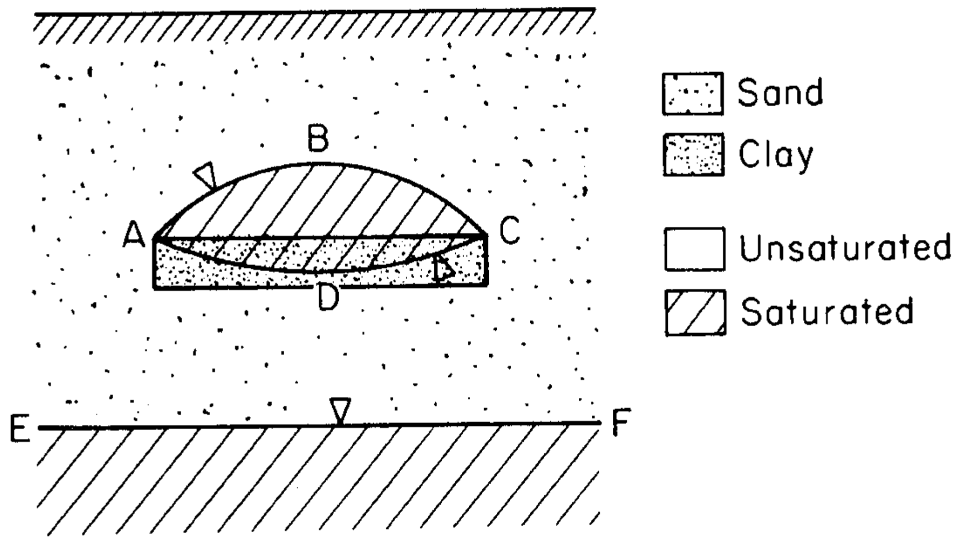
Groundwater Regimes

- Capillary suction causes saturation of above the water table
- Groundwater movement in the vadose zone tends to be dominated by capillary forces
- Groundwater movement below the water table is dominated by viscous forces



Groundwater Regimes

- Local or isolated liquid saturation in the vadose zone is referred to as "perched water"
- Perched water occurs wherever the downward percolation rate exceeds the hydraulic conductivity of the medium



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Darcy's Law

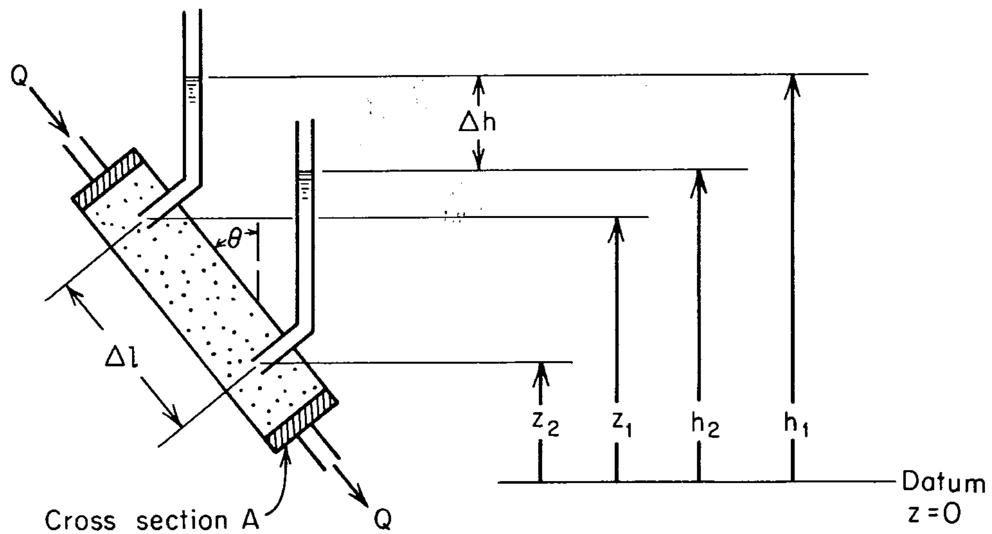

Figure 2.1 Experimental apparatus for the illustration of Darcy's law.

Darcy's Law

$$Q = KA\frac{\Delta h}{\Delta l}$$

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$$q = K\frac{\Delta h}{\Delta l}$$

Q = volumetric flow rate
q = specific discharge
K = hydraulic conductivity

Hydraulic Properties

$$K = k\frac{\rho \cdot g}{\mu}$$

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$$T = b \cdot K$$

k = intrinsic permeability
ρ = density of water
g = acceleration of gravity
μ = dynamic viscosity of water
T = aquifer transmissivity
b = aquifer thickness

Hydraulic Properties

$$S_s = \rho \cdot g(\alpha + n\beta)$$

$$S_y \approx n$$

$$S = b \cdot S_s$$

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S_s = specific storage (confined aquifer)

S_y = specific yield (unconfined aquifer)

S = storativity of a confined aquifer

α = compressibility of the aquifer

β = compressibility of water

Properties of Geologic Media

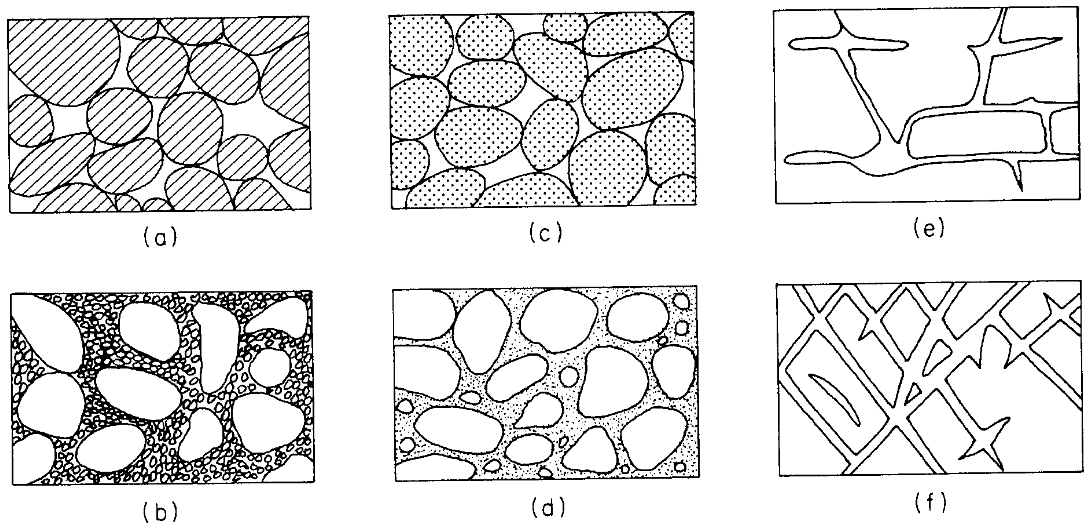


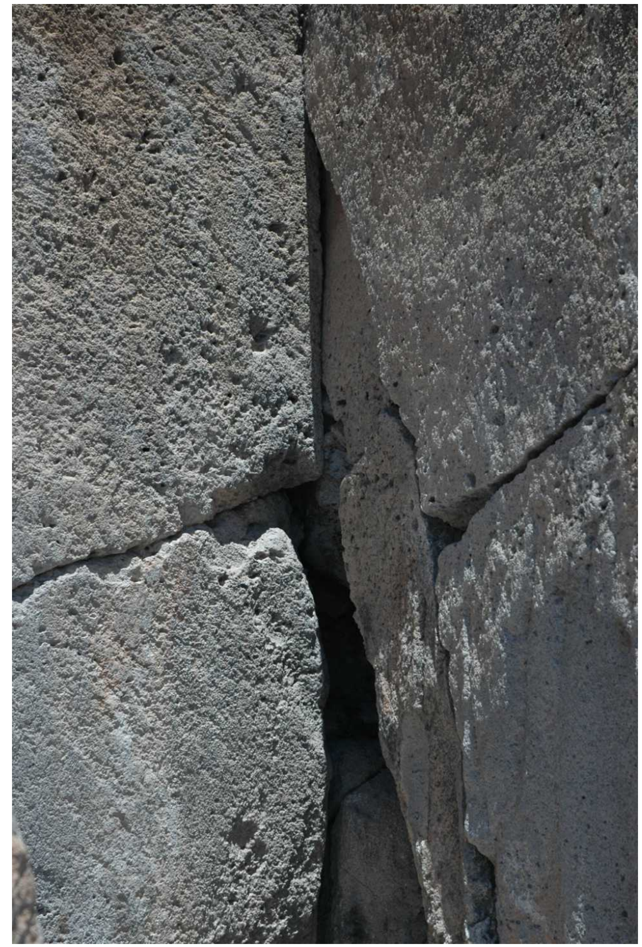
Figure 2.11 Relation between texture and porosity. (a) Well-sorted sedimentary deposit having high porosity; (b) poorly sorted sedimentary deposit having low porosity; (c) well-sorted sedimentary deposit consisting of pebbles that are themselves porous, so that the deposit as a whole has a very high porosity; (d) well-sorted sedimentary deposit whose porosity has been diminished by the deposition of mineral matter in the interstices; (e) rock rendered porous by solution; (f) rock rendered porous by fracturing (after Meinzer, 1923).

Properties of Geologic Media

Porous Media

Properties of Geologic Media

Fractured Media



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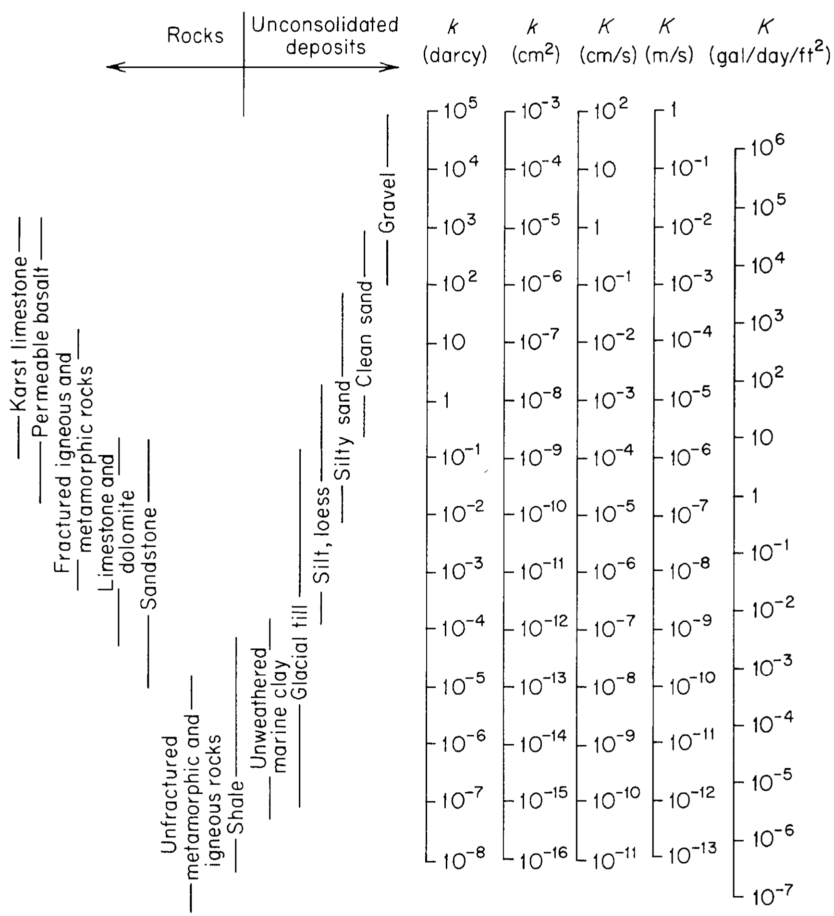
Properties of Geologic Media

Table 2.2 Range of Values of Hydraulic Conductivity and Permeability



Properties of Geologic Media

- **Porosity indicates the groundwater content under saturated conditions**
- **“Effective porosity” is defined as the porosity accessible by significant groundwater flow and is less than total porosity**
- **Groundwater velocity is inversely proportional to effective porosity of the medium**

Table 2.4 Range of Values of Porosity

	n(%)
Unconsolidated deposits	
Gravel	25–40
Sand	25–50
Silt	35–50
Clay	40–70
Rocks	
Fractured basalt	5–50
Karst limestone	5–50
Sandstone	5–30
Limestone, dolomite	0–20
Shale	0–10
Fractured crystalline rock	0–10
Dense crystalline rock	0–5

Properties of Geologic Media

- Geologic materials differ from engineered materials because they are typically highly heterogeneous and anisotropic
- Layered sedimentary geologic media usually have significant vertical anisotropy, with vertical hydraulic conductivity much less than horizontal hydraulic conductivity
- Groundwater flow direction is influenced by anisotropy in hydraulic conductivity

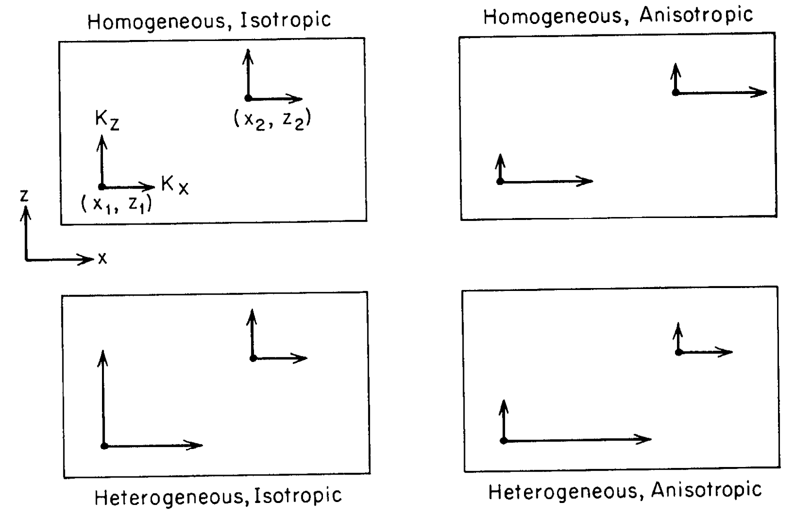


Figure 2.8 Four possible combinations of heterogeneity and anisotropy.

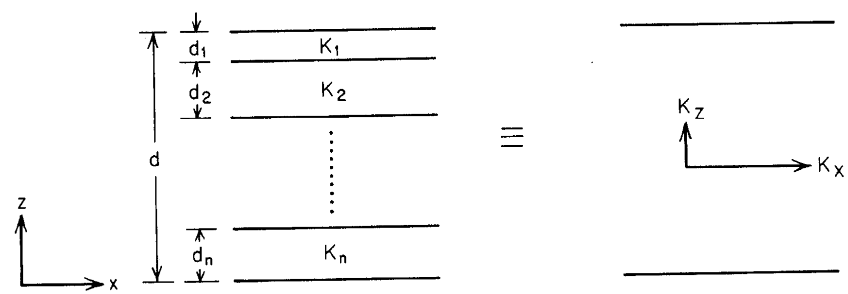


Figure 2.9 Relation between layered heterogeneity and anisotropy.

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Properties of Geologic Media

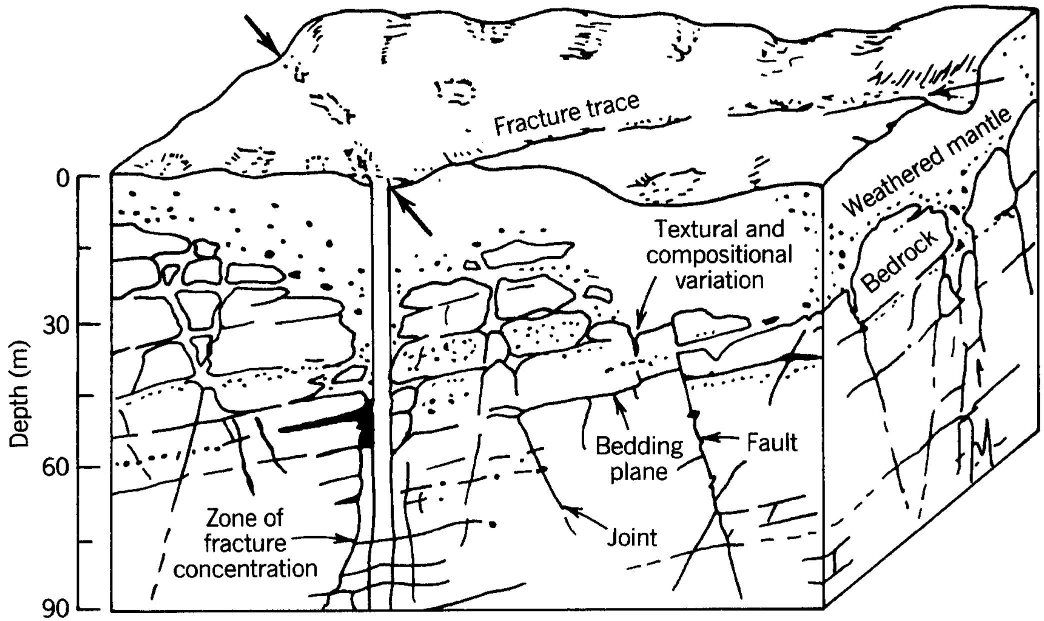


Figure 2.3
Occurrence of permeability zones in fractured carbonate rock. Highest well yields occur in fracture intersection zones (from Lattman and Parizek, 1964). Reprinted with permission of Elsevier Science Publishers, from J. Hydrol., v. 2, p. 73–91.

Properties of Geologic Media

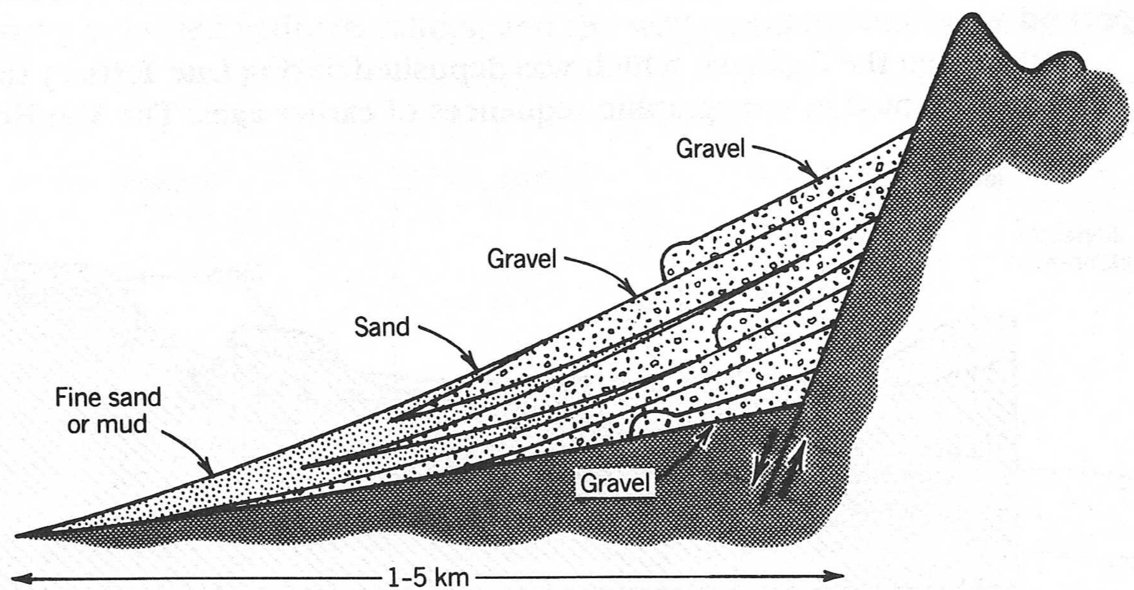


Figure 2.8
Diagrammatic cross section of an alluvial fan (from Rust and Koster, 1984). Reprinted with permission of the Geol. Assoc. of Canada.

Properties of Geologic Media

- **Geometric structure of sedimentary geologic material is often determined by its depositional environment**
- **Understanding the continuity and structure of hydraulic conductivity in an aquifer may be critical to predicting groundwater movement and contaminant migration**

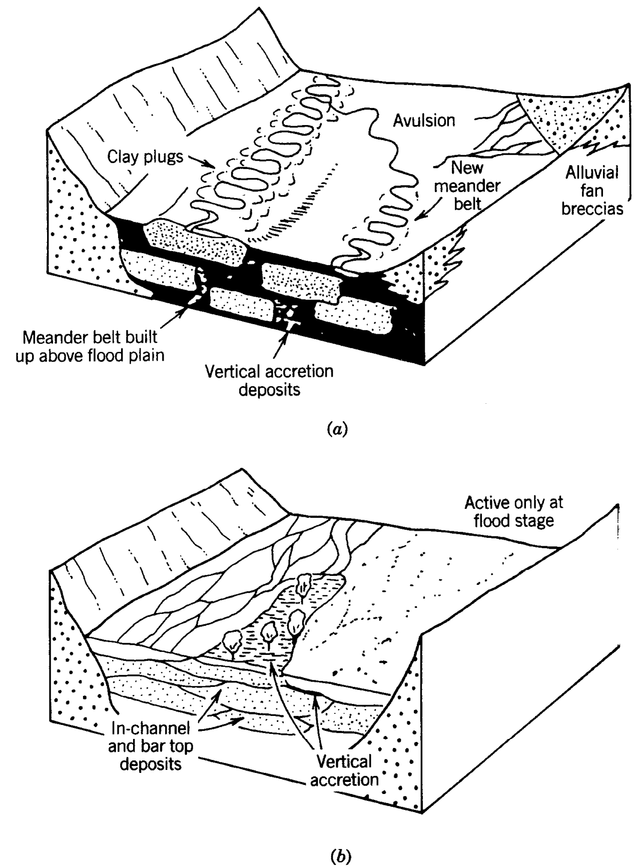


Figure 2.7
Contrasting the geometry of meandering (*a*) and braided (*b*) rivers (from Walker and Cant, 1984). Reprinted with permission of the Geol. Assoc. of Canada.

Unsaturated Groundwater Flow

- **Flow in the vadose zone is a non-linear process and a complex topic**
- **Moisture content (degree of saturation) of unsaturated media is a function of capillary pressure**
- **Hydraulic conductivity of unsaturated media is also a function of capillary pressure**
- **Both functional relationships are hysteretic, with the functional form differing for wetting and drying**

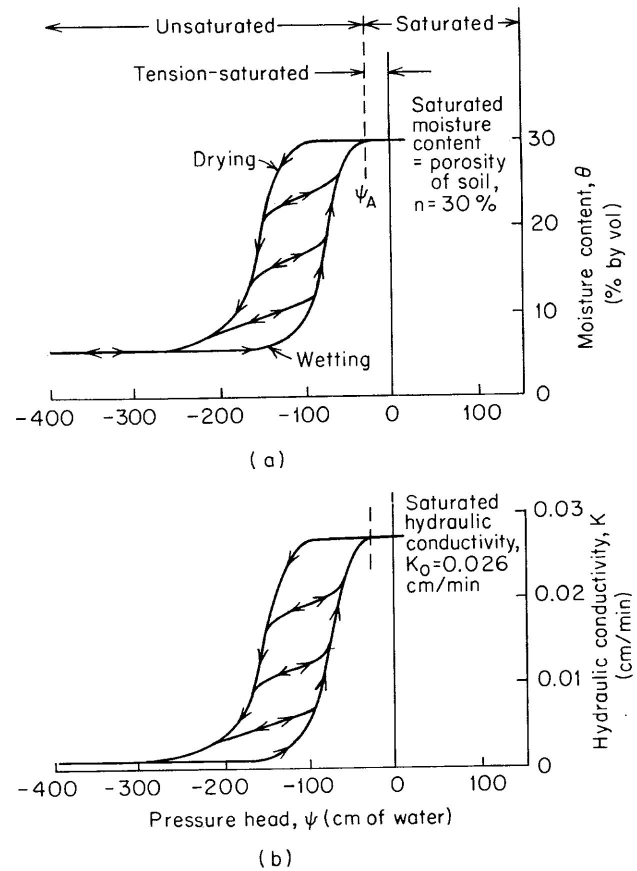
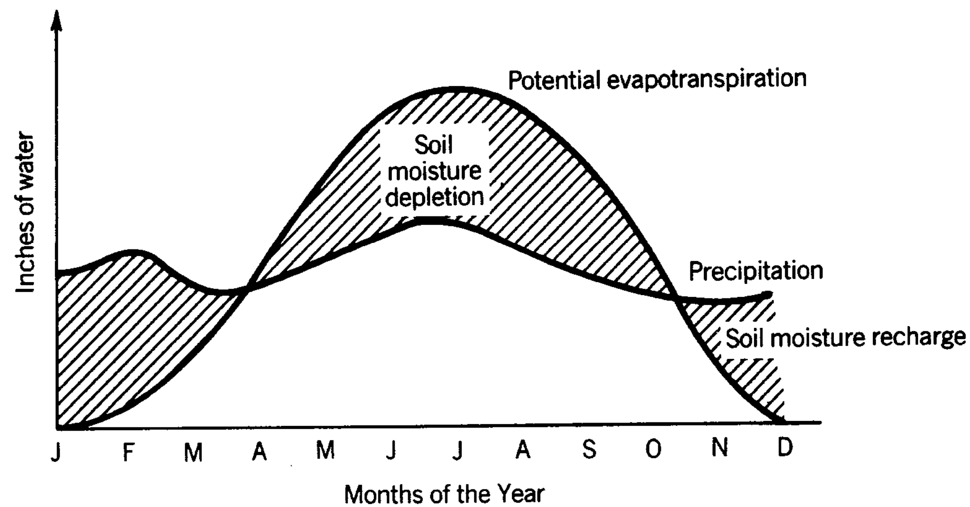


Figure 2.13 Characteristic curves relating hydraulic conductivity and moisture content to pressure head for a naturally occurring sand soil (after Liakopoulos, 1965a).

Unsaturated Groundwater Flow

- **Infiltration, evapotranspiration, and percolation of moisture in the vadose zone tend to be transient processes**
- **In temperate climates soil moisture increases during months of low plant activity and solar radiation in the winter and decreases during the summer**



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