CE 626

Regional Groundwater

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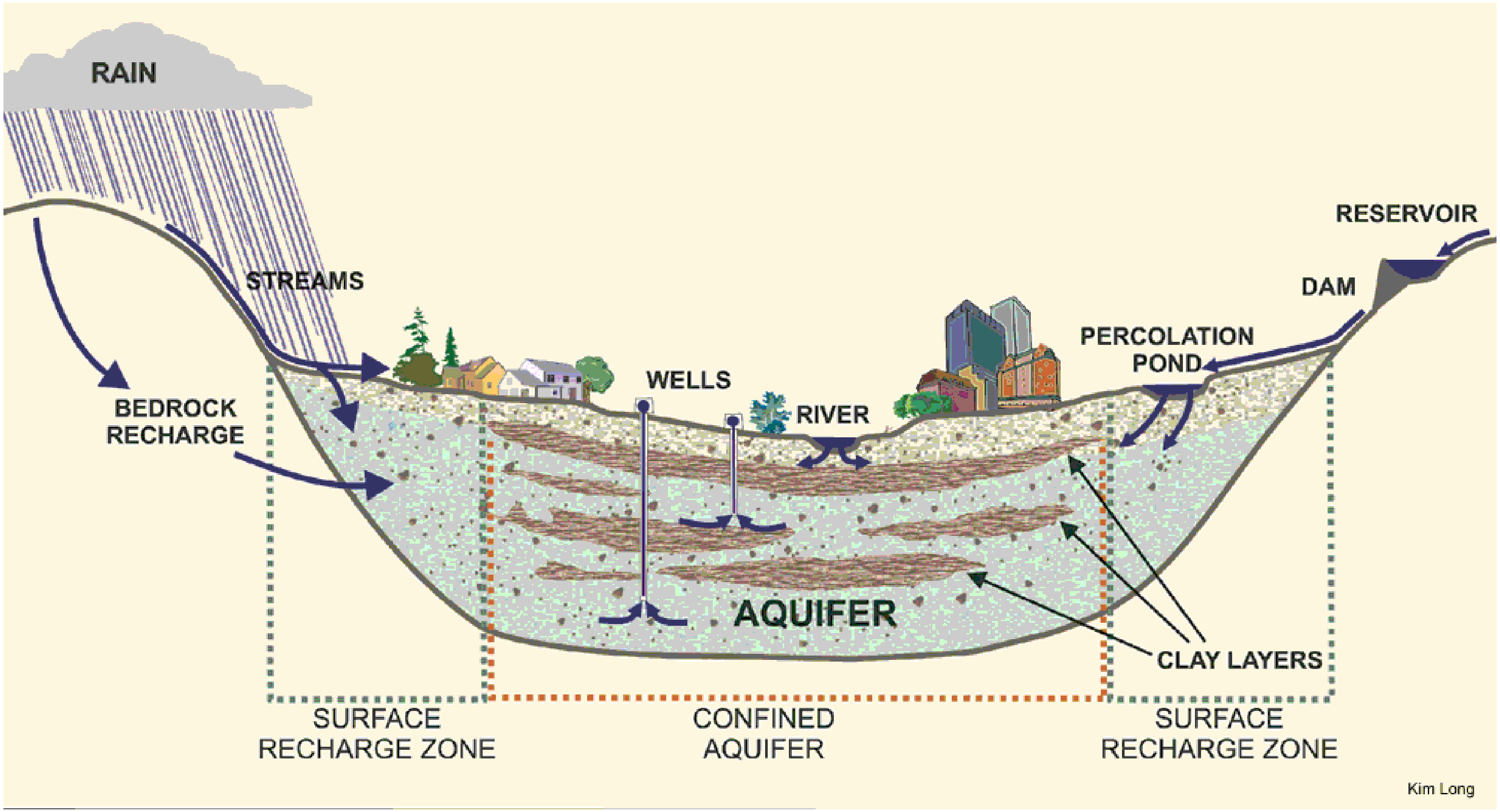
Lecture 9

Today we will learn about…

- Groundwater basin
- Groundwater flow systems

REGIONAL GROUNDWATER FLOW

Groundwater basins: volume of the subsurface through which groundwater flows from areas of recharge to discharge



http://explore.museumca.org/creeks/z-groundwater.html

Catchment scale water balance:

$$P = \left(Q_{out} - Q_{in}\right) + \left(Q_{gw,out} - Q_{gw,in}\right) + E \pm \Delta S_s \pm \Delta S_G$$

P: precipitation, Q: streamflow, Q_{gw}: groundwater flow, E: evapotranspiration
S_s: surface storage, S_g: groundwater storage

Groundwater reservoir or basin water balance:

$$\Delta S_G = Q_{g,\mathrm{in}} + RR + RF + AR + S_{lake} + S_{canal} - Q_{g,out} - S - E - W$$

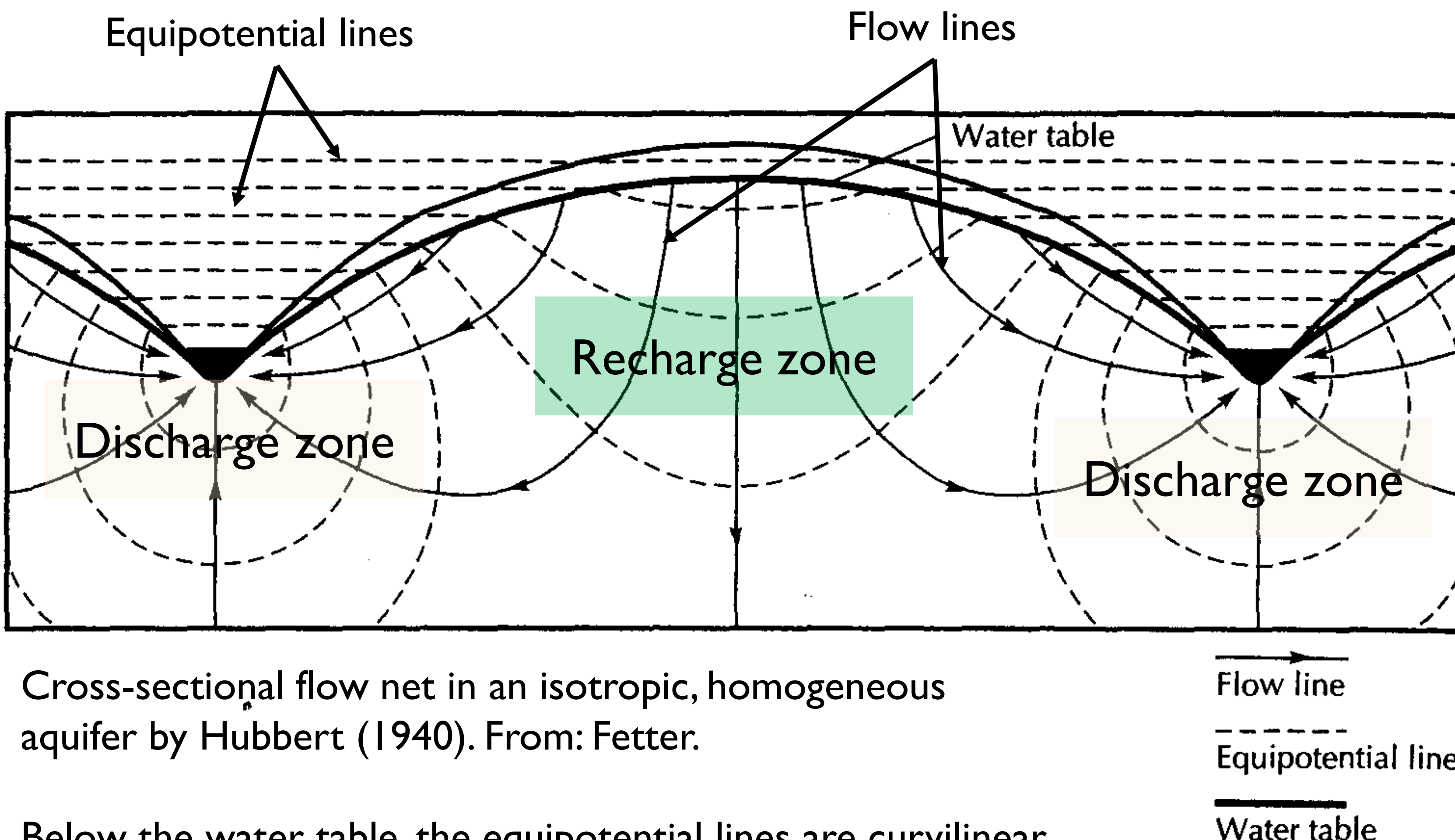
S_g: groundwater storage, $Q_{gw,in/out}$: groundwater in/out flow, RR: rainfall recharge, RF: return flow from irrigation, AR: artificial recharge, $S_{lake, canal}$: seepage from lakes or canals, S: spring discharge, E: evapotranspiration losses when water table is close to surface, W: groundwater withdrawal by pumping

Recharge vs. discharge areas (unconfined aquifers)

- Recharge areas:
  - Topographically higher
  - Deep unsaturated zone between water table and land surface
  - Flow lines diverge from recharge areas
- Discharge areas:
  - Topographic lows
  - Water table relatively close to (or at) the land surface
  - Flow lines converge to discharge areas
  - Located by identifying presence of vegetation or surface water, in the form of spring, seeps, lakes, or streams

Water table in unconfined aquifers generally has the same shape as the surface topography (humid regions)

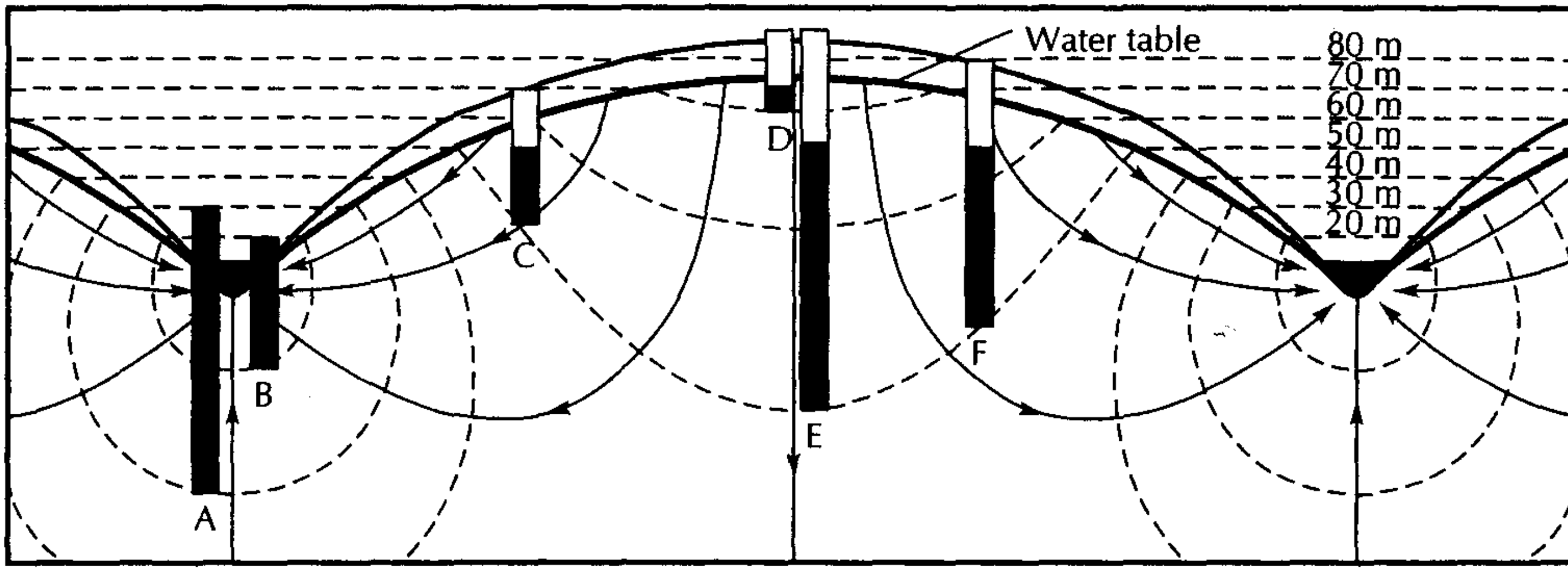
Groundwater flow in homogeneous aquifers



Cross-sectional flow net in an isotropic, homogeneous aquifer by Hubbert (1940). From: Fetter.

Below the water table, the equipotential lines are curvilinear, reflecting the sum of elevation and pressure heads.
Recharge zone: hill, discharge zone: valleys

Water level in piezometer rises to the elevation of the hydraulic head



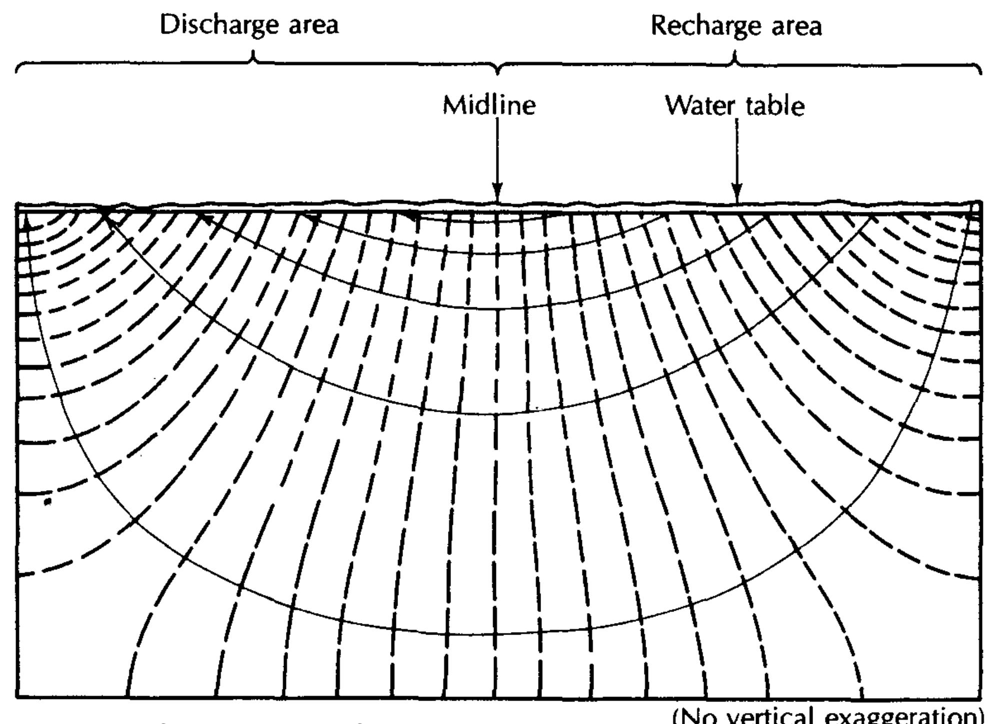
Piezometers superimposed on the isotopic, homogeneous, aquifer. by Hubbert (1940). From: Fetter.

C, E, F: are on the 50 m equipotential line, thus the water level in each rises to the same height. Length of the water column varies.
A and B are nearly at the same location but A is deeper than B and has a greater head, thus hydraulic gradient is upward in the discharge zone.

Toth (1962) proposed an analytical solution to the Laplace equation for the case when water table has a linear slope

$$h = g\left(z_o + \frac{\tan\alpha L}{2}\right) - \frac{4g\tan\alpha L}{\pi^2}\sum_{m=0}^{\infty}\frac{\cos\left[(2m+1)\pi x/L\right]\cosh\left[(2m+1)\pi z/L\right]}{(2m+1)^2\cosh\left[(2m+1)\pi z_o/L\right]}$$

H: head(L),
g: gravitational constant (L/T^2),
z_o: elevation of the water table at its lowest point above the bottom of the aquifer (L),
z: elevation of the water table above the bottom of the aquifer (L),
tanα: slope of the water table,
L: length of the flow system (L),
x: horizontal distance from the place where the water table is at its lowest elevation (L)



Regional flow pattern for sloping linear topography and water table. From: Fetter.

Toth also showed the presence of local, intermediate and regional flow systems

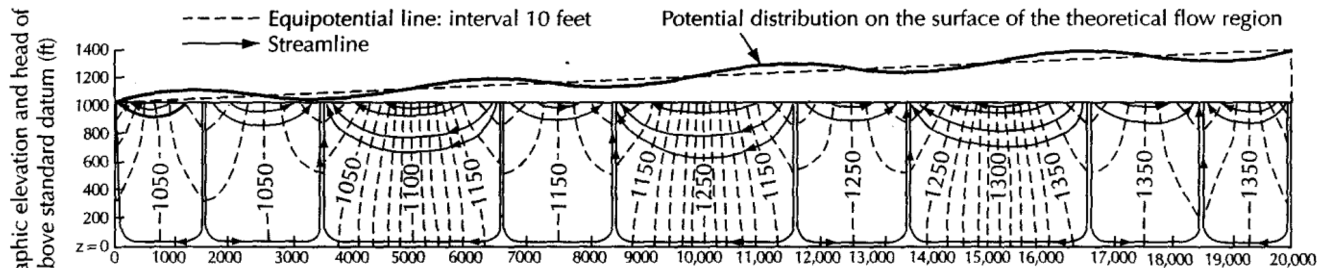
Well-defined local relief gives rise to local GW systems (humid regions)

Topographic relief causes undulations in the water table.

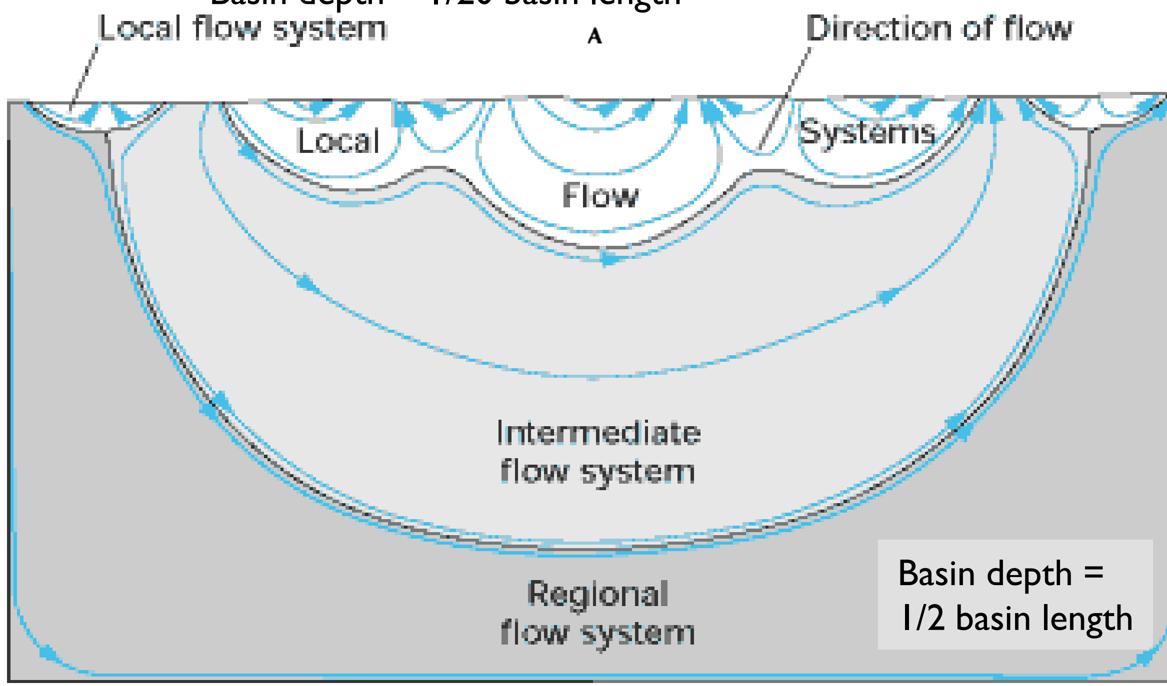
Local GW systems have recharge area at topographic highs and discharge area at adjacent topographic lows

Intermediate flow systems have at least one local flow system between their recharge and discharge areas

Regional flow systems have recharge area at the basin divide and discharge area at the valley bottom



Basin depth = 1/20 basin length

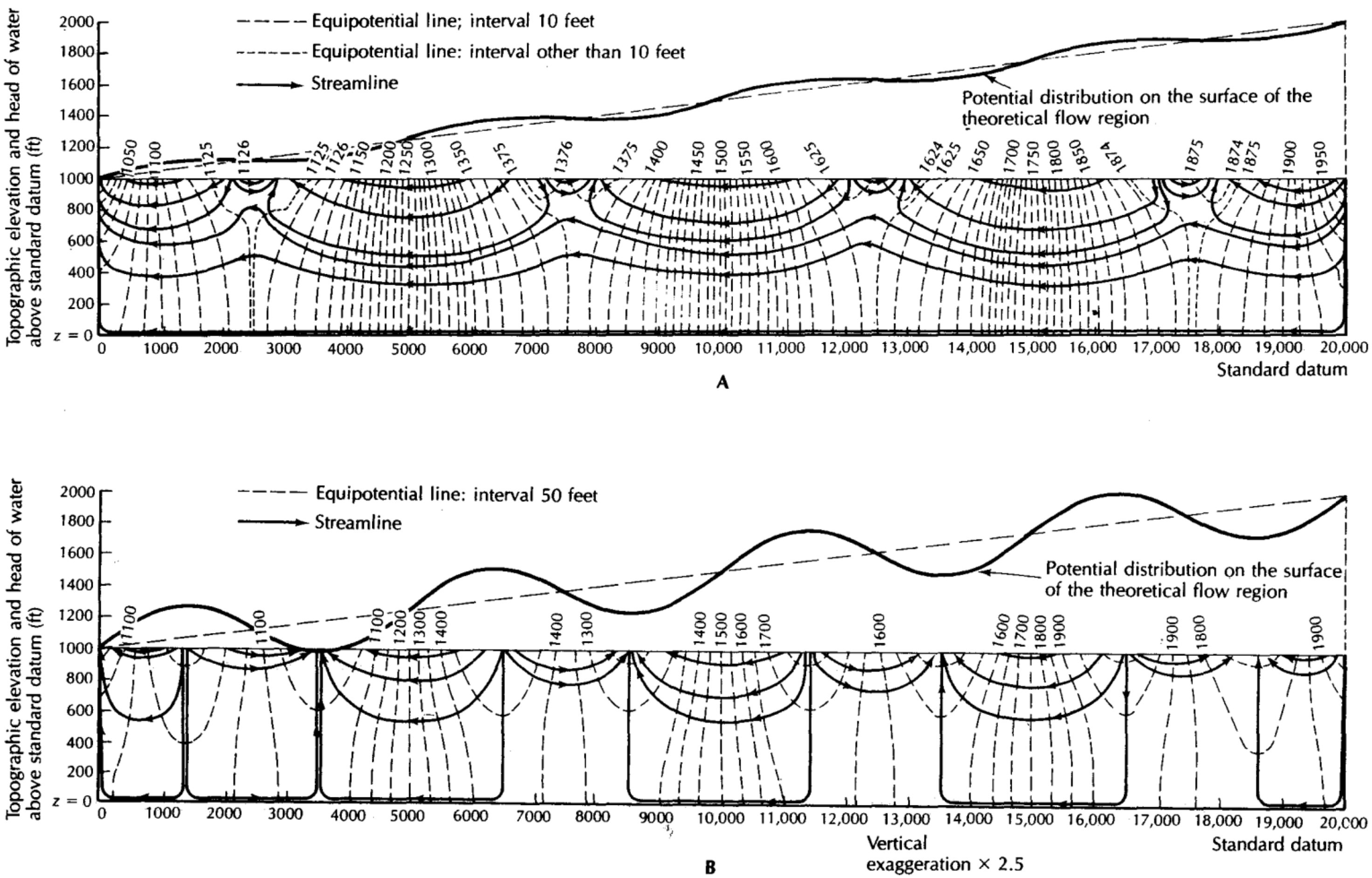


Basin depth = 1/2 basin length

https://pubs.usgs.gov/circ/circ1139/htdocs/boxa.htm

Role of basin depth to length ratio in developing local, intermediate, and regional flow systems. From: Fetter

Greater undulations in water table may lead to formation of only local systems even for higher depth to length ratios

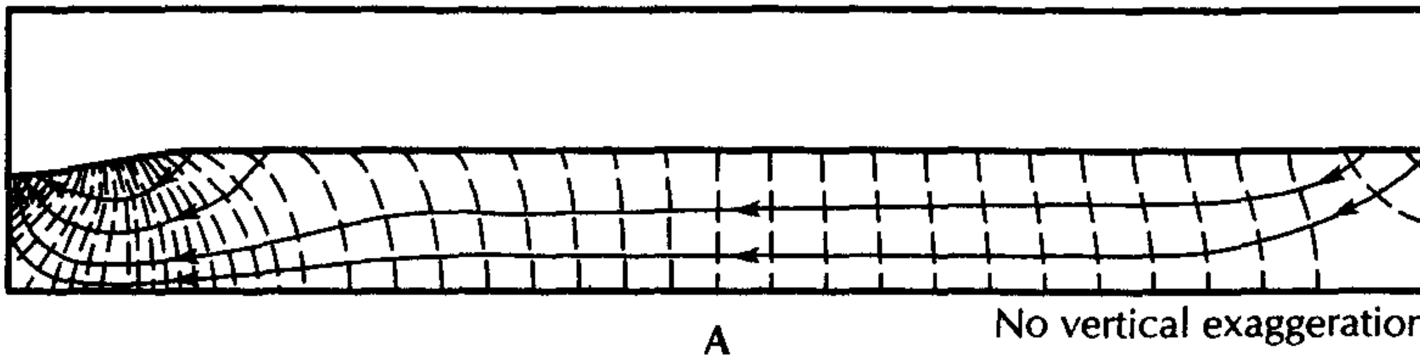


Amplitude of undulation in the water table controls the depth of local flow systems. (A) low amplitude, (B) high amplitude. From: Fetter

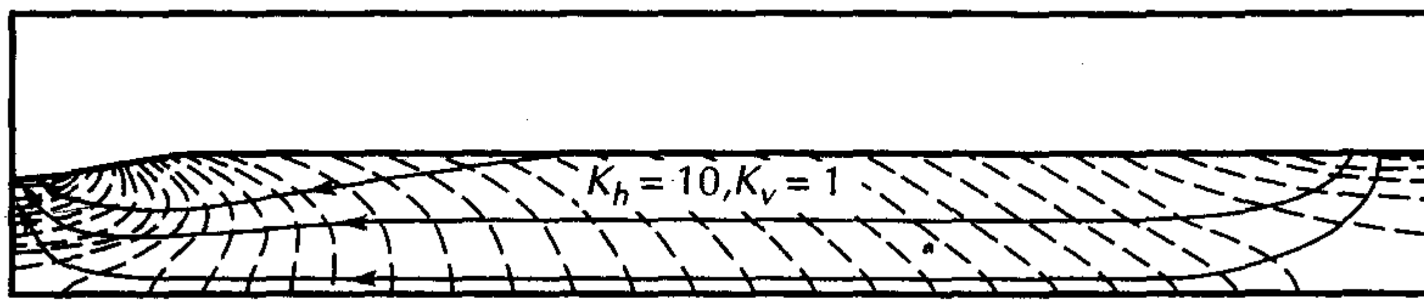
Local, intermediate and regional flow systems: differences

Characteristics	Local flow system	Regional flow system
	Areas of rapid circulation of GW, much more active in hydrologic cycle	Long residence times, not very active hydrologically
Flow paths	Short	Long
Speed of movement	High	Slow
Depth of movement	Shallow	Deep
Degree of mineralization (contact with aquifer material and resulting chemical transformations in water)	Low	High
Time spent as groundwater	Low	High
Temperature	Close to air temperature	Can be elevated due to geothermal gradients (2.5°C per 100 m)
Ratio of surface area where recharge takes place to volume of water stored in that region	High	Low

Freeze and Witherspoon (1966, 1967) developed a numerical method of solving the Laplace equation



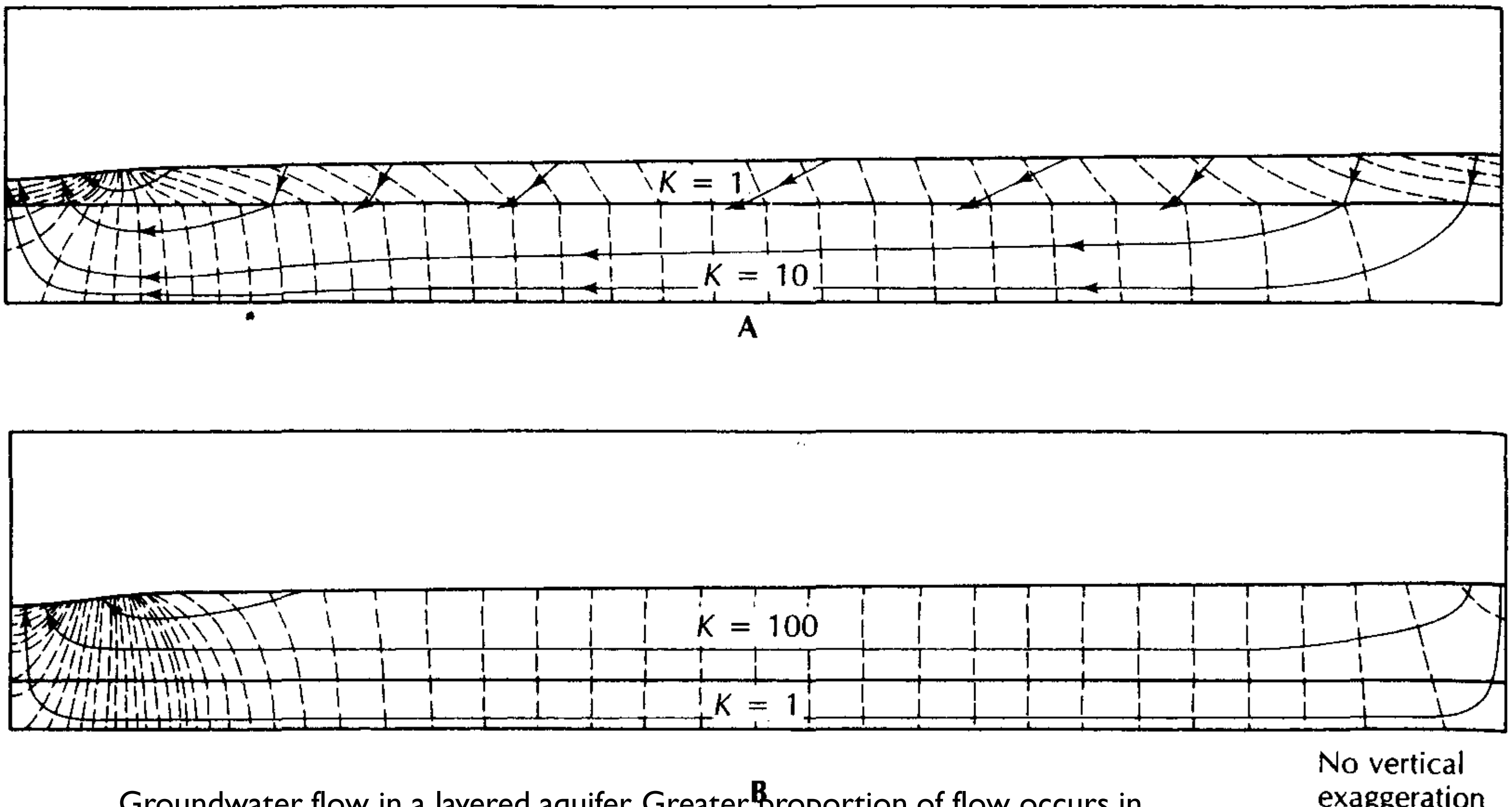
A



B

Groundwater flow in an aquifer with two linear slopes, one being much steeper and covering only a small portion of the lower part of the groundwater basin. (A) Isotropic homogeneous aquifer, (B) Horizontal hydraulic conductivity ten times the vertical. From: Fetter.

Impact of layering in aquifers



Groundwater flow in a layered aquifer. Greater proportion of flow occurs in the layer with higher hydraulic conductivity. From: Fetter.