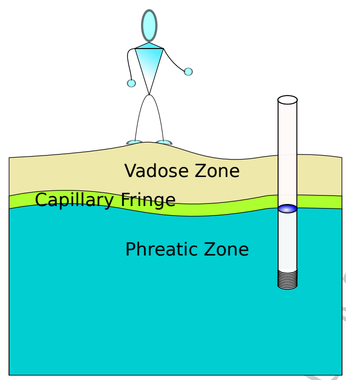
1 Terms

Hydraulic Subsurface Zones

- Vadose Zone
- Phreatic Zone
- Capillary Fringe



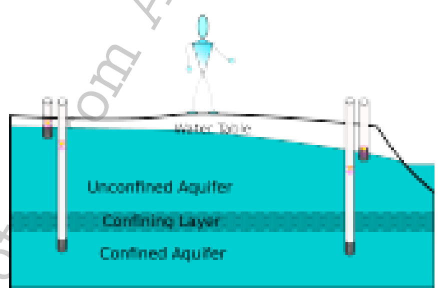
Hydrogeologic Units

Aquifer

- Unconfined
- Confined

Confining Units

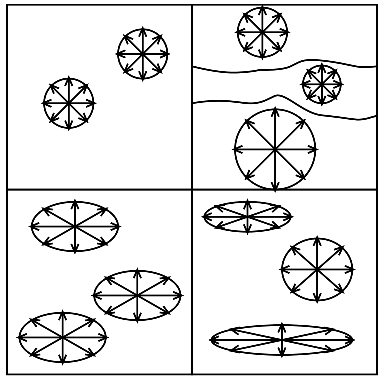
- Aquitard: impedes flow
- Aquiclude: low K, significant storage
- Aquifuge: low K, little storage



2 Heterogeneity

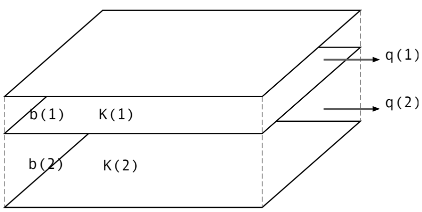
Heterogeneity and Anisotropy

Geologic materials are rarely uniform. The material properties (hydraulic conductivity, porosity, etc.) change with position and direction. These variations will influence flow.



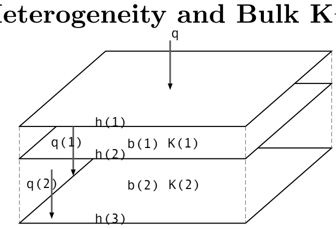
Heterogeneity and Bulk K_H

- geologic settings is typically layered
- flow in direction of layers
- weighted average



$$K_H = \sum_i \frac{b_i \cdot K_i}{b_{total}}$$

Heterogeneity and Bulk K_V



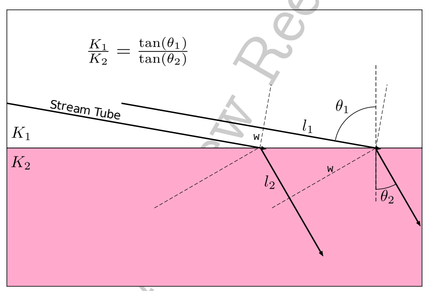
$$K_V = \frac{b_{total}}{\sum_i \frac{b_i}{K_i}}$$

$$q_{total} = q_1 = q_2$$
$$K_{bulk} \cdot \frac{dh}{dl}_{bulk} = K_1 \cdot \frac{dh}{dl}_1 = K_2 \cdot \frac{dh}{dl}_2$$
$$K_{bulk} \cdot \frac{h_3 - h_1}{b_{total}} = K_1 \cdot \frac{h_2 - h_1}{b_1} = K_2 \cdot \frac{h_3 - h_2}{b_2}$$
$$K_{bulk} \cdot \frac{h_3 - h_1}{b_{total}} = Kbulk \cdot \frac{(h_3 - h_2) + (h_2 - h_1)}{b_{total}}$$
$$i_{total} = \frac{h_3 - h_1}{b_{total}}$$
$$K_{bulk} \cdot i_{total} = \frac{K_{bulk}}{b_{total}} \left(\frac{b_1 \cdot K_{bulk} \cdot i_{total}}{K_1} + \frac{b_2 \cdot K_{bulk} \cdot i_{total}}{K_2} \right)$$
$$1 = \frac{K_{bulk}}{b_{total}} \left(\frac{b_1}{K_1} + \frac{b_2}{K_2} \right)$$
$$\frac{b_{total}}{\frac{b_1}{K_1} + \frac{b_2}{K_2}} = K_{bulk}$$

Tangent Law

- Groundwater flow refracts across layers
- refracts 'into' unit of lower K
- discharge in stream tube must be constant across layers
  - stream tube is an arbitrary region bounded by flow lines

Tangent Law

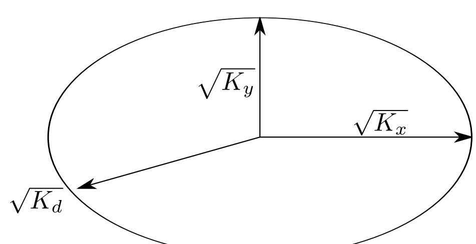


$$Q_1 = Q_2 : K_1 \cdot w_1 \frac{dh}{l_1} = K_2 \cdot w_2 \frac{dh}{l_2}$$
$$\frac{K_1 \cdot dh}{tan(\theta_1}) = \frac{K_2 \cdot dh}{tan(\theta_2})$$
$$\frac{K_1}{tan(\theta_1)} = \frac{K_2}{tan(\theta_2)}$$

3 Anisotropy

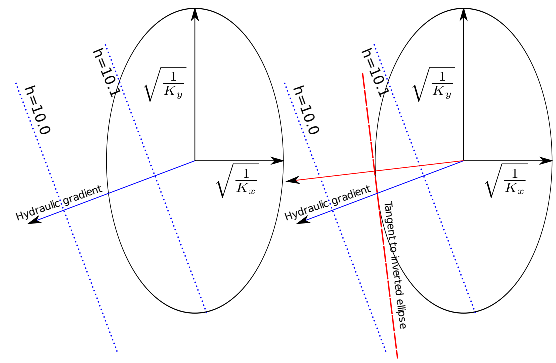
Ellipsoid of Conductivity

- Representation of variation in hydraulic conductivity with direction.
- Flow driven by gradient and shaped by K
- 3-D (shown in 2-D in these slides)

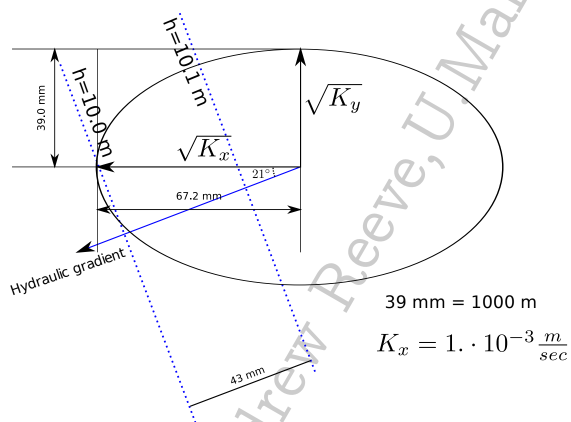


Inverse Ellipse

Graphical method for determining flow direction in anisotropic setting



Vector Method



Vector Method

Problem-solving steps:

- make sure drawn to scale
- align coordinate system with ellipse of K
- calc. components of hydraulic gradient
- calc. components of hydraulic cond.
- calc. q_x and q_y
- use components of q to determine flow magnitude and direction

Vector Method

$$\frac{\sqrt{K_x}}{\sqrt{K_y}} = \frac{67.2}{39.0}$$

$$K_x = 10^{-3} \rightarrow Ky = 3.4 \cdot 10^{-4}$$

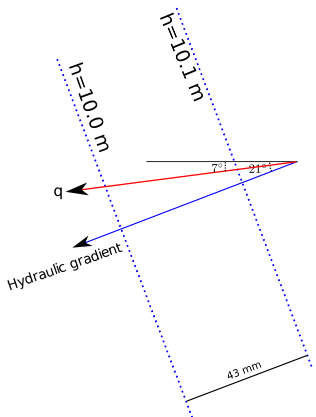
$$\frac{dh}{dl} = \frac{10.1 - 10.}{43 \cdot 1000/39} = 9.1 \cdot 10^{-5}$$

$$\frac{dh}{dx} = \frac{dh}{dl} \cdot \cos(21.^\circ) = 8.47 \cdot 10^{-05}$$

$$\frac{dh}{dy} = \frac{dh}{dl} \cdot \sin(21.^\circ) = 3.25 \cdot 10^{-05}$$

$$qx = -Kx\frac{dh}{dx}$$
$$qy = -Ky\frac{dh}{dy}$$
$$q = \sqrt{qx^2 + qy^2}$$
$$angle = \tan(\frac{qy}{qx}) = 7.44°$$

Vector Method



4 Characterizing Units

Characterizing Subsurface Geology

- Maps
  - topography
  - hydrography
  - geology at surface
- Drilling/Excavation
- Geophysics
  - Near Surface
  - Borehole

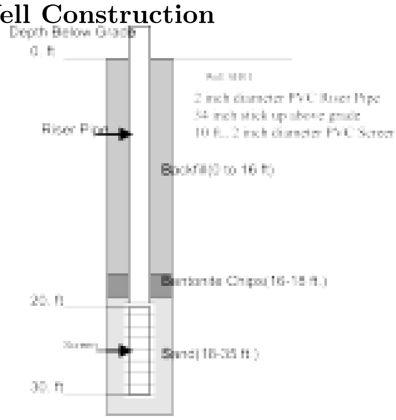
Drilling

- Direct Push
  - Cone Penetrometer (measures force required to advance tip)
  - Pore Pressure (estimate K)
  - Sample collection
- Augers (Hollow and Solid Stem)
  - Split Spoon
  - Shelby Tube
- Rotary (Air, Mud, Water)
  - Rock Cores
- Cable Tool

Well Construction

- Riser Pipe and Screen
- Sand Pack
- Bentonite Seal
- Grout or Backfill
- Protective Cover

Well Construction

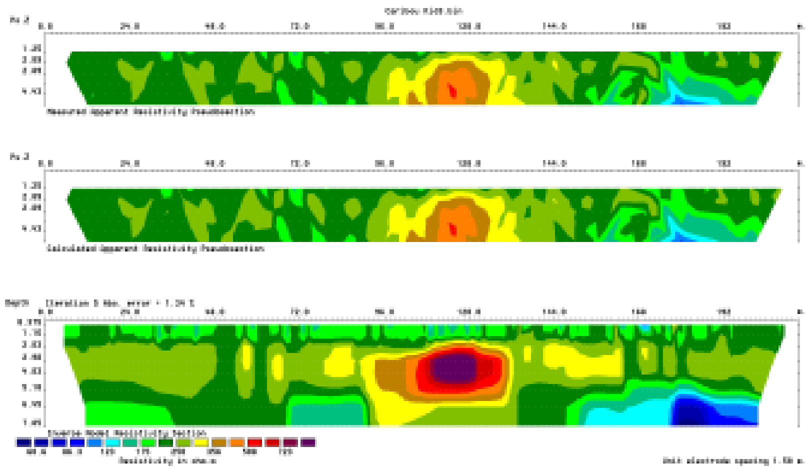


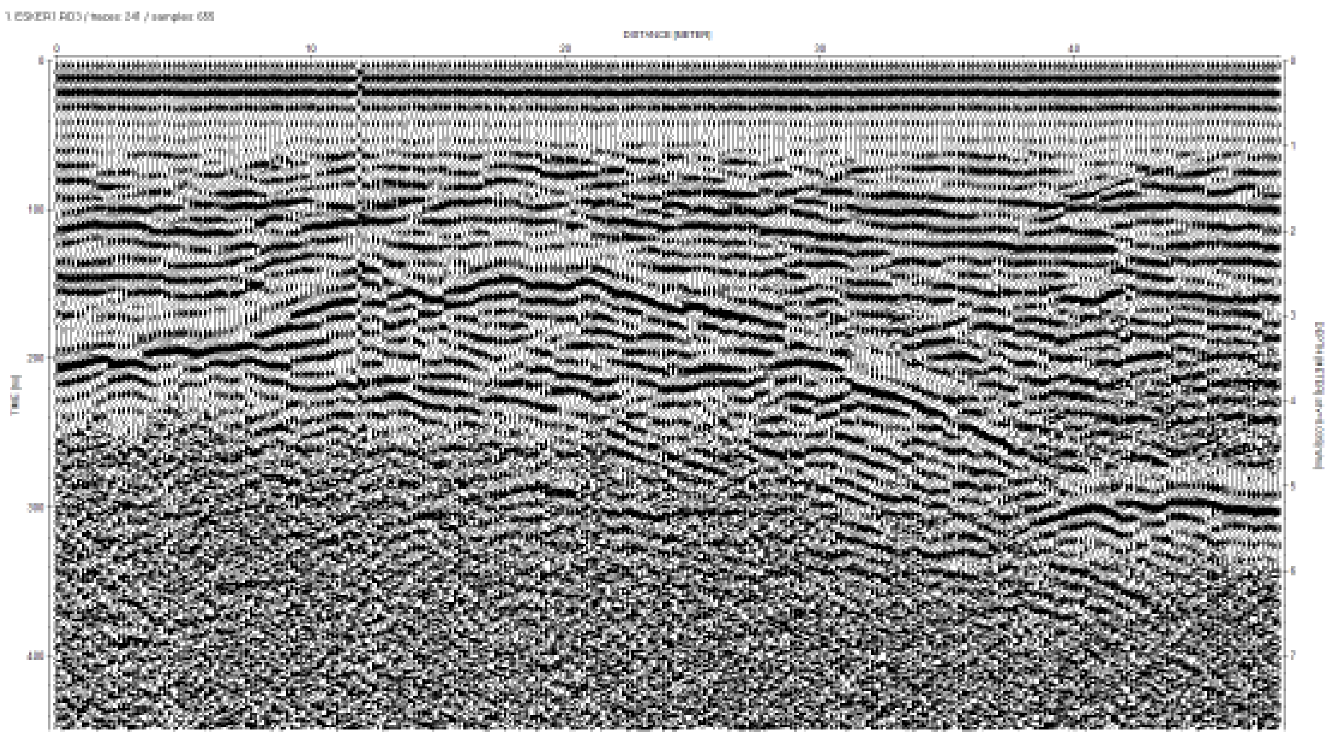
Near-Surface Geophysics

- Ground Penetrating Radar
- Seismic
- Resistivity
- Electromagnetics
- Magnetometry

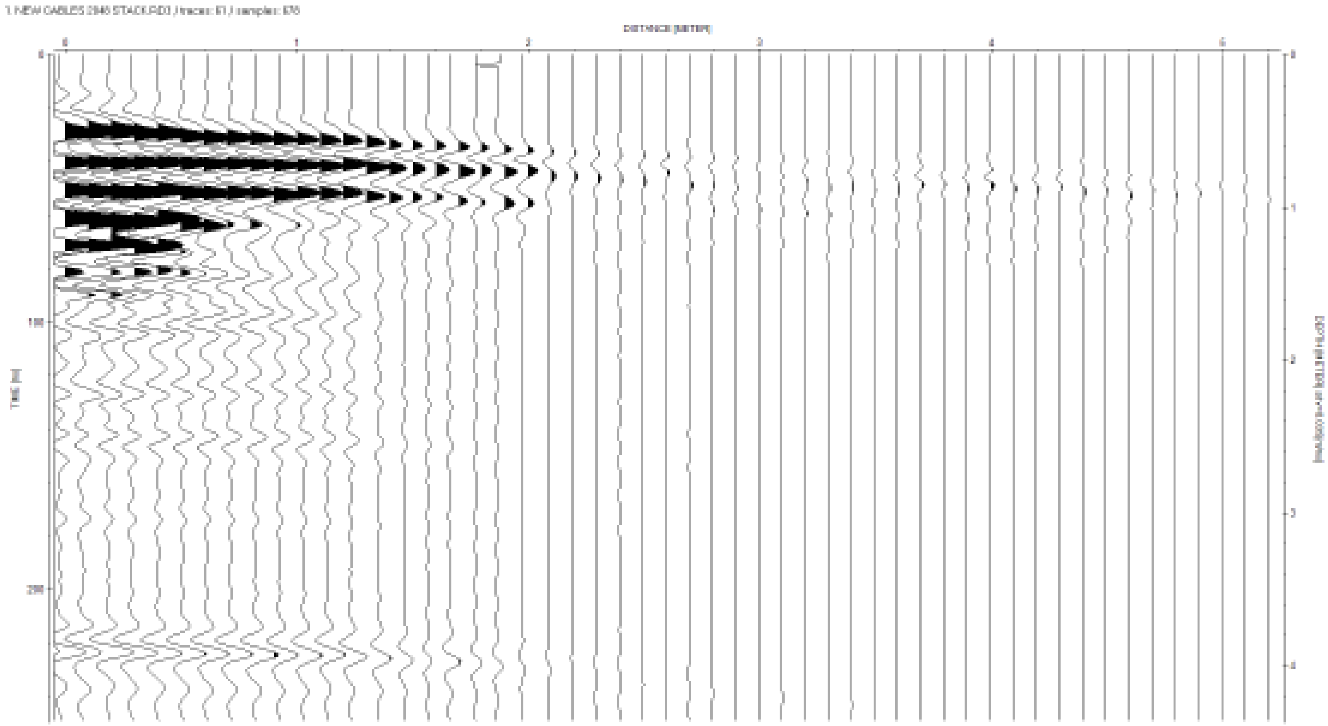
Near-Surface Geophysics

Near-Surface Geophysics





Near-Surface Geophysics

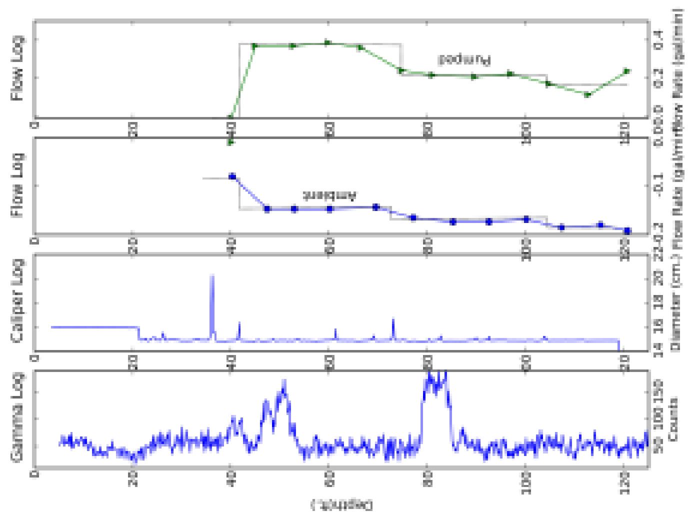


Borehole Geophysics

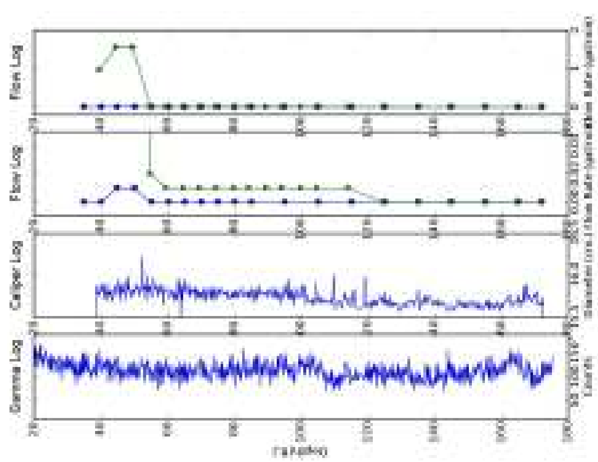
- Flow Measurements
  - Spinner
  - Heat Pulse
  - EM
- Televiewer
  - Acoustic
  - Optical
- Caliper
- Fluid Temperature
- Fluid Resistivity
- Gamma

Borehole Geophysics

Borehole Geophysics

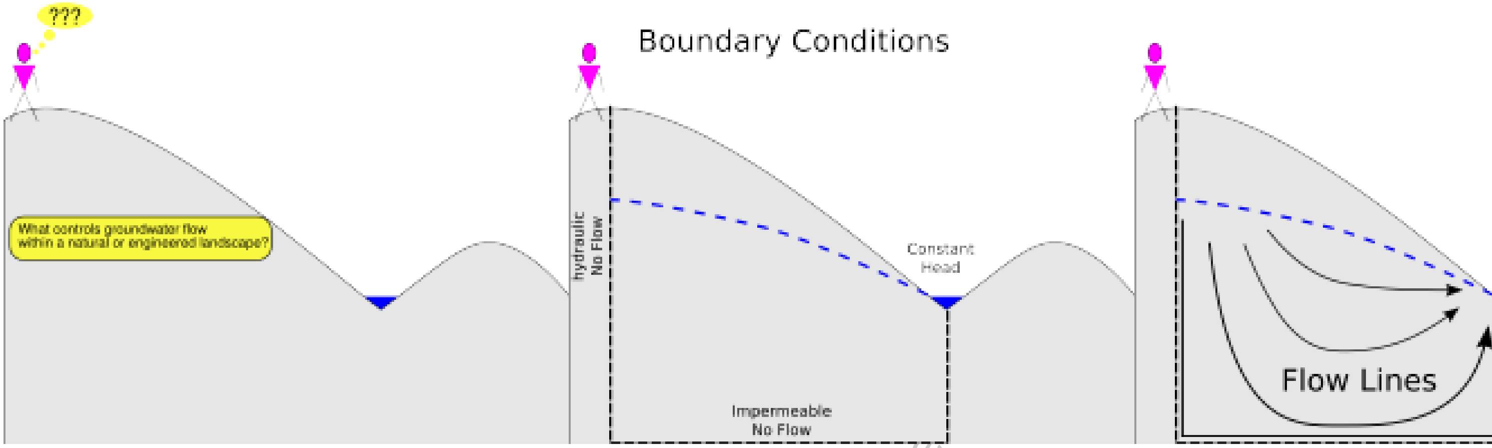


Borehole Geophysics



5 Idealized Flow

Conceptualizing Groundwater Flow



6 Groundwater/Surface Water

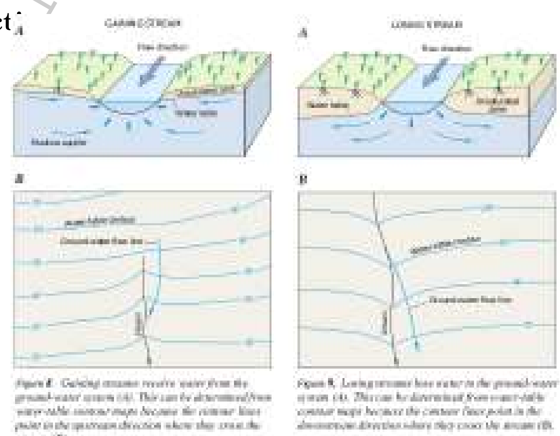
GW interaction with SW

- Surface-water data widely available
- Topography data widely available
- Water table is subdued and smoothed replica of land surface (w/caveats)
- Use available data to tentatively conceptualize groundwater flow

GW interaction with SW

- Surface water acts as constant head boundaries
- Equipotentials 'V' when crossing streams
  - Loosing
  - Gaining
- Lakes
  - Recharge
  - Discharge
  - Flow-Through

Stream-Groundwater Interact



T.C. Winter, J.W. Harvey, O.L. Franke, and W.M. Alley, 1998. Ground Water and Surface Water A Single Resource. U.S. Geological Survey circular 1139.

Stream-Groundwater Interaction

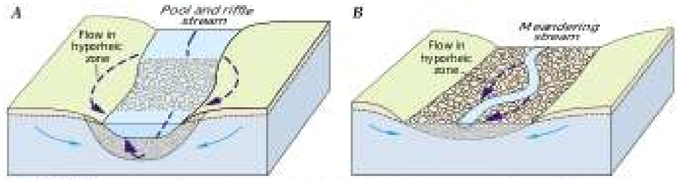


Figure 14. Surface-water exchange with ground water in the hyporheic zone is associated with abrupt changes in streambed slope (A) and with stream meanders (B).

T.C. Winter, J.W. Harvey, O.L. Franke, and W.M. Alley, 1998. Ground Water and Surface Water A Single Resource. U.S. Geological Survey circular 1139.

Lal iteraction

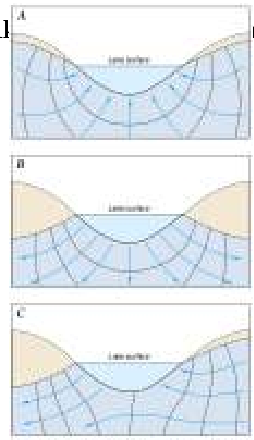


Figure 16. Lakes can receive ground-water inflow (A), lose water as seepage to ground water (B), or both

T.C. Winter, J.W. Harvey, O.L. Franke, and W.M. Alley, 1998. Ground Water and Surface Water A Single Resource. U.S. Geological Survey circular 1139.

Lake-G

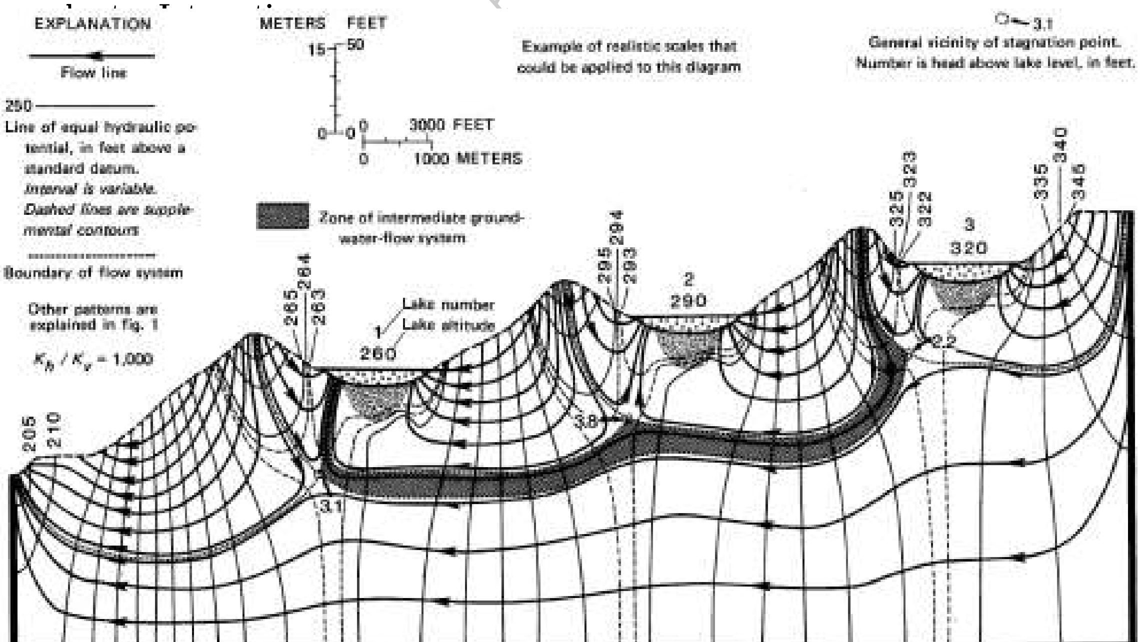


FIGURE 4.—Hydrologic section showing a quasi-quantitative flow net of ground-water flow near lakes in a multiple-lake system that does not contain aquifers.

Winter, Thomas C.,1976. Numerical simulation analysis of the interaction of lakes and ground water. USGS Professional Paper 1001.

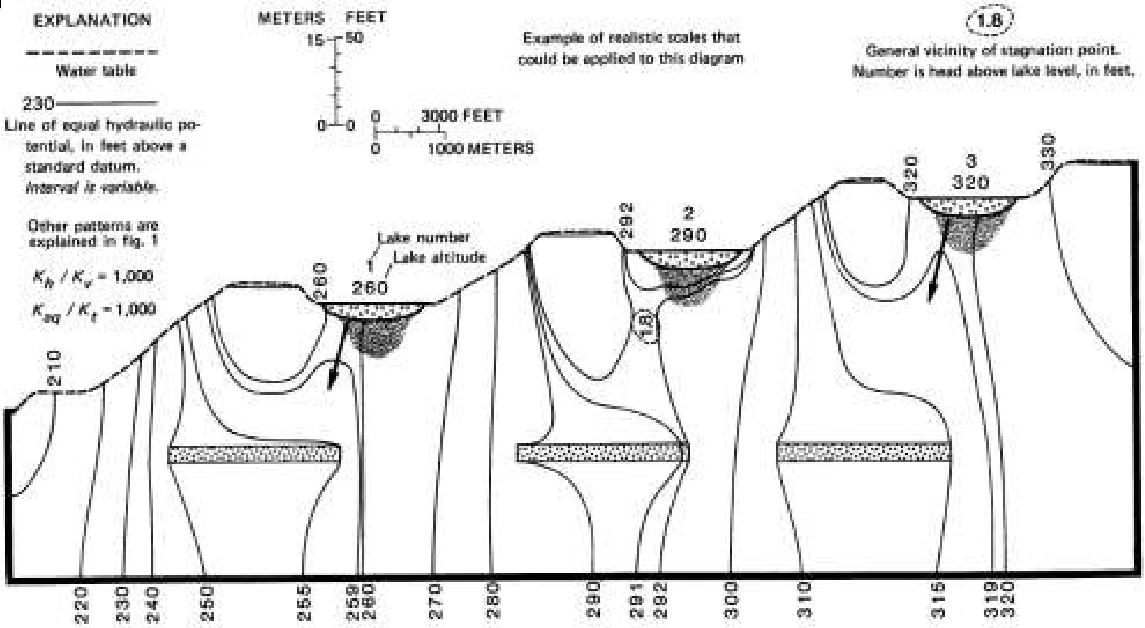


FIGURE 23.—Hydrologic section showing distribution of hydraulic head in the ground-water reservoir of a multiple-lake system that has low water-table mounds and aquifers of limited extent in the middle of the system.

Winter, Thomas C.,1976. Numerical simulation analysis of the interaction of lakes and ground water. USGS Professional Paper 1001.