CE 626

GROUNDWATER INTERACTIONS

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Lecture 8

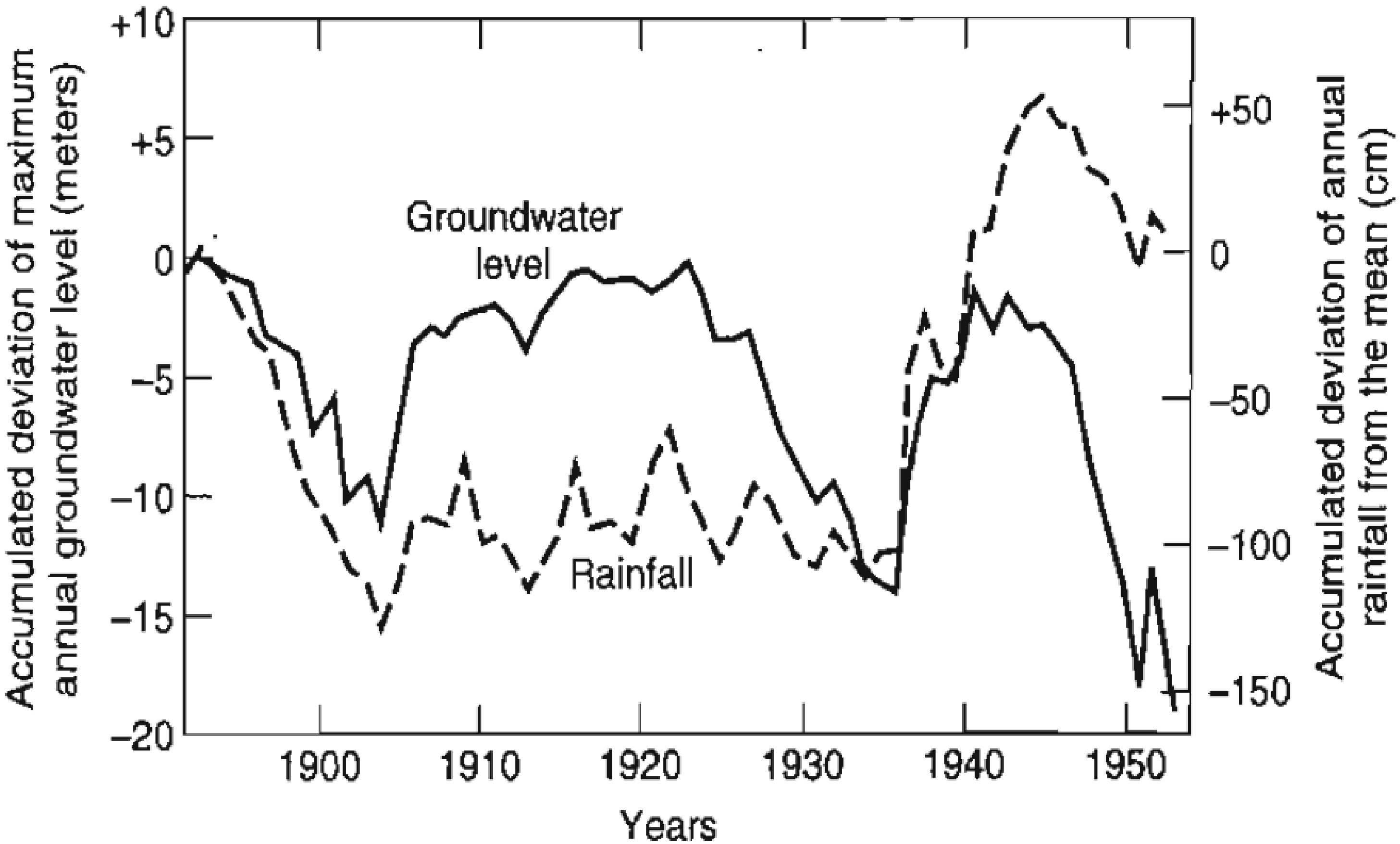
Today we will learn about…

- Surface water-groundwater interactions
- Soil water-evaporation-groundwater interactions
- Role of humans

What causes variations in groundwater depths?

- Variations of flow in streams that are connected to groundwater
- Evapotranspiration from groundwater
- Recharge to groundwater
- Tides
- Earthquakes and other external loads
- Human influences: pumping, artificial recharge, land cover changes, etc.

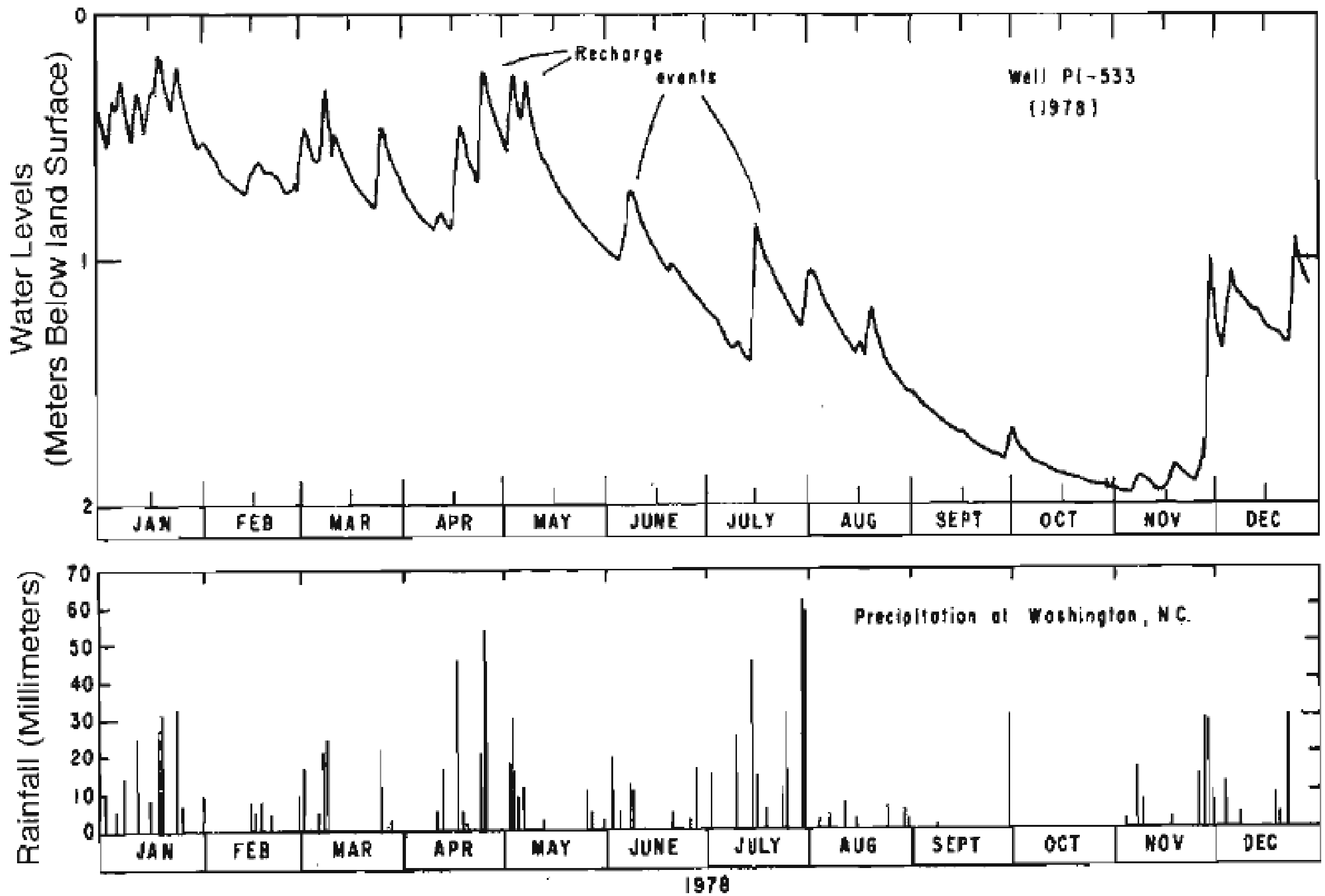
Long term variations in GW levels at a location may vary over periods of years or more



Variations of maximum annual groundwater levels and annual rainfall in San Bernardino Valley, California. Source: Todd

Seasonal variation of GW levels:

GW levels = f(recharge, evapotranspiration, pumping, type of aquifer)
Recharge = f(rainfall intensity, distribution and amount of surface runoff, total rainfall)



SURFACE WATER-GROUNDWATER INTERACTIONS

Recall that we talked about baseflow as the water that enters from persistent slowly varying sources and maintains streamflow between water-input events

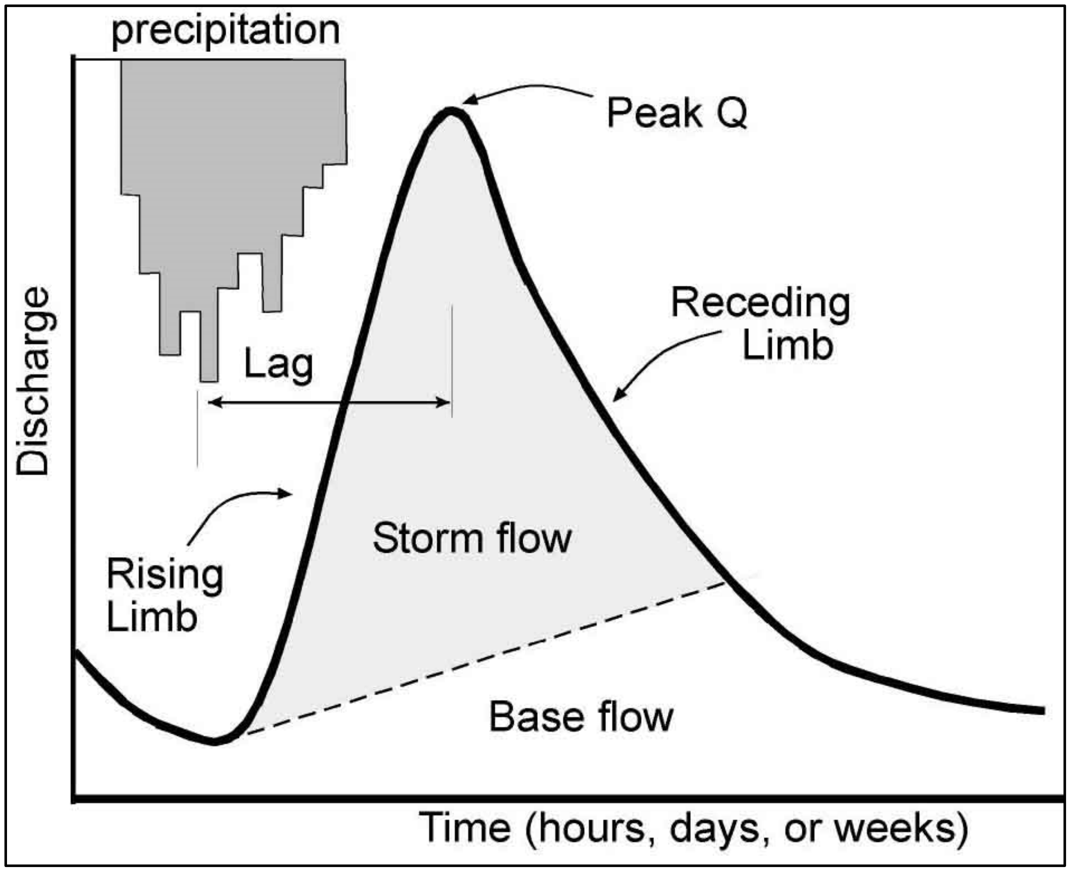


Image: http://www.geogonline.org.uk/images/storm_1.gif

Streams can be classified into different types based upon their interaction with the ground water system

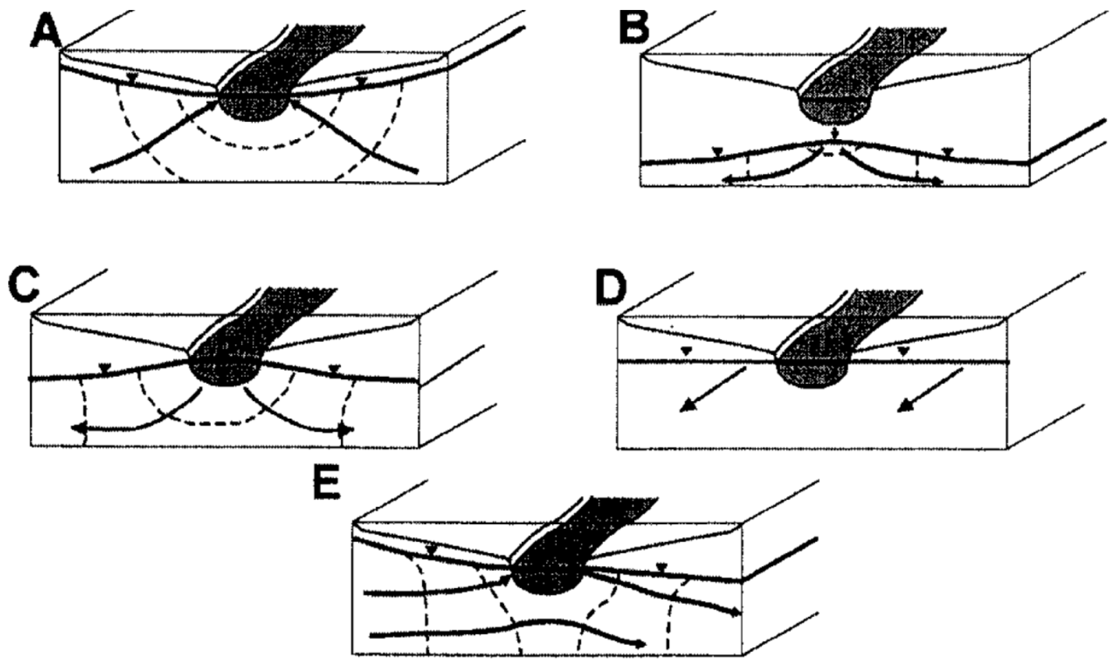


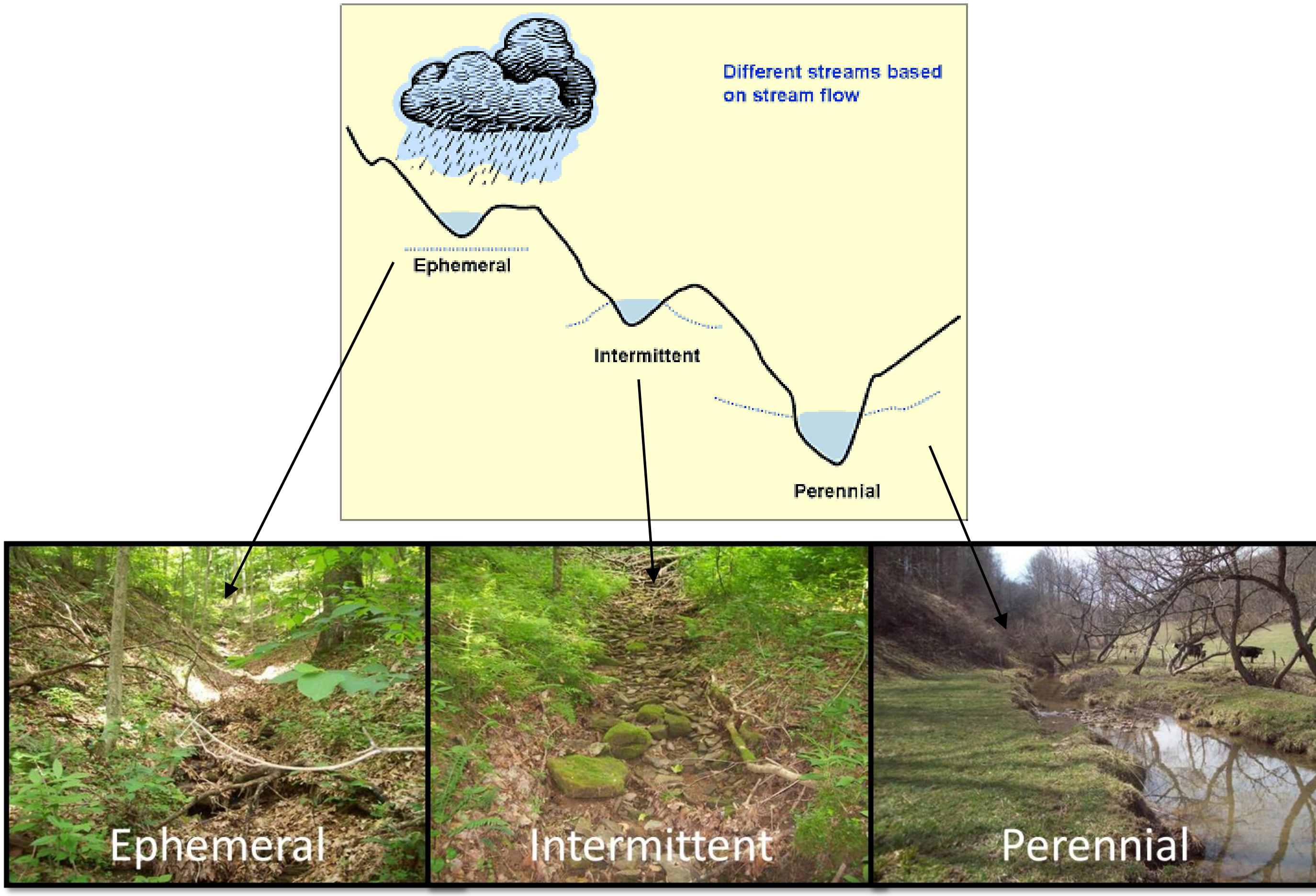
Figure 2. Fluvial plain–ground water and stream channel interactions

Streams can be connected to the ground water system or be perched above.

A flow-through stream is one that simultaneously receives and loses ground water.

Woessner, W.W., 2000. Stream and fluvial plain ground water interactions: rescaling hydrogeologic thought. *Groundwater*, *38*(3), pp.423-429.

Yet another classification can be tied to stream-ground water interactions



Intermittent streams generally are sustained by GW flow between events, while ephemeral streams are usually loosing

Image: http://cals.arizona.edu/watershedsteward/resources/module/Stream/images/stream_classn_pg2_clip_image001.gif (top)
http://www.truthaboutsurfacemining.com/WaterQuality/Water101/PublishingImages/Ephemeral%20intermittent%20perenial%20picture.png (bottom)

Water in streams and under the ground is continuously exchanged within a catchment.
This challenges the reductionist approach to manage these two resources as independent of each other.

Image: https://www.ufz.de/export/data/2/91553_streambed_flow_homepage.png

Baseflow recession curve: the part of hydrograph with no excess precipitation, decays generally following an exponential curve

Discharge during baseflow recession period comprises entirely of groundwater. Baseflow recession depends on:

1. Topography
2. Drainage pattern
3. Soils and geology

Baseflow recession equation is:

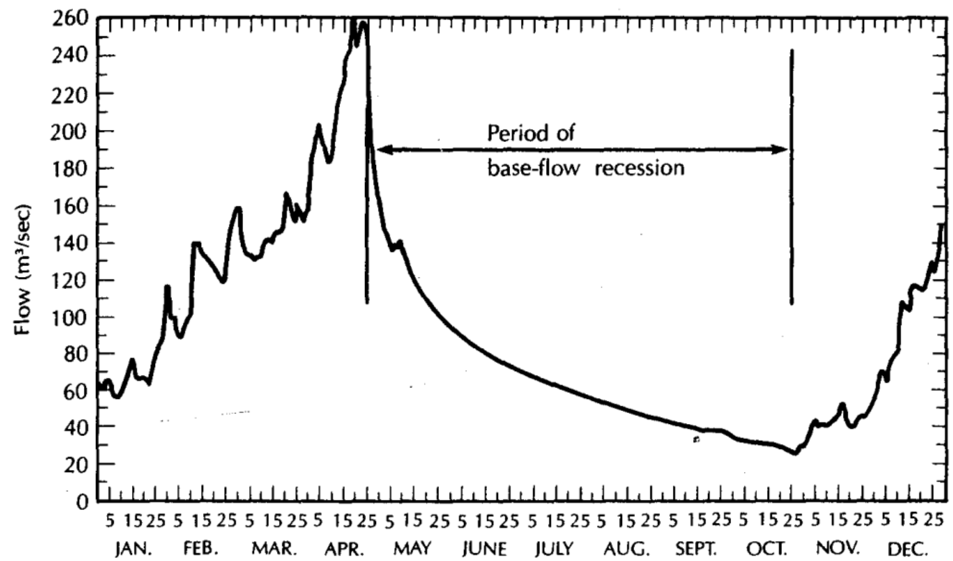
$$Q = Q_o e^{-at}$$

Where, Q is the flow rate at time t after the beginning of recession

Q_o is the flow at the start of recession

a is the recession constant for the basin

t is the time since the start of recession.



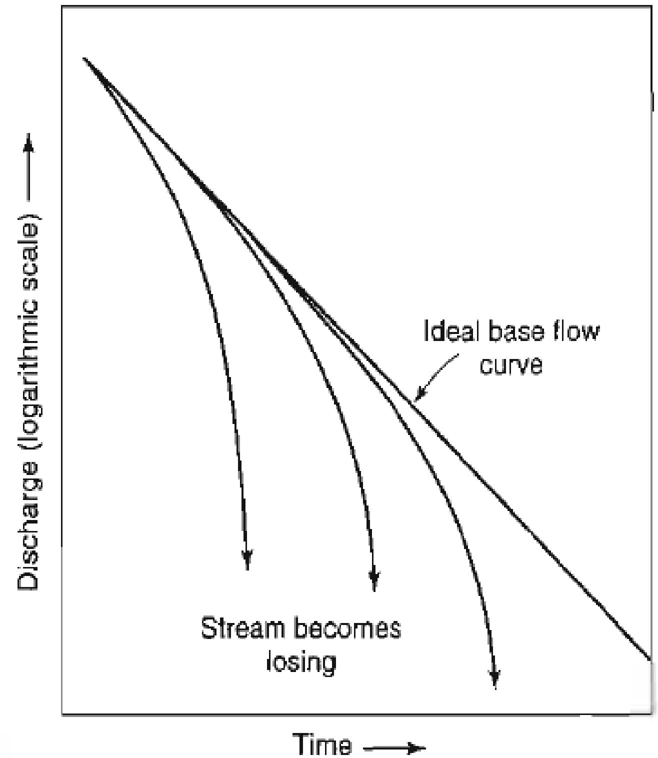
A hydrograph with a long dry summer showing the recession period. Lualaba river, Central Africa. (Fetter, 2018)

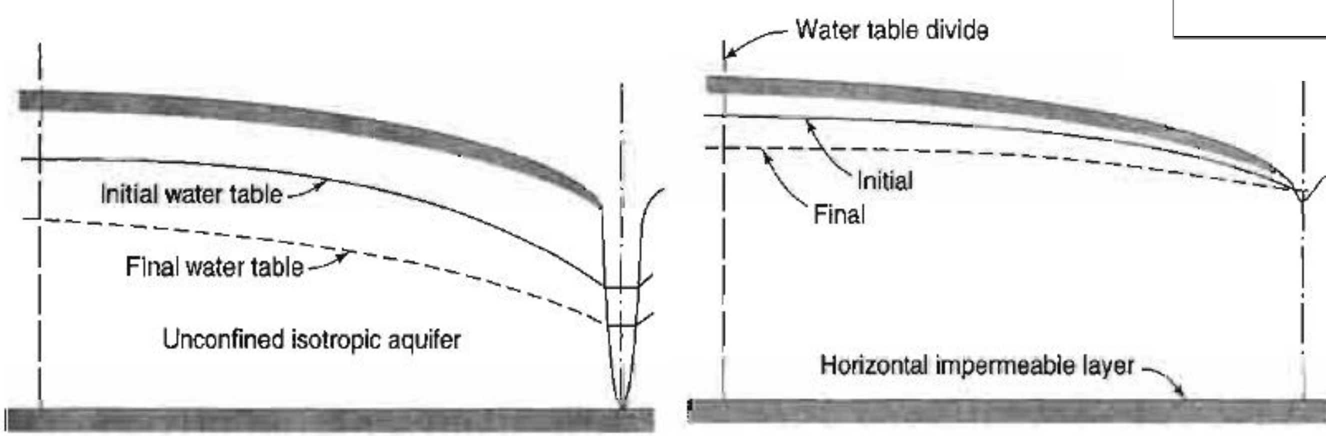
Linear reservoir with storage, S=kQ:

$$\left.\begin{aligned} \frac{dS}{dt} &= -Q \\ S &= KQ \end{aligned}\right\} \rightarrow Q = Q_o e^{-t/\mathrm{K}}$$

Shape of the recession curve depends upon:

- Evapotranspiration from the groundwater
- How much does the stream penetrate the aquifer?
  - Shapes are closer to the exponential approximation for deep aquifers with partially penetrating streams
  - Fully penetrating streams do not plot as straight lines on semi-log plot, recession rate continuously decreases with time instead
- Groundwater draining to deeper layers in addition to the stream





(a) (b)

Estimating baseflow or recharge:

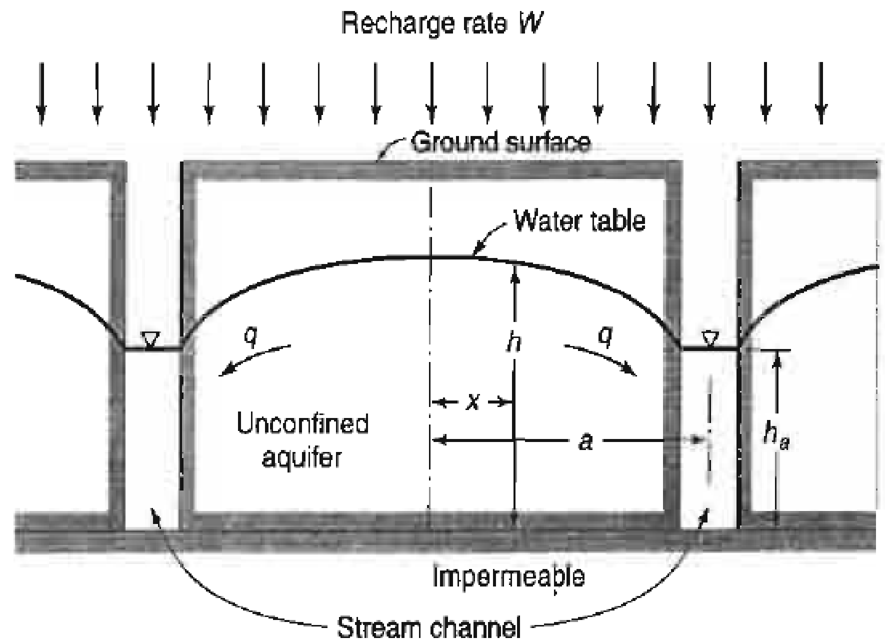
Equating the flux through a cross section with the recharge in that section at equilibrium:

$$q_w = -Kh\frac{dh}{dx}, \;\; q = Wx$$

$$\rightarrow h^2 = h_a^2 + \frac{W}{K}\left(a^2 - x^2\right)$$

The same equation can be derived using the earlier form by adequately adjusting the axes:

$$h = \sqrt{h_1^2 - \frac{\left(h_1^2 - h_2^2\right)x}{L} + \frac{w}{K}\left(L - x\right)x}$$



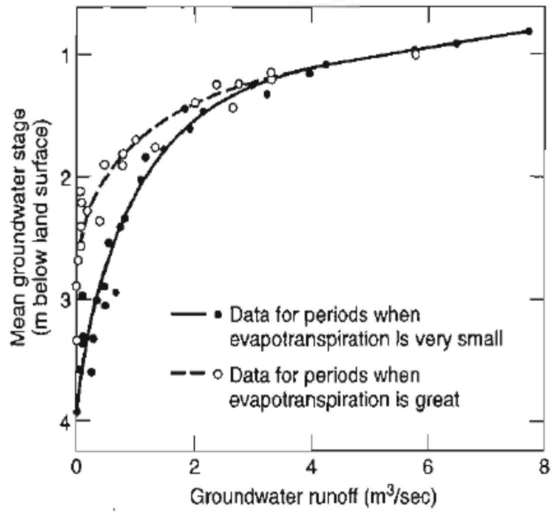
Steady flow between two parallel streams from a uniformly recharged unconfined aquifer

From symmetry and continuity: $Q_b = 2aW$

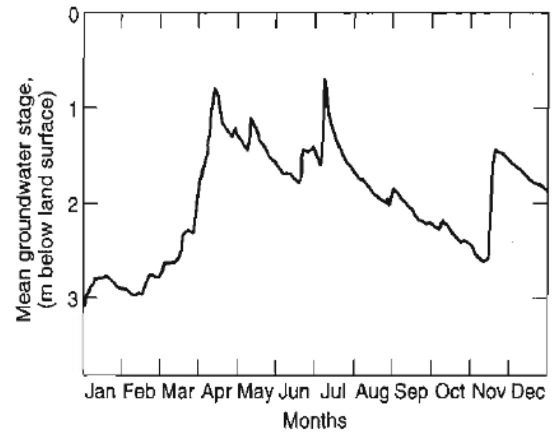
Here, Q_b is the baseflow entering the stream from the aquifer per unit length of the stream channel.

In order to estimate baseflow, head measurements in the aquifer can be made, and substituted in the above equations to estimate W and Q_b.

Estimating baseflow from streamflow and groundwater level data:



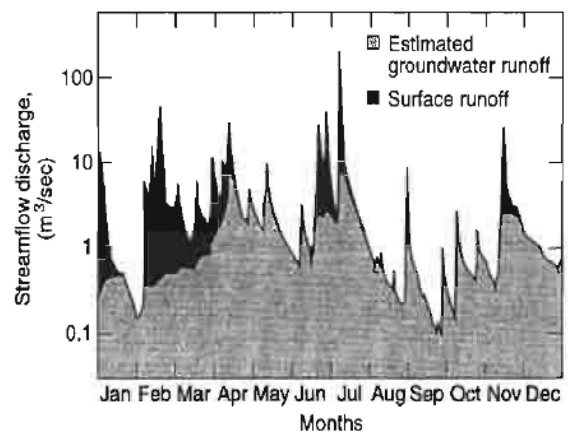
(a)



(b)

Baseflow rating curves as in (a) are developed using groundwater levels data and groundwater runoff estimates.

Note two curves, one when evapotranspiration is present and another when it is absent.



(c)

A hydrograph with a long dry summer showing the recession period. Lualaba river, Central Africa. (Todd, 2014)

Measurement of chemical concentration of a major ion in GW and surface water can also enable baseflow estimation

$$C_{TR}Q_{TR} = C_{GW}Q_{GW} + C_{SR}Q_{SR}$$

Where C is ionic concentration is Q is discharge, TR stands for total runoff, GW for groundwater contribution (baseflow) and SR for surface runoff. Concentration of ion in groundwater are measured during rainfall periods, concentrations in surface runoff are derived from measurements of small streams during storm events, and total flow concentrations are measured during peak flow in main stream.

And continuity implies: $Q_{TR} = Q_{GW} + Q_{SR}$

Solving for baseflow:

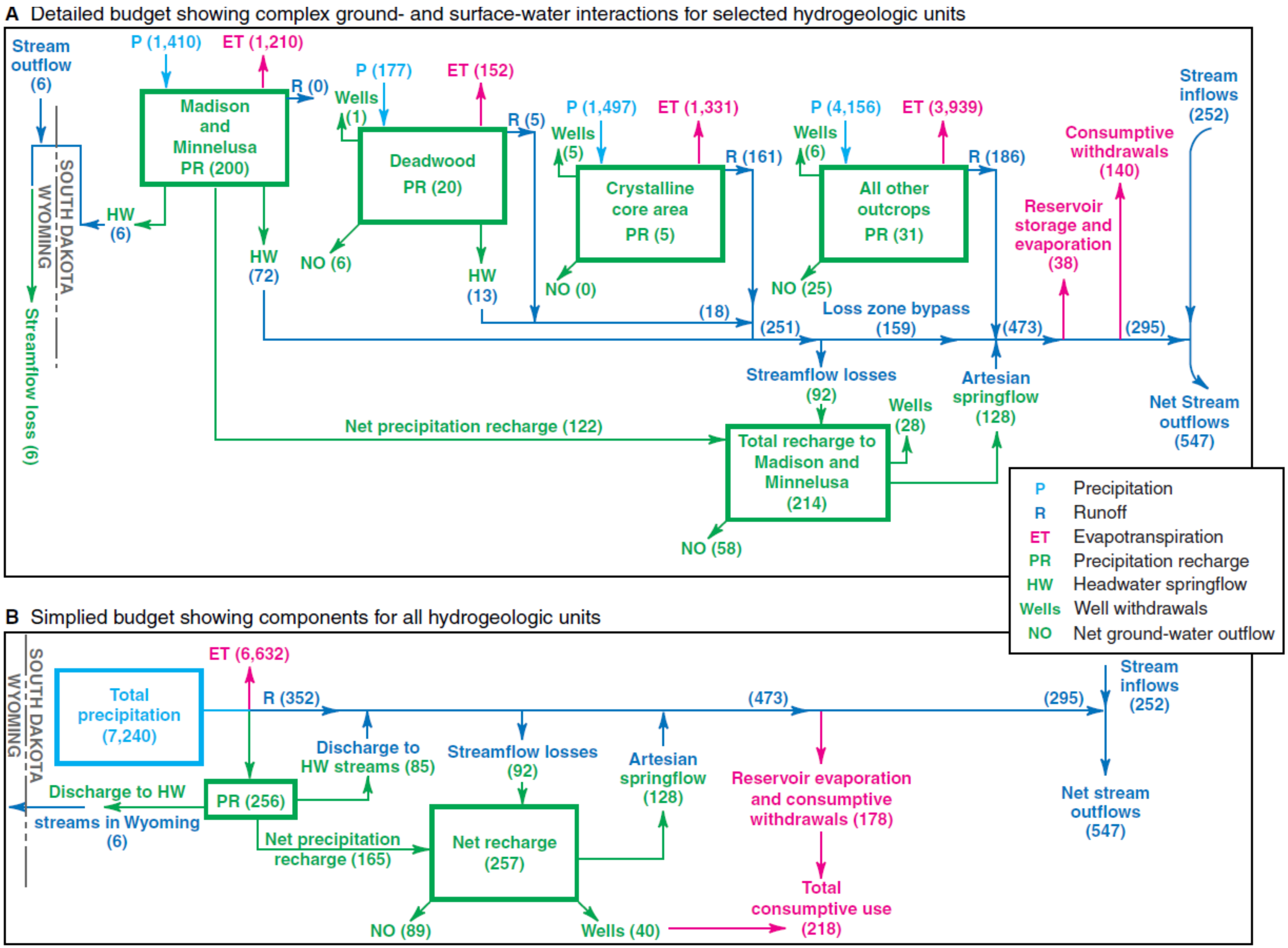
$$Q_{GW} = \frac{Q_{TR}\left(C_{TR} - C_{SR}\right)}{C_{GW} - C_{SR}}$$

Baseflow in GW resource assessment for India

The total ground water resources for water table aquifers is taken as annual ground water recharge plus potential recharge in shallow water table zone. The total ground water resource, thus computed would be available for utilization for irrigation, domestic and industrial uses. The base flow in rivers is a regenerated ground water resource and is some times committed for lift irrigation schemes and other surface irrigation works. It is, therefore, recommended that 15% of total ground water resources be kept for drinking and industrial purposes, for committed base flow and to account for the irrecoverable losses. The remaining 85% can be utilized for irrigation purposes. But wherever the committed base flows, domestic and industrial uses are more than 15%, the utilisable resources for irrigation may be considered accordingly.

Ground Water Resource Estimation Methodology. Report of the Ground Water Resource Estimation Committee.. Ministry of Water Resources, Government of India, New Delhi 2009

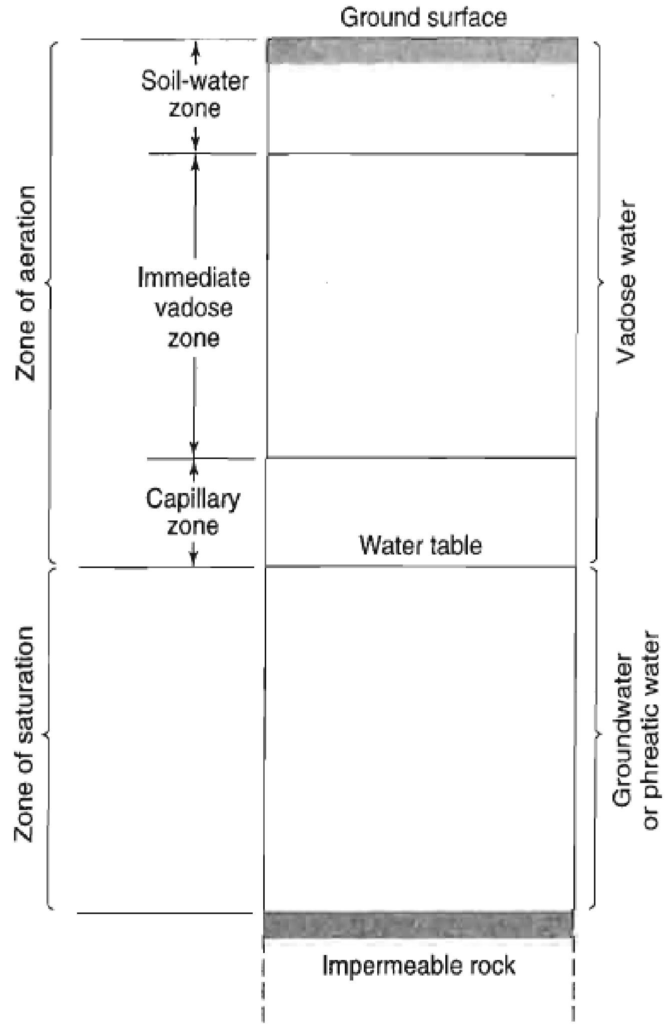
Example of a combined regional budget



Driscoll, D.G., Carter, J.M., Williamson, J.E. and Putnam, L.D., 2002. Hydrology of the Black Hills area, South Dakota. *US Geol Surv Water Resour Invest Rep*, *24094*, p.150.

SOIL WATER-EVAPORATION-GROUNDWATER INTERACTIONS

Recall the different vertical zones in which subsurface water can be found:



Plants grow in the soil-water zone.

Soil moisture depends upon precipitation and evapotranspiration

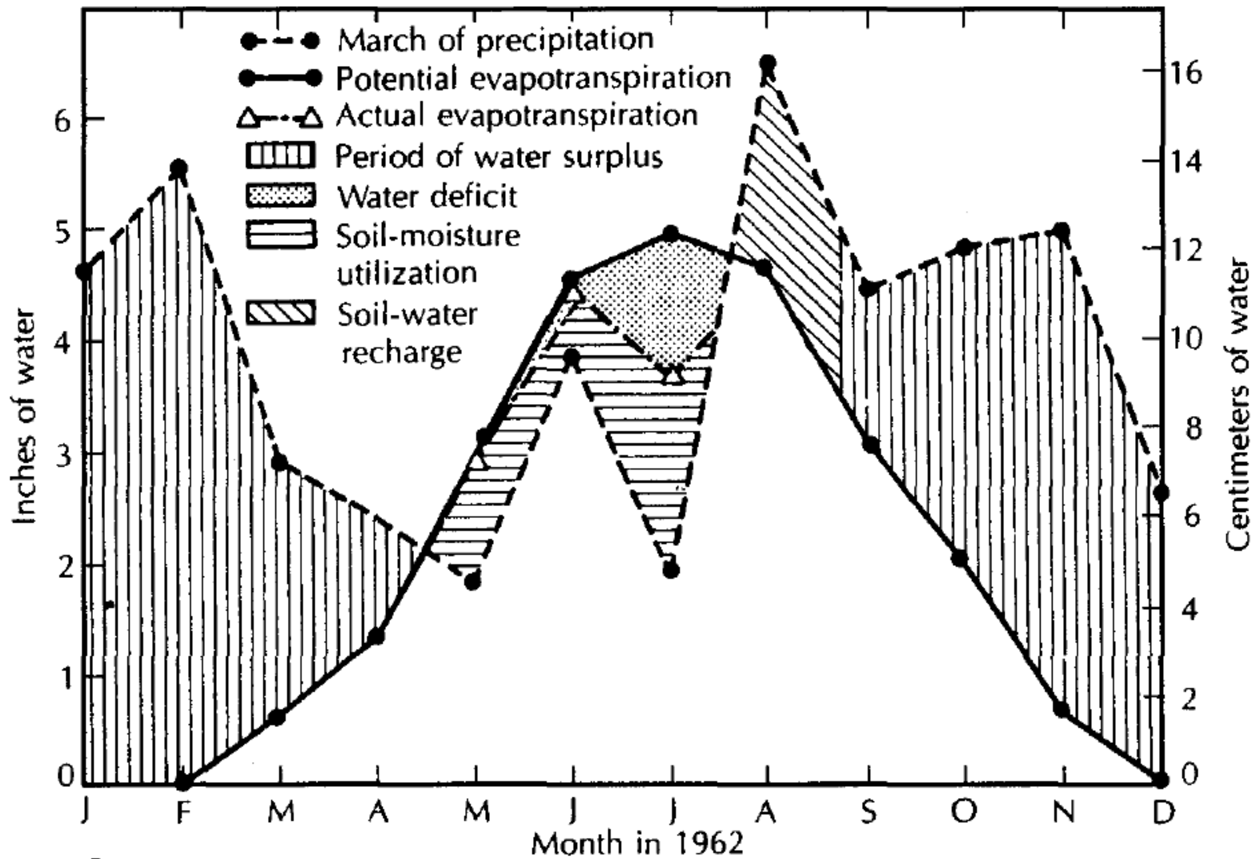
Evapotranspiration reduces soil moisture and precipitation/ snow melt increase it

Surplus water becomes runoff or infiltrates. Infiltrated water can recharge groundwater.

Moisture travels downwards by gravity flow (Green-Ampt's conceptualization)

When force of gravity = surface tension, gravity drainage stops, this is the field capacity.

Further drop in soil moisture results in a moisture content at which plants can no longer withdraw it, this is the wilting point.



Soil moisture budget for Bridgehampton, New York. From Fetter.

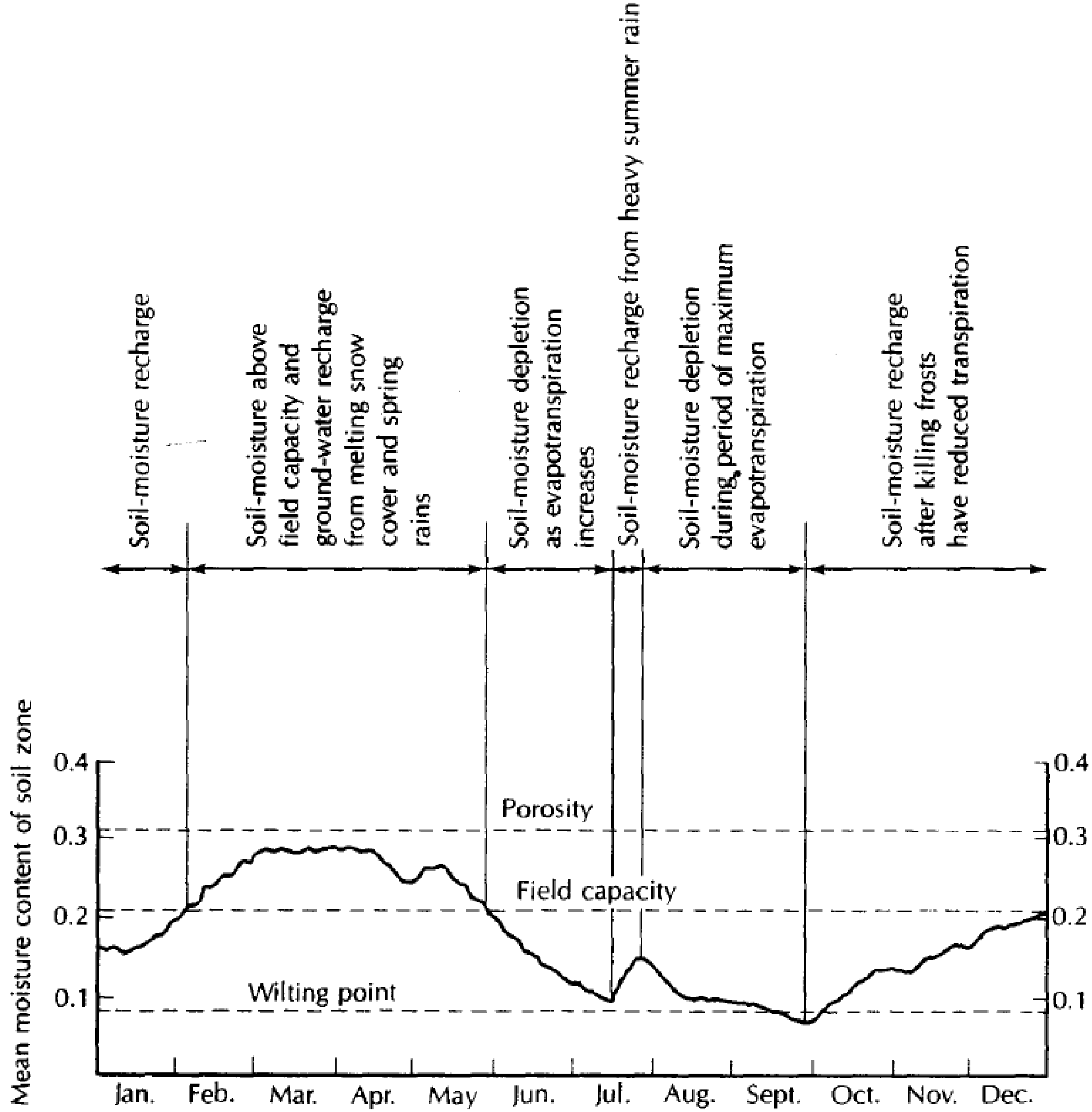
Occasional rainstorms in summer not likely to induce recharge.

If evapotranspiration slows, soil moisture can increase if rainfall and infiltration continue.

Water in a soil above the field capacity will drain downward if the soil is permeable.

If the soil has very low permeability, land will become water logged, and there will be little to no recharge.

Preferential flow paths allow GW recharge even in conditions of soil moisture deficit.



Hypothetical fluctuation of soil moisture for sandy loam soil through an annual cycle in a region with a moderate rainfall (50-75 cm) and heavy rains in spring. From: Fetter

Infiltration to recharge:

A) Infiltration begins with a saturated top soil layer. Here, rainfall > infiltration capacity. Rate of downward movement of soil moisture is controlled by the vertical hydraulic conductivity of the soil

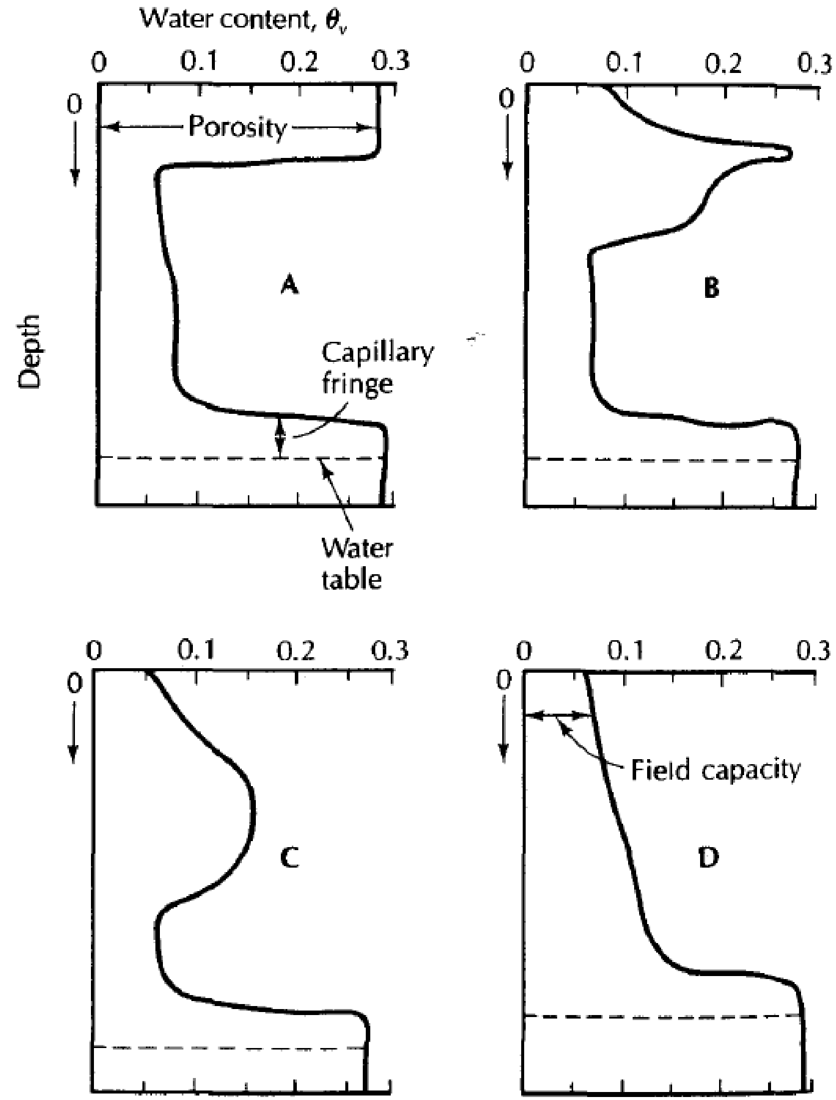
B) Infiltration stops. Downward movement continues.

C) All vertical sections above GW table are unsaturated, downward movement is controlled by the unsaturated hydraulic conductivity.

D) Moisture reaches the water table and raises it.

Time of movement of infiltrating water to the GW table = f(thickness of the unsaturated layer, vertical unsaturated hydraulic conductivity of the soil)

Water may take anywhere between a few hours to a few years to pass through the unsaturated zone!



Hypothetical fluctuation of soil moisture for sandy loam soil through an annual cycle in a region with a moderate rainfall (50-75 cm) and heavy rains in spring. From: Fetter

Soil moisture and water table elevation

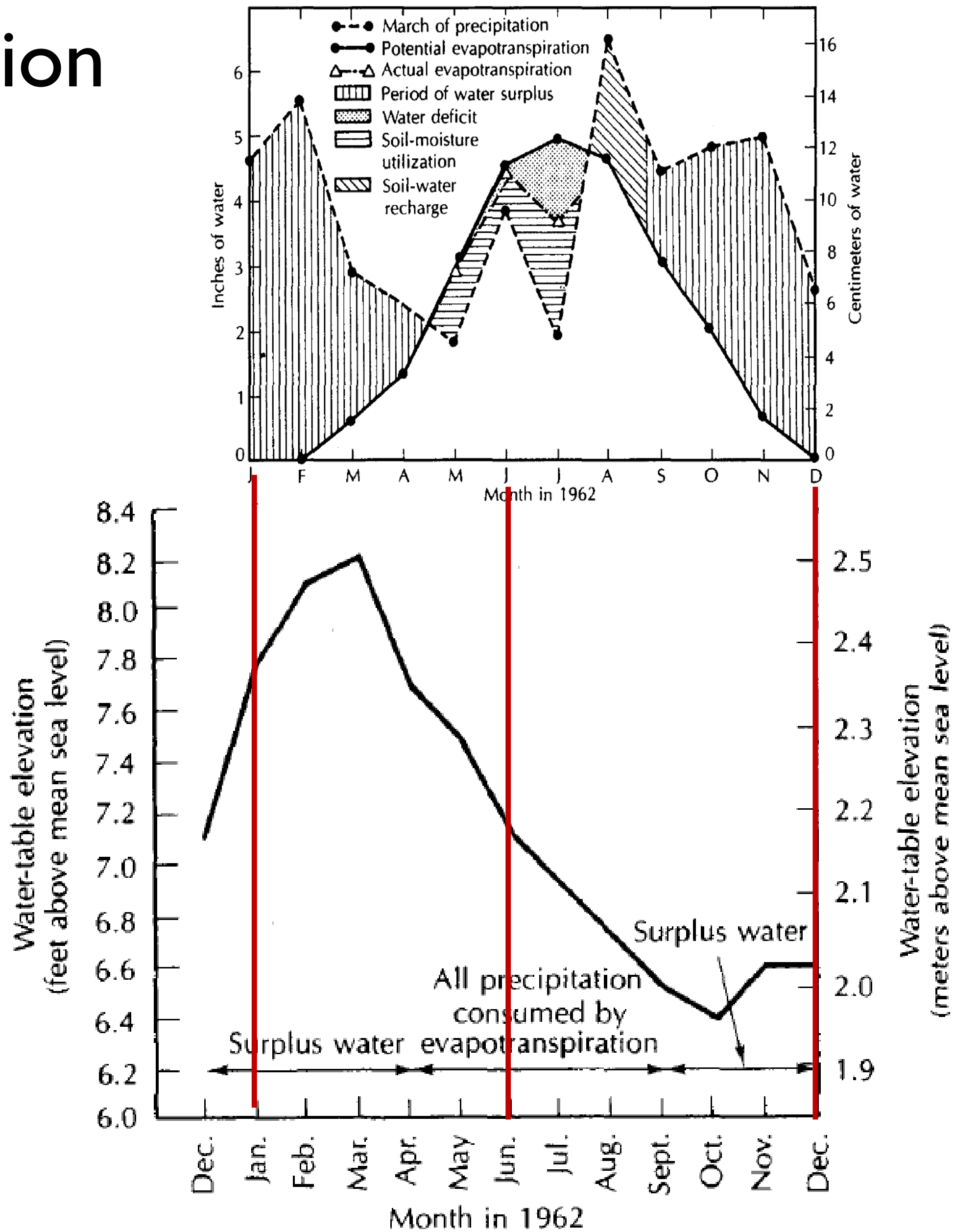
Groundwater is flowing out to streams and springs.

A decline in water levels occurs when there is no recharge or recharge is less than groundwater outflow.

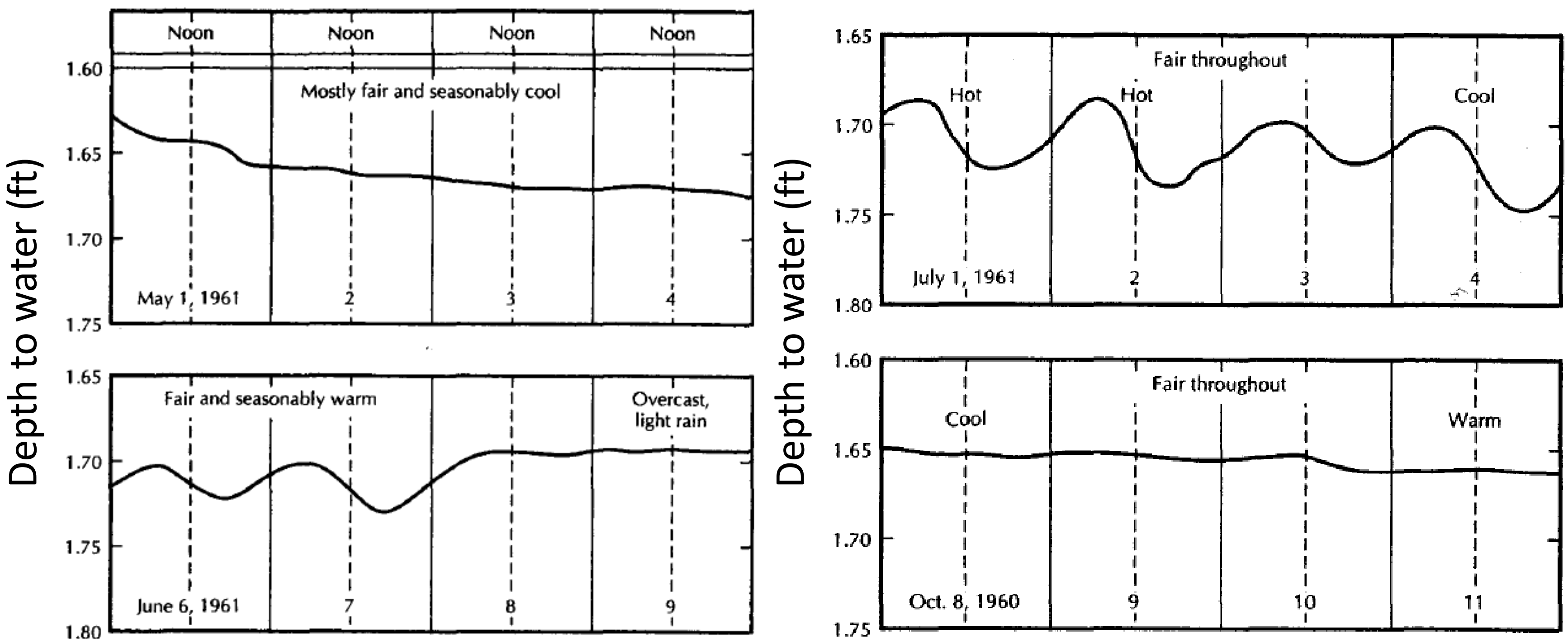
March peak corresponds to snow melt and spring rains.

Rising trend in November is due to recharge from surplus water in that period.

Relatively quick response of water table to soil moisture changes.



Direct evapotranspiration of groundwater occurs when capillary fringe reaches the land surface



Greater evapotranspiration during the day may cause diurnal variations in groundwater levels.

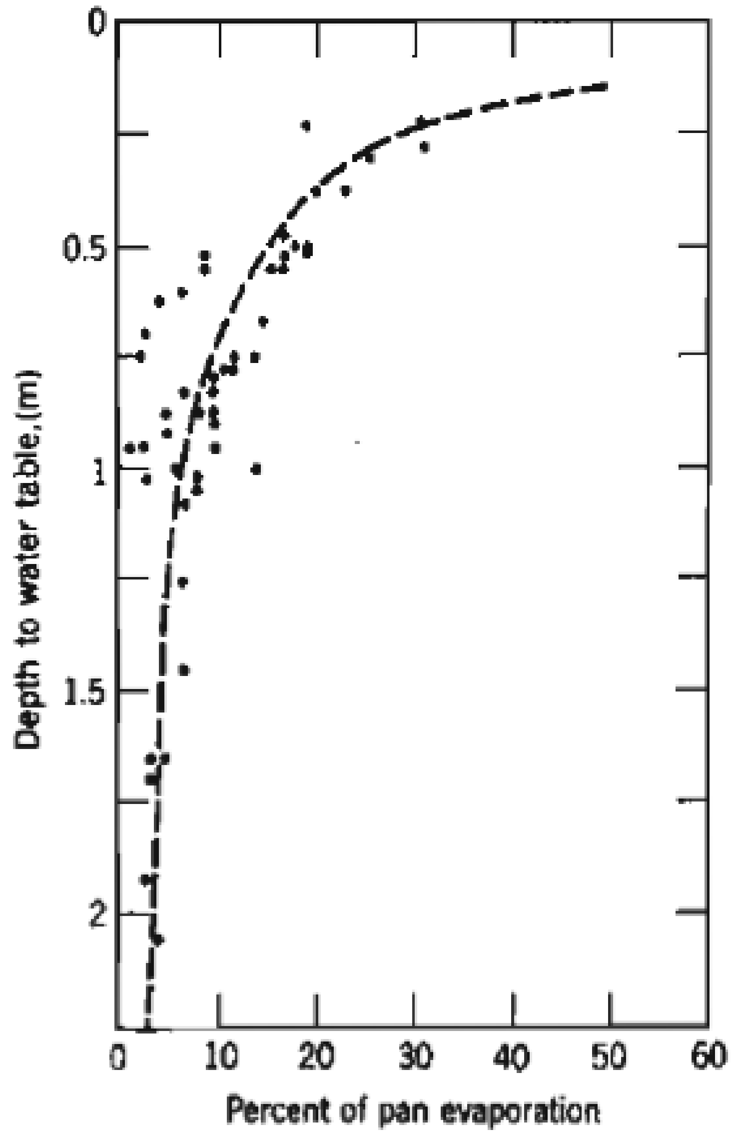
Evaporation of groundwater as a function depth to water table

More evaporation as water table is closer to the surface

Rate of evaporation depends upon the soil structure (capillary tension and hydraulic conductivity)

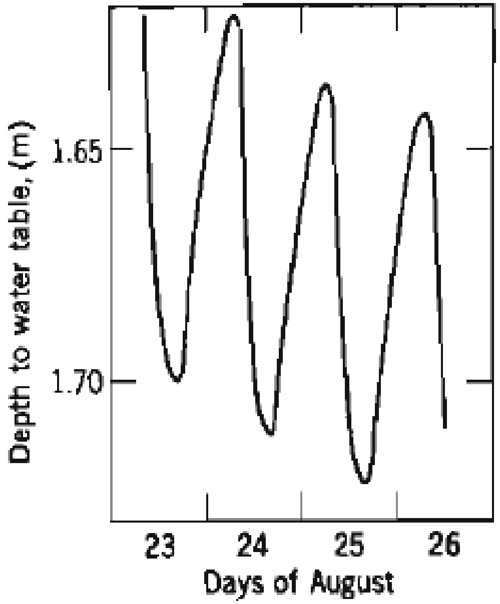
Near the surface (within 1m): evaporation is controlled by atmospheric conditions

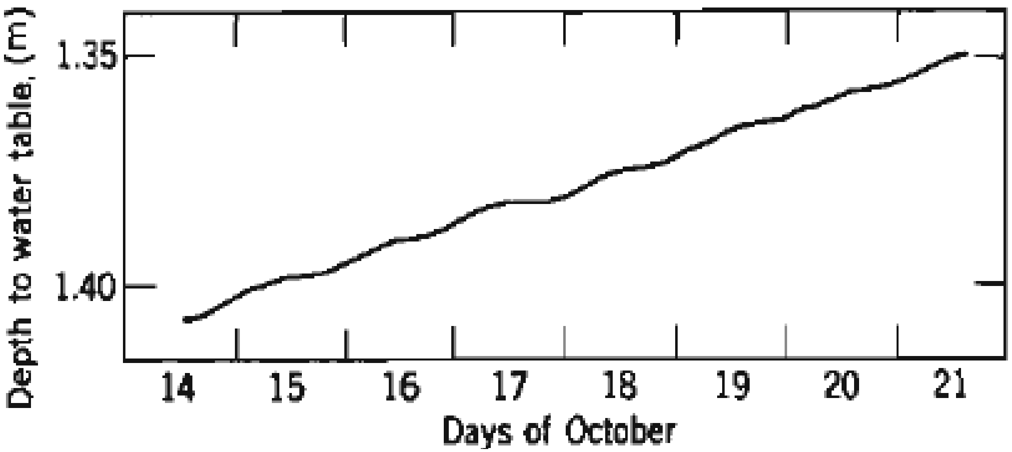
Deeper: evaporation is controlled by soil properties, sharp decrease of evaporation with depth



Transpiration from groundwater=f(vegetation, season, weather)

Fluctuation of GW in a well in a thicket of willows. Rapid foliage growth in August causing daily fluctuations averaging about 10 cm. Water table is 1.5 to 1.8 m below the ground surface.





Heavy frost and dormant vegetation (leaves have fallen), negligible diurnal fluctuations

Image: http://www.askthewillows.com/who-are-the-willows/ (left)
https://commons.wikimedia.org/wiki/File:Pollard_willows,_Arnhem,_the_Netherlands.jpg (right)

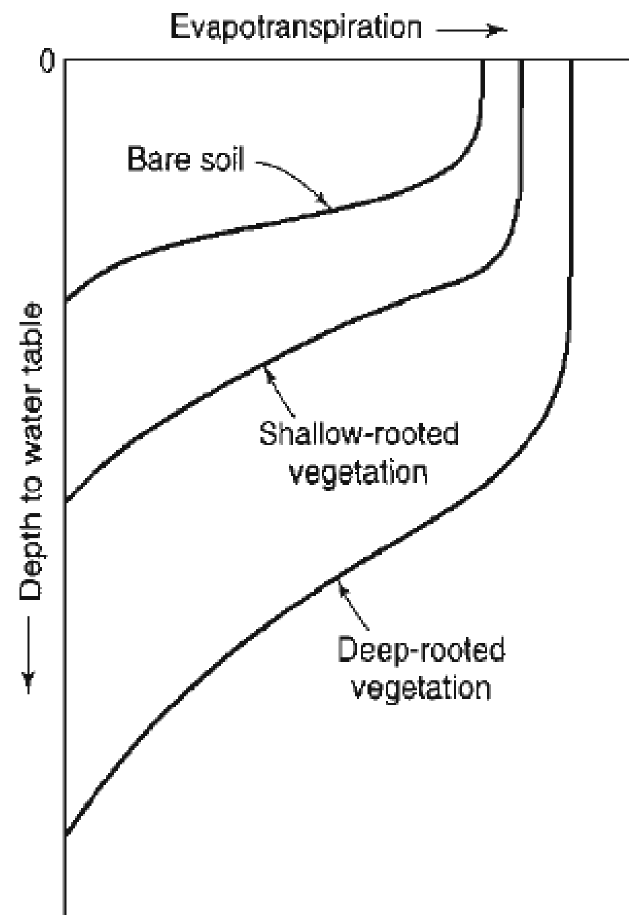
Generalized variation of evapotranspiration (consumptive use) from groundwater

It is hard to separate the effects of evaporation and transpiration

A combination of the two, termed, evapotranspiration, or, consumptive use, represents the total loss of water to atmosphere

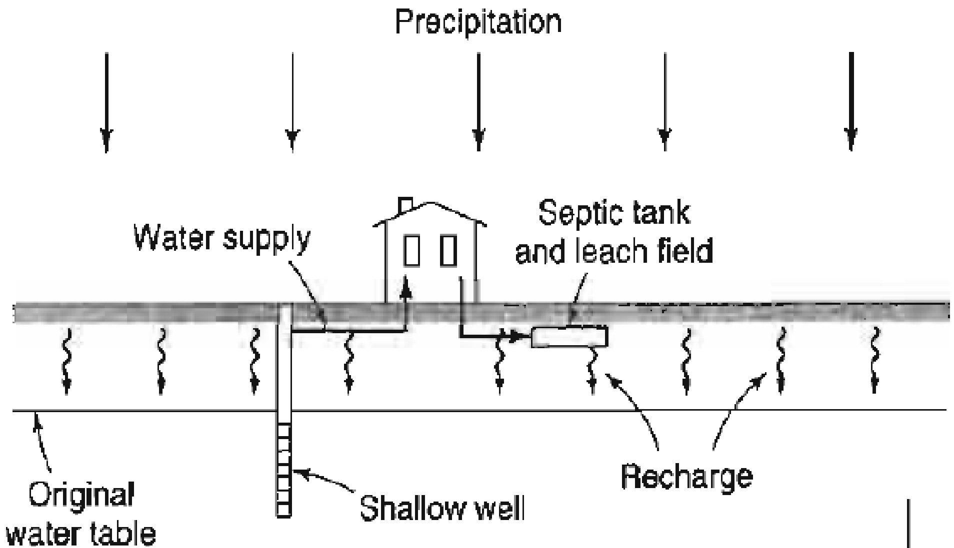
Generally, evapotranspiration rates depend upon the type of the surface

Deep rooted vegetation can penetrate to great depths to extract water from groundwater



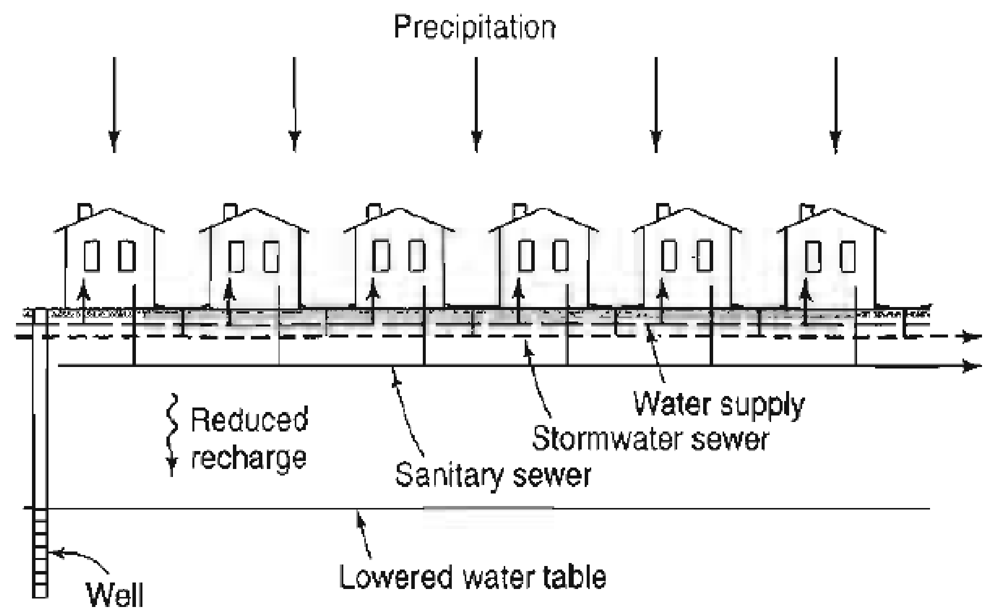
ROLE OF HUMANS

Urbanization: decreases recharge, increases extraction



Shallow wells and septic tanks in rural areas

Deep wells and sewer systems in urban areas



Urbanization affects the overall hydrologic budget, including the GW components