CHAPTER 1

GROUNDWATER HYDROLOGY

GROUNDWATER HYDROLOGY

- **Role of Groundwater**
  - **Water Supply**
  - **Drainage; Seepage, excavations, and foundations;**
  - **Subsidence of land; Special problems**
    - **sea water intrusion, artificial recharge, waste disposal, pollution**

GROUNDWATER HYDROLOGY

- **Role of Groundwater**
  - **Water management – (concerned with) underground storage, conservation, minimum cost, quantity available, quality available, time and space variations.**

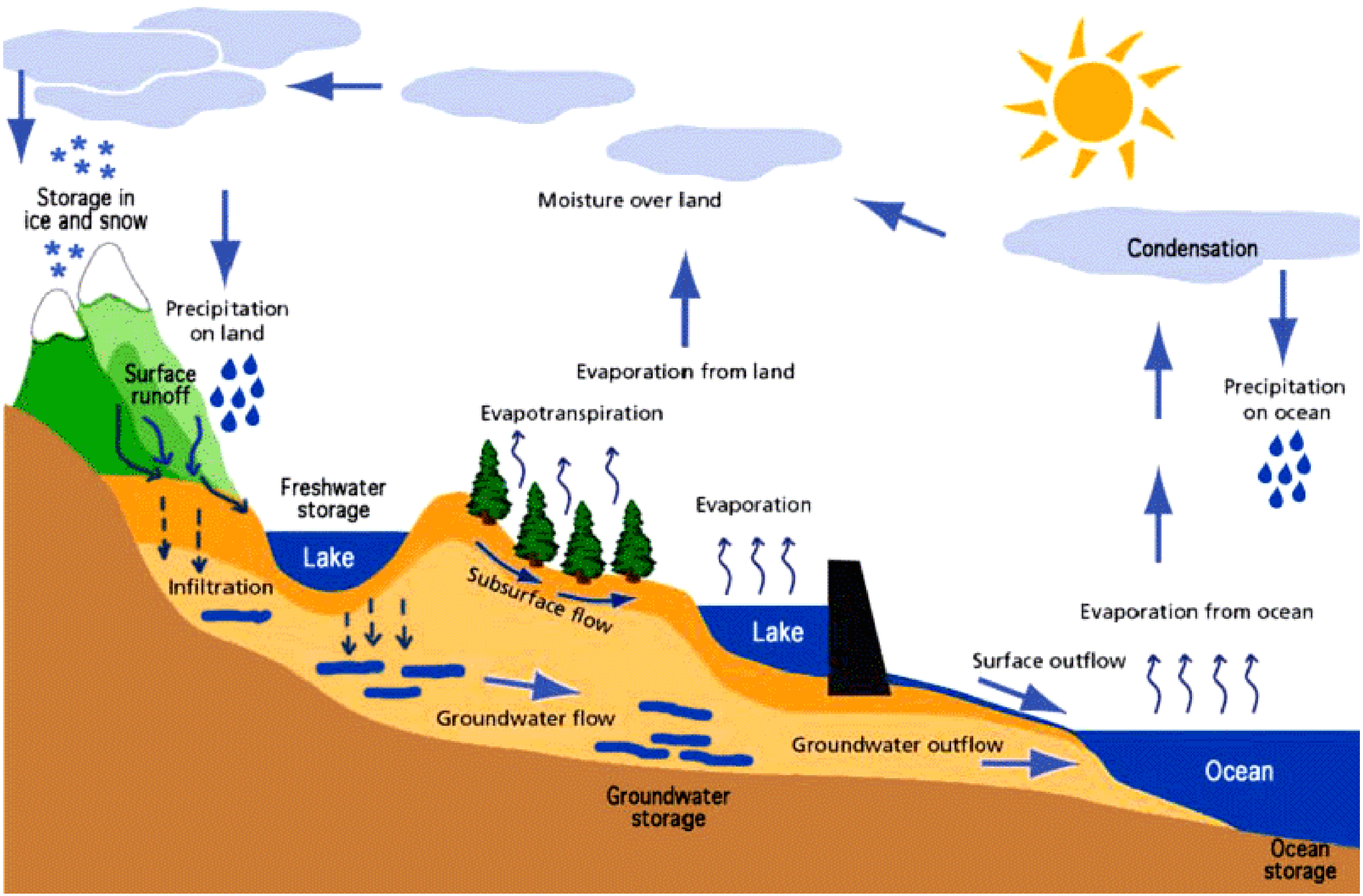
GROUNDWATER HYDROLOGY

- **Groundwater and other applications**
  - **Geology: oil, gas, salt deposits, fresh water mining**
  - **Petroleum Engineering**
  - **Agriculture: irrigation, drainage, soil moisture**
  - **Soil Science (Agronomy): soil-plant-water relations**

GROUNDWATER HYDROLOGY

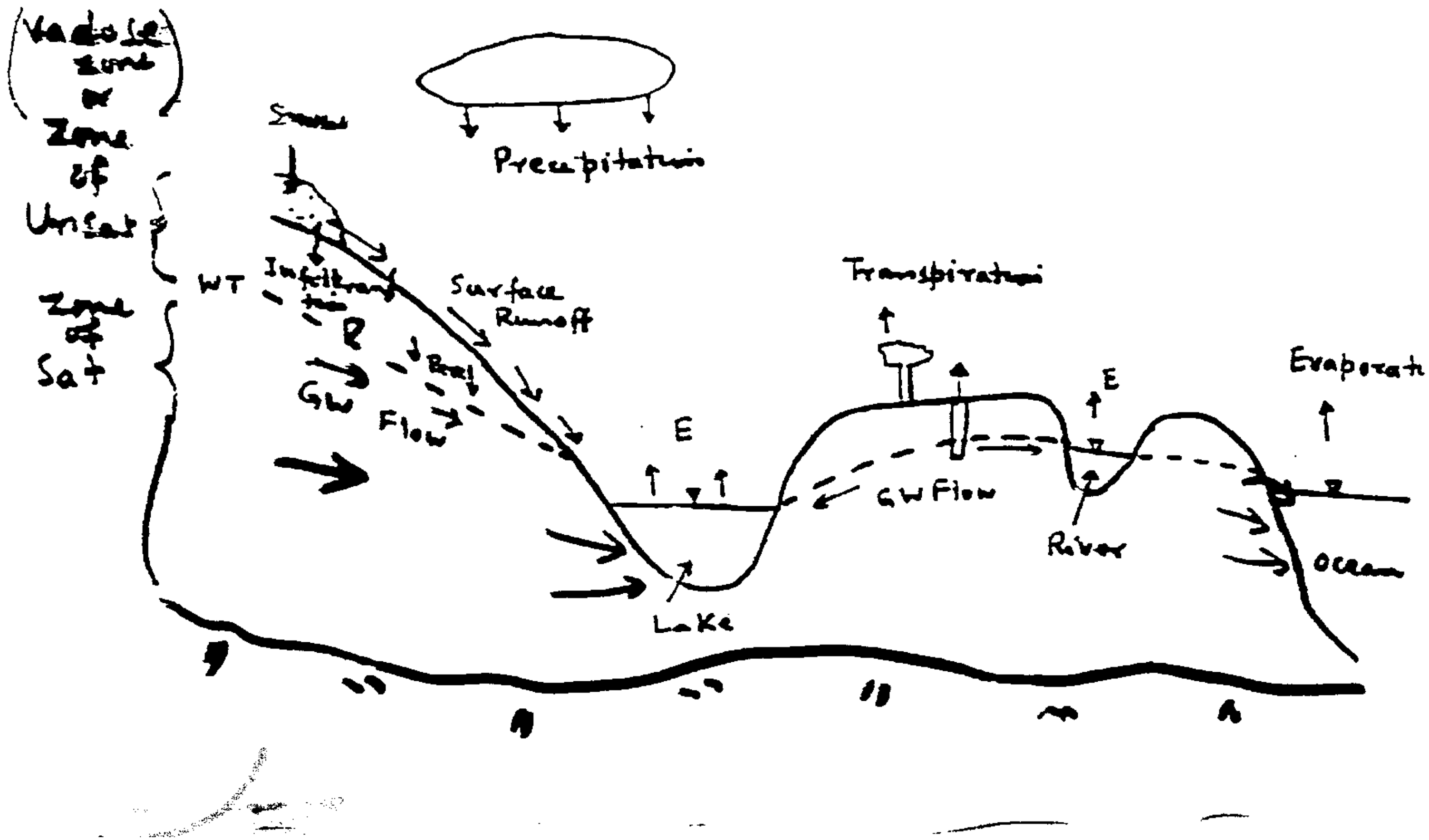
- **Groundwater and other applications**
  - **Public Health**
  - **Law: groundwater rights, RCRA, CERCLA, SARA, LUST**
  - **Economics: natural resources (G.W.), agriculture (G.W.)**
  - **Geography**
  - **Political Science: between nations and states**

GROUNDWATER HYDROLOGY



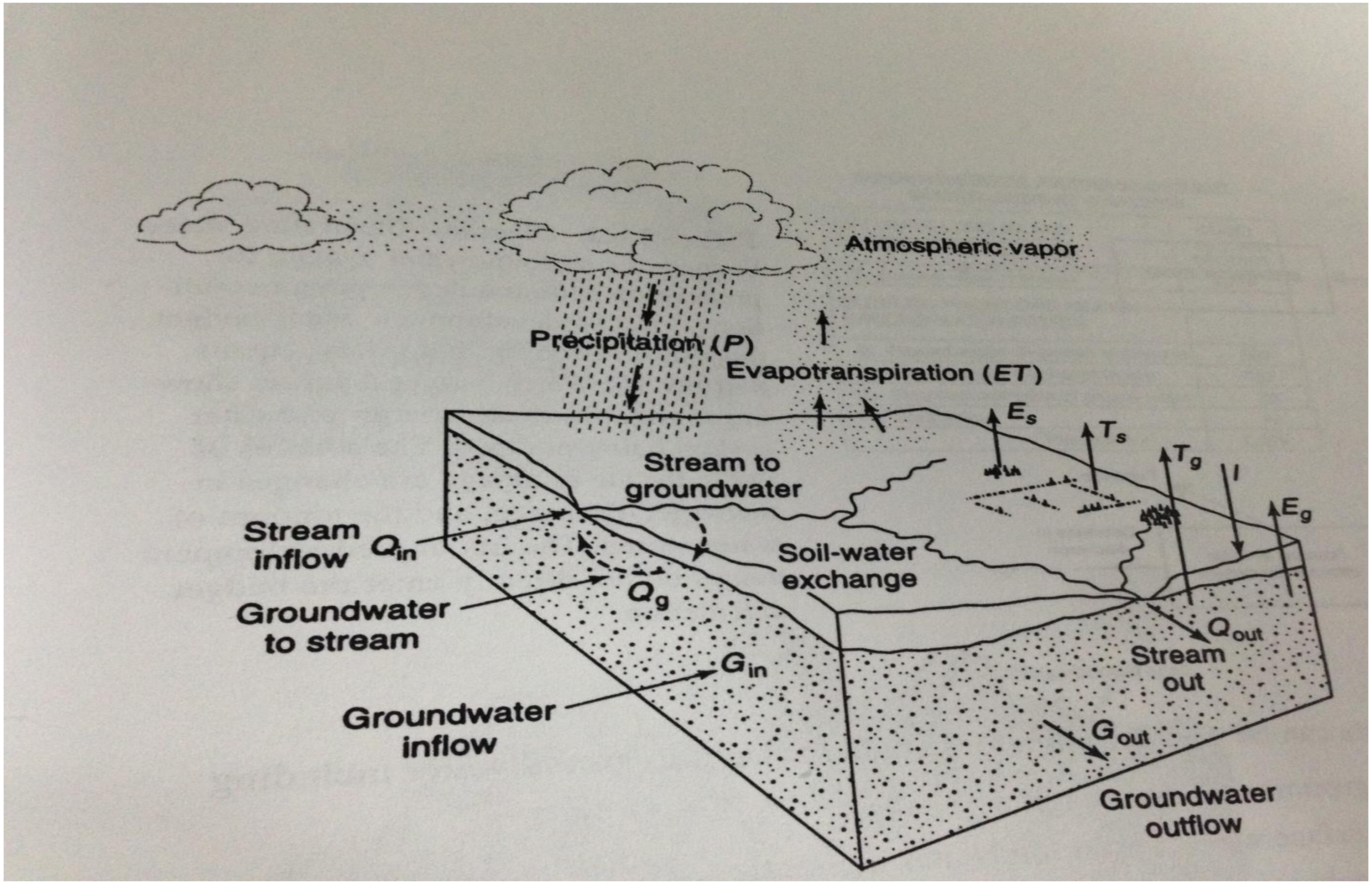
GROUNDWATER HYDROLOGY

- **Groundwater in Hydrologic cycle:**



GROUNDWATER HYDROLOGY

- **Hydrologic Budget:**



GROUNDWATER HYDROLOGY

- **Hydrologic Budget:**

$$\boldsymbol{P + Q_{in} - Q_{out} + Q_g - E_s - T_s - I = \Delta S_s}$$

P = is the precipitation,

Q_{in} = into surface water flow

Q_{out} = out surface water flow

Q_g = into groundwater

E_s = surface evaporation

T_s = transpiration

I = infiltration

ΔS_s= change of water storage

GROUNDWATER HYDROLOGY

EXAMPLE 1.6.1

During 1996, the water budget terms for Lake Annie in Florida[60] included precipitation (P) of 43 inch/yr, evaporation (E) of 53 inch/yr, surface water inflow (Q_{in}) of 1 inch/yr, surface outflow (Q_{out}) of 173 inch/yr, and change in lake volume (ΔS) of −2 inch/yr. Determine the net groundwater flow (the groundwater inflow minus the groundwater outflow).

SOLUTION

Assuming $T_g = 0$, the water budget equation (1.6.4) to define the net groundwater flow for the lake is

$$G = \Delta S - P + E - Q_{in} + Q_{out}$$

$$= -2 - 43 + 53 - 1 + 173$$

$$= 180 \text{ inch/yr}$$

■

EXAMPLE 1.6.2

During January 1996, the water-budget terms for Lake Annie in Florida[60] included precipitation (P) of 1.9 inch, evaporation (E) of 1.5 inch, surface water inflow (Q_{in}) of 0 inch, surface outflow (Q_{out}) of 17.4 inch, and change in lake volume (ΔS) of 0 inch. Determine the net groundwater flow for January 1996 (the groundwater inflow minus the groundwater outflow).

SOLUTION

The water budget equation to define the net groundwater flow for the lake is

$$G = \Delta S - P + E - Q_{in} + Q_{out} = 0 - 1.9 + 1.5 - 0 + 17.4 = 17 \text{ inch for January 1996}$$

■

GROUNDWATER HYDROLOGY

- **Sources of GW**
  - **Precipitation**
  - **Natural recharge**
  - **Artificial recharge**

GROUNDWATER HYDROLOGY

- **Disposal of Groundwater**
  - **Outflow – stream, spring, lake, ocean**
  - **Use of water – wells, drains**
  - **Evapotranspiration**

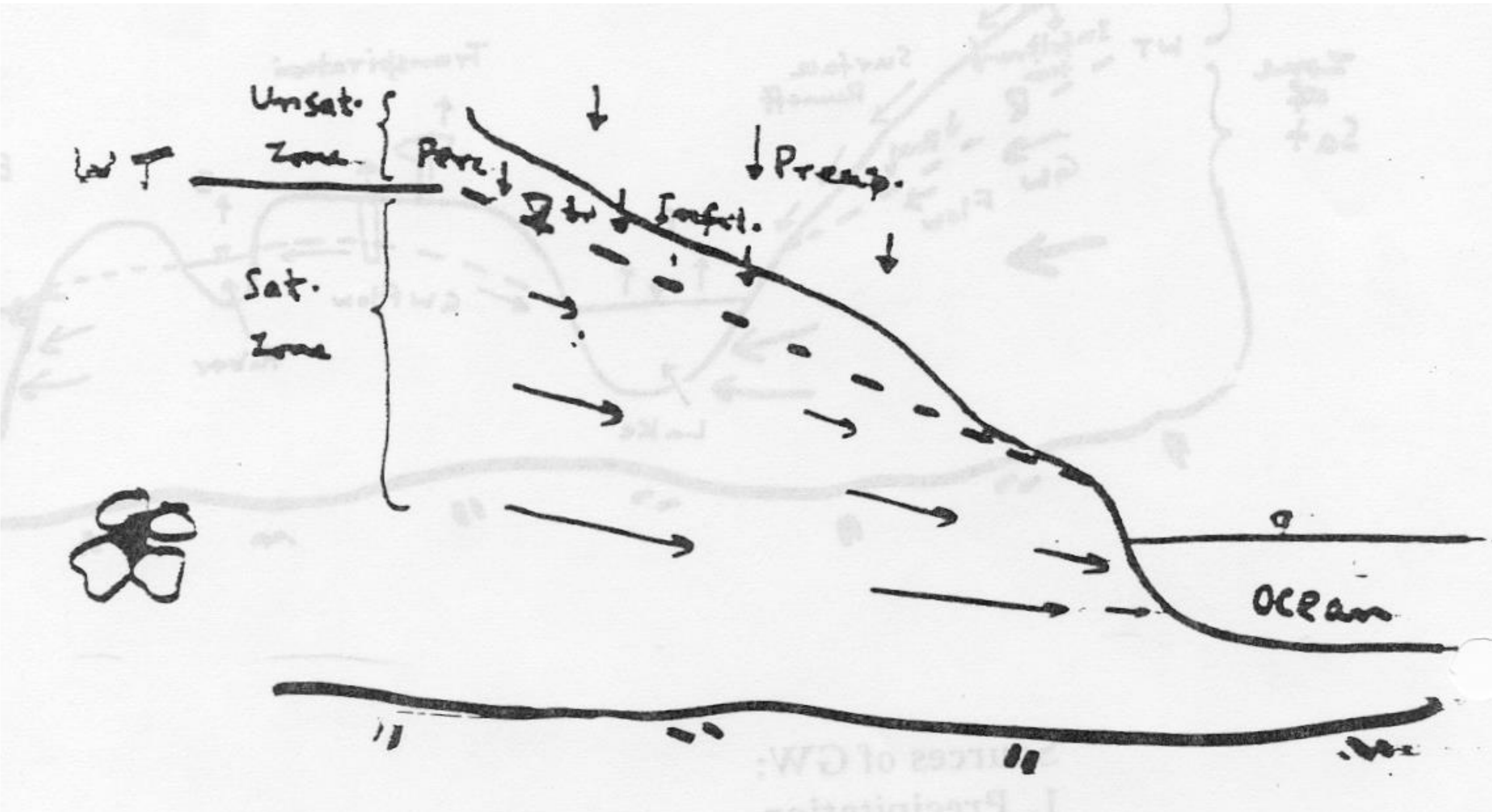
GROUNDWATER HYDROLOGY

- **Groundwater as Resource**
  - **“Renewable” natural resource**
  - **Largest fresh water source**
    - **concerned with its development and management**

GROUNDWATER HYDROLOGY

- Groundwater Occurrence
  - GW occurs in saturated and unsaturated zones, but GW supply tapped from saturated zones.

GROUNDWATER HYDROLOGY



GROUNDWATER HYDROLOGY

- Infiltration – water entering the ground.
- Percolation – water movement within the ground
- Unsat. Zone – water percolates vertically downward
- Sat. Zone – water percolates horizontally and may move in any direction depending on the boundaries of the aquifer.

GROUNDWATER HYDROLOGY

- Historical Background
  - Water Development
    - Groundwater development described from 800 BC
    - Dug Well

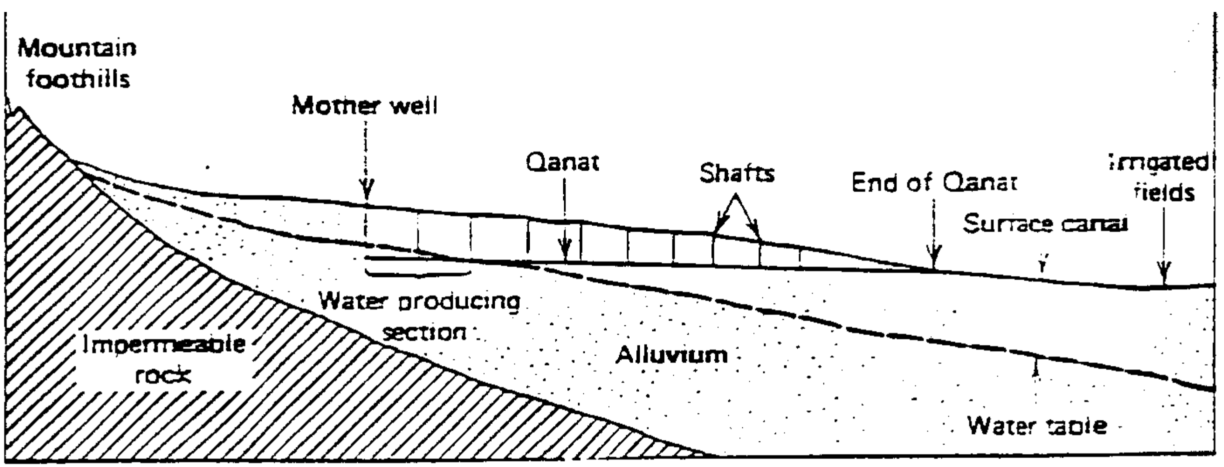


Fig. 1.1 Vertical cross section along a qanat (after Beaumont[5]).

GROUNDWATER HYDROLOGY

- Kanat (Qanat)
  - Iran and Egypt
  - Avg. Length = 5km
  - Q = 400 l/s = 35000 m^3/d = 6420 gpm
  - No. = 35,000
  - Water runs to waste due to continuous flow in canals.

GROUNDWATER HYDROLOGY

- 17th Century
  - Perrault – rainfall and runoff estimates for a river basin
  - Mariotte – infiltration theory
  - Halley - evaporation

GROUNDWATER HYDROLOGY

- 18th Century
  - Fundamentals of geology established with a basis for understanding the occurrence and movement of groundwater.

GROUNDWATER HYDROLOGY

- 19th Century
  - Henry Darcy
    - Darcy's Law
    - Well Drilling
  - Groundwater Hydraulics – Boussinesq, Dupuit, Forcheimer, Thiem

GROUNDWATER HYDROLOGY

- 20^{th} Century
  - USGS: data collection in the U.S.

GROUNDWATER HYDROLOGY

- Groundwater use in the U.S.
Year	B.G.D.
1935	10
1945	20
1960	50
1975	80
1985	110

GROUNDWATER HYDROLOGY

- G.W. / T.W. = 20% and increasing (US)
- G.W. / T.W. = 87% (Kansas)
- G.W. / T.W. = 63% (Oklahoma)

GROUNDWATER HYDROLOGY

- Relative use of Groundwater in the US
  - Irrigation 65%
    - 91% in 17 western states.
  - Industry 21%
  - Public Supply 10%
  - Rural Supply 4%

GROUNDWATER HYDROLOGY

- Top Industrial Uses of Groundwater
  - Oil Refinery
  - Paper Manufacturing
  - Metal Manufacturing
  - Chemical Manufacturing
  - Air Conditioning and Refrigeration Plants
  - Distilling
  - Ice Manufacturing
  - Food Processing
  - Food Processing
  - Nuclear Power Plants

World's water distribution – Table 1.1

	% of total water
(1) Surface water	99.3711
Salt water in oceans	97.2
Salt water in lakes + inland areas	0.008
Fresh water in lakes	0.009
Fresh water in streams	0.0001
Fresh water in glaciers + icecaps	2.15
Water in biomass	0.004
(2) Groundwater	0.625
Unsaturated zone	0.005
GW within 0.8 km (shallow percolation)	0.31
GW 0.8 – 4.0 km (deep percolation)	0.31
(3) Atmospheric water	0.001
	100.00%

GROUNDWATER HYDROLOGY

- Compare
  - Shallow GW 0.31%
  - Fresh water in lakes and streams 0.0091%
  - Fresh water in glacier icecaps 2.15%

GROUNDWATER HYDROLOGY

- Origins of Groundwater
  - Meteoric Water:
    - Water infiltrated from precipitation, lakes and streams
    - Part of the hydrologic cycle
    - Recent geologic time, generally good quality

GROUNDWATER HYDROLOGY

- Origins of Groundwater
  - Connate Water
    - Water entrapped in sedimentary rocks at the time of deposition
    - Isolated from the hydrologic cycle, though of atmospheric origin
    - Found in lower parts of deep GW
    - Highly mineralized; in contact with salt deposits
    - Much older than meteoric water

GROUNDWATER HYDROLOGY

- Origins of Groundwater
  - Juvenile Water
    - Formed within earth; of volcanic or magmatic origin
    - Can move up with volcanic activity
    - Not part of the hydrologic cycle
    - Highly mineralized; insignificant as a water resource

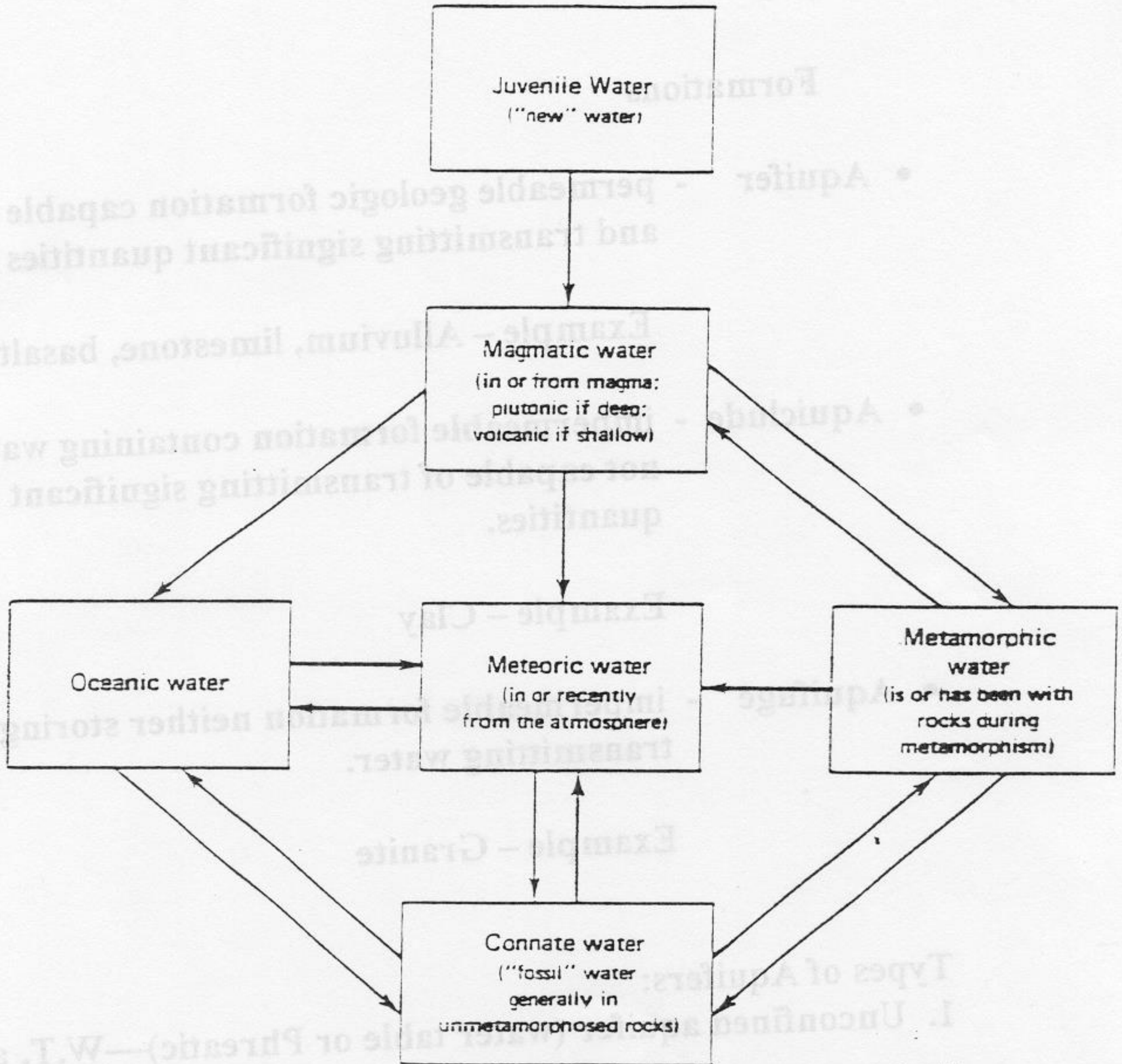


Fig. 2.1 Diagram illustrating relationships of genetic types of water (after White[19]; courtesy The Geological Society of America, 1957).

GROUNDWATER HYDROLOGY

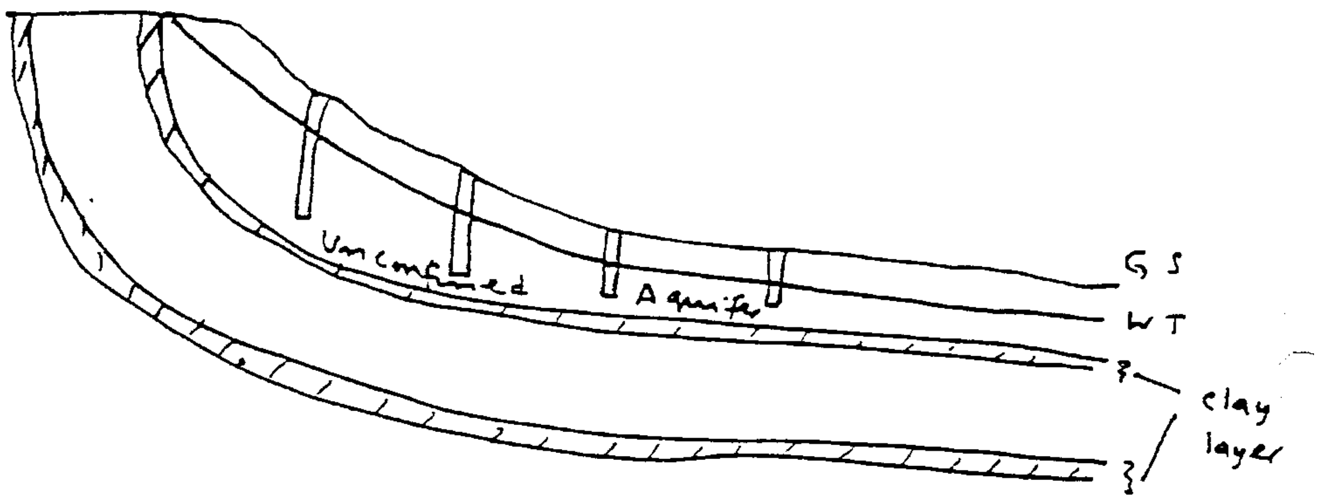
- Formations
  - Aquifer: permeable geologic formation capable of storing and transmitting significant quantities of water.
    - Ex. – alluvium, limestone, basalt, gravel
  - Aquiclude: impermeable formation containing water, but not capable of transmitting significant quantities
    - Ex. – clay

GROUNDWATER HYDROLOGY

- Formations
  - Aquifuge: impermeable formation capable of neither storing nor transmitting water
    - Ex. - Granite

GROUNDWATER HYDROLOGY

- Types of Aquifers
  - Unconfined Aquifer: WT as upper boundary



GROUNDWATER HYDROLOGY

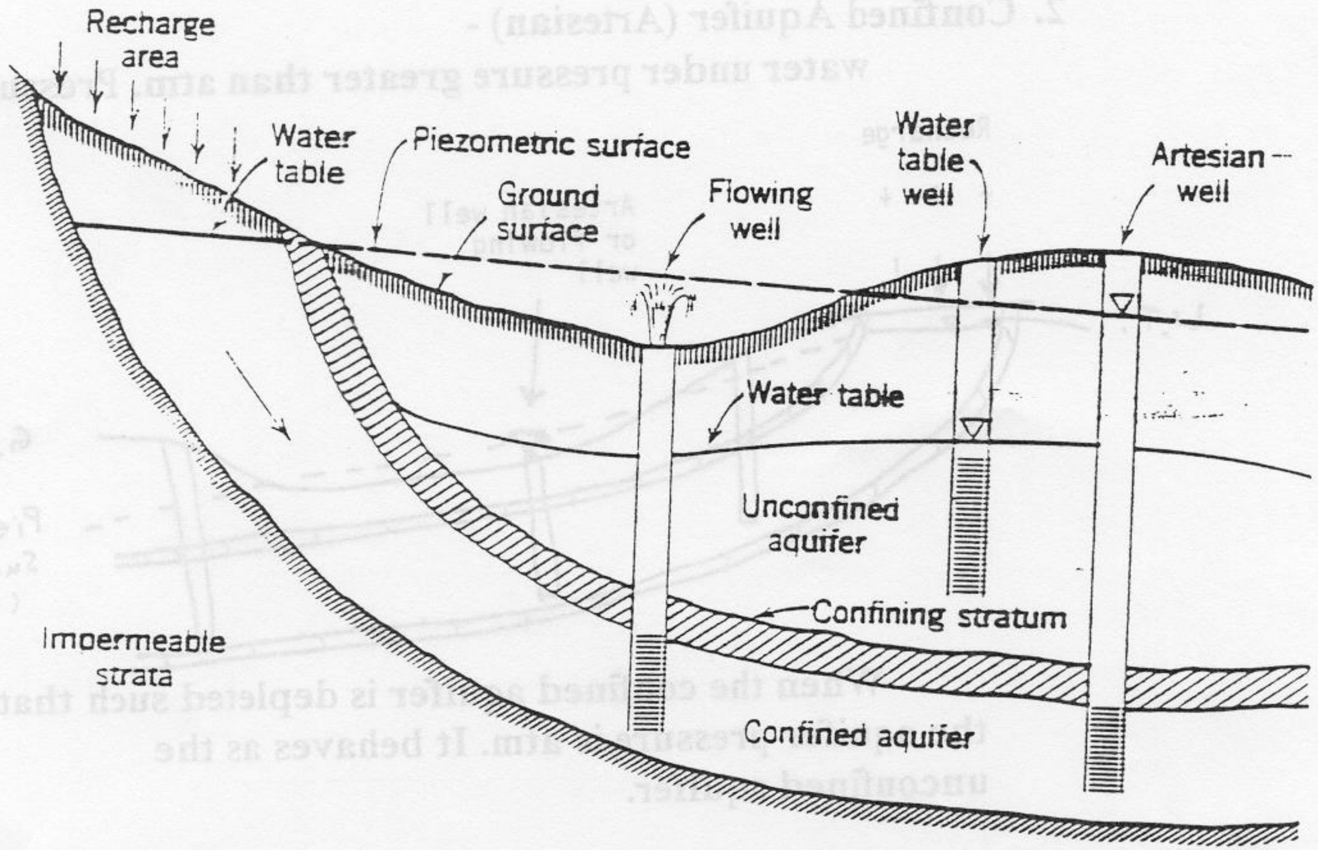
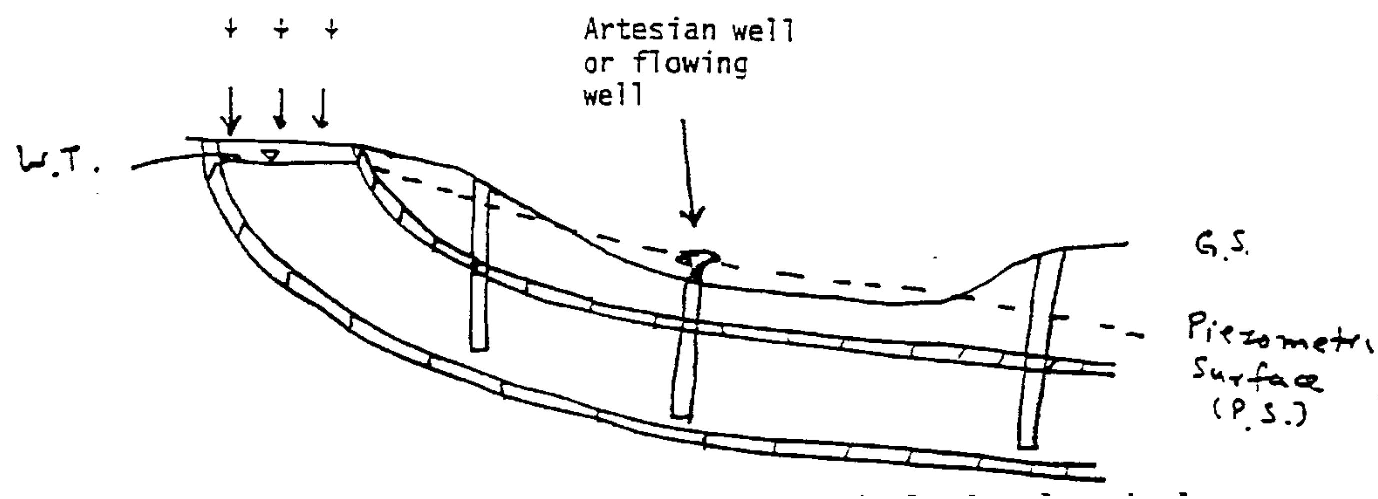


Fig. 2.11 Schematic cross section illustrating unconfined and confined aquifers.

GROUNDWATER HYDROLOGY

- Confined Aquifer: water under pressure greater than atmospheric pressure.
  - When the confined aquifer is depleted such that the aquifer pressure is atmospheric, it behaves as an unconfined aquifer.



GROUNDWATER HYDROLOGY

- Semi-Confined Aquifer (Leaky):
  - WT > PS, water moves from UA to CA
  - WT < PS, water moves from CA to UA

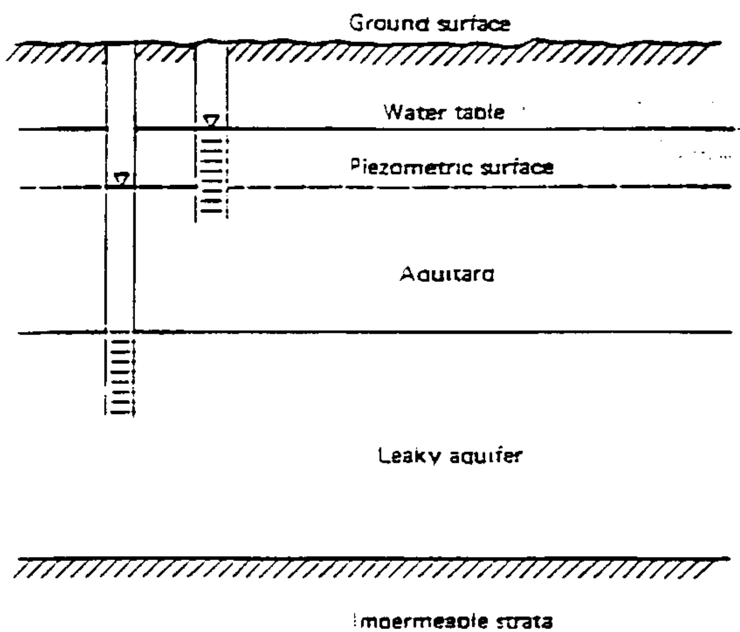


Fig. 2.13 Sketch of a leaky, or semiconfined, aquifer.

GROUNDWATER HYDROLOGY

– Perched Aquifer: Upper WT of limited extent. False WT

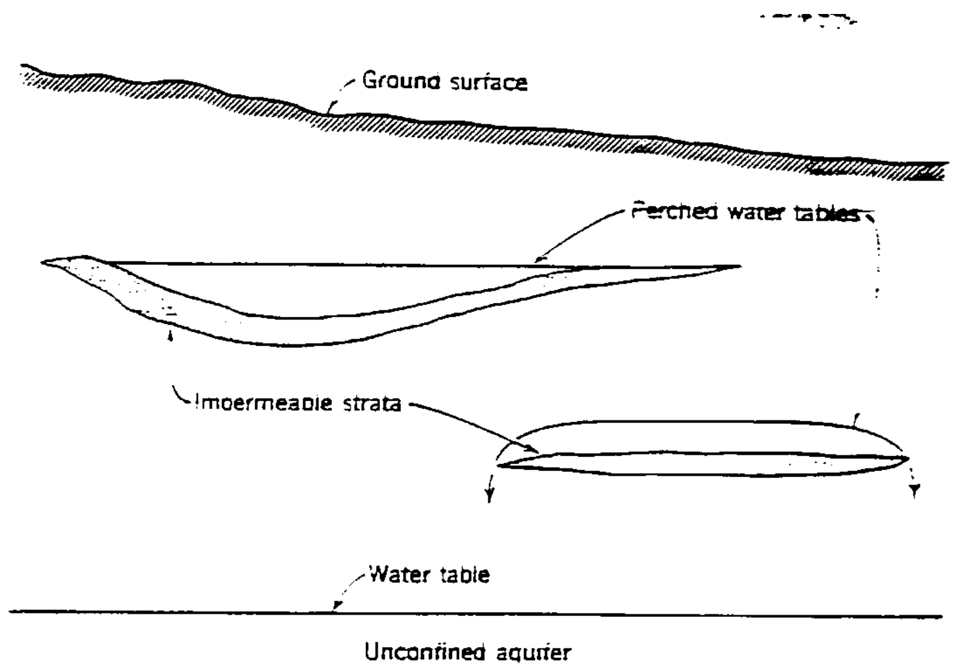


Fig. 2.12 Sketch of perched water tables.