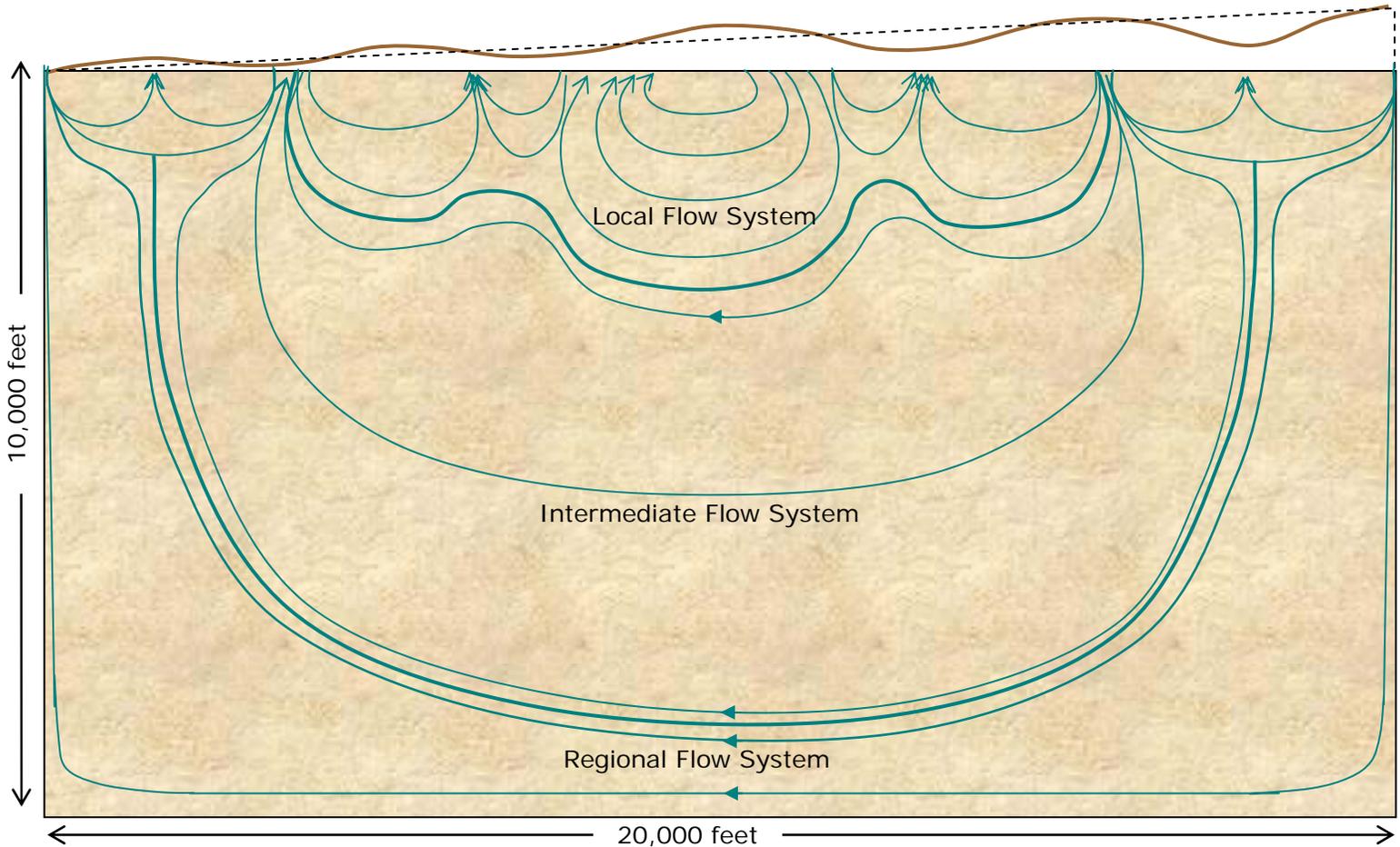


1.72, Groundwater Hydrology  
Prof. Charles Harvey  
**Lecture Packet #5: Groundwater Flow Patterns**



Hydrologic section showing local, intermediate and regional groundwater flow systems determined from an analytical solution to the groundwater flow equation

Conceptual picture based on Hubbert's potentials

Recharge Zone between two streams.

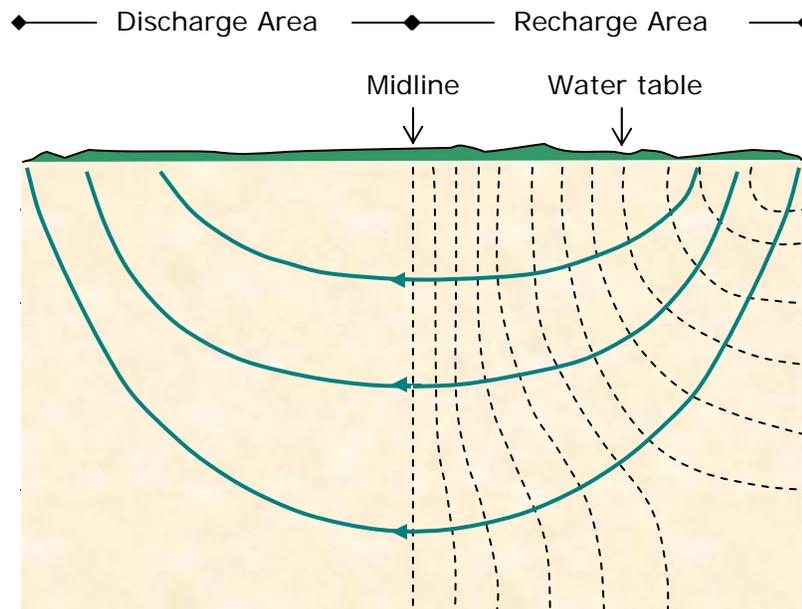
Discharge Zone (generally 5% to 30% of a watershed)

Beneath ridge and valley one gets **Groundwater Divide**, an imaginary impermeable boundary.

- Recharge area – saturated flow is directed away from the water table.
- Discharge area – a component of flow upward and saturated flow is toward the water table.

Streamlines exist for steady-state systems. Is this realistic?

Pathlines can be constructed for transient systems. A **pathline** is the trajectory a particle would travel over time.

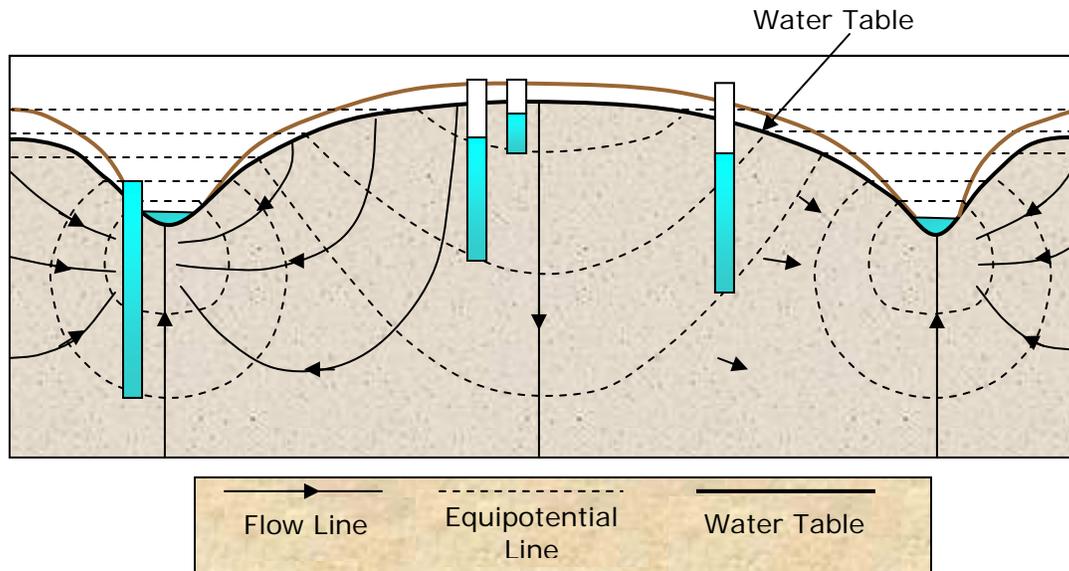


## Groundwater Flow Patterns in Homogeneous Aquifers

From flow nets we know that:

- Equipotential lines corresponding to the water table reflect the elevation head.
- Equipotential lines beneath the water table are curvilinear and reflect both pressure and elevation.

Note: artesian conditions can be **geologically controlled** or **topographically controlled**.



## Effects of Geology or Regional Flow (contrasts in K)

Three most influential factors affected head distribution:

1. Ratio of basin depth to extent.
2. Configuration of the water table.
3. Variations in hydraulic conductivity.

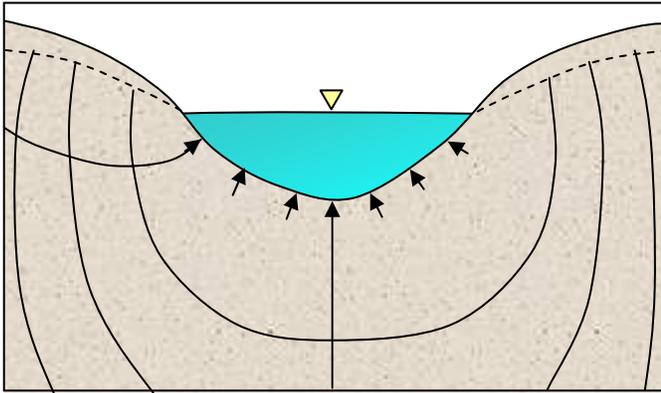
Layered systems: lower layer 10 times the hydraulic conductivity.

If the lower layer increased to 100 times the hydraulic conductivity:

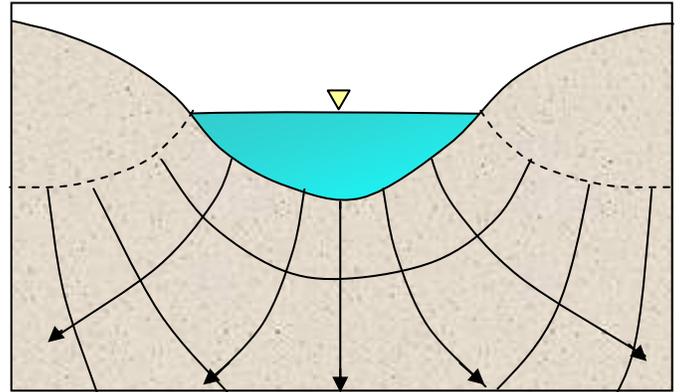
- Lower gradient in lower aquifer.
- More flow through the system (less bottom impedance).
- Lower aquifer acts like a pirating agent for flow creating near vertical flow through upper aquifer.
- Large discharge area in upper aquifer for water to get out.

## Groundwater-Lake Interactions

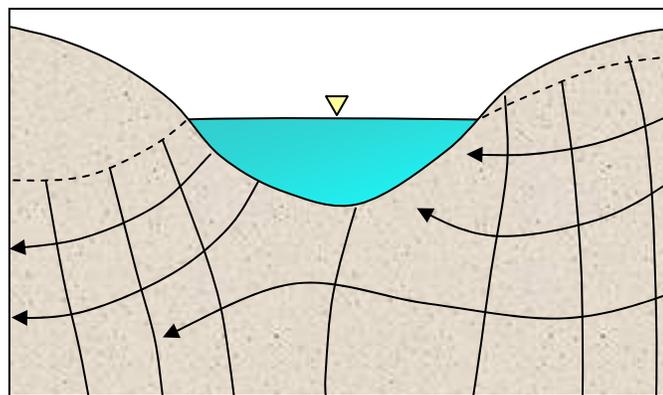
- Lake type
  - Surface water dominated
    - Most of the lake water was originally surface water
    - Lake has an inlet and an outlet (rivers)
  - **Groundwater dominated**
    - Most of the lake is groundwater
- Seepage Distribution
  - Recharge Lake.
  - Discharge Lake.
  - Flow-through Lake.
  - Combinations of the above.
- Seepage depends on groundwater-lake communication, which depends on the "Darcy parameters"
  - Thickness and permeability of lake sediments.
  - Hydraulic gradient across lake sediments.
  - But lake is in the context of a regional flow system.



Discharge Lake



Recharge Lake



Flow-through Lake

## Numerical Modeling of Groundwater-Lake Interactions

- Winter (1976) presents numerical model of lake flow systems
- The focus of the study is the effect on the position and head value of stagnation point of
  - Height of water table relative to lake level
  - $K_h/K_v$
  - Position and size of aquifers
  - Lake depth

### The Model

- Boundary Conditions
  - Aquifer base is impermeable
  - Vertical no-flow boundaries on sides
    - Major topographic high on upslope side
    - Major drain (stream) on downslope side
  - Upper boundary is the water table
- Parameters chosen to be consistent with lakes and glacial terrain.
  - Silty till
  - Sand
  - Ratios of  $K_h/K_v = 100$  and  $1000$  based on field observations

### Stagnation Point

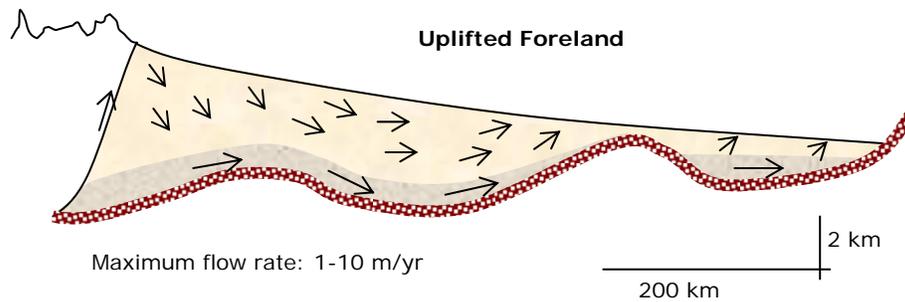
- A location where flow is zero (stagnant)
- Complex flow systems show one or more stagnation points
- The point of lowest head on dividing streamline is a stagnation point
  - There is a head value at the location of the stagnation point
  - For lake systems occurs under the shoreline on the downslope side of the lake
  - If the head at the stagnation point is higher than the head in a lake, flow is toward the lake (no water flows out the bottom of the lake)

### Groundwater-Lake Flow Systems

- Flow systems exist on different scales
  - Local
  - Intermediate
  - Regional
- Flow systems are separated by dividing streamlines
  - Separation of flow systems explains chemical differences between nearby lakes
  - More minerals dissolve the longer water is in flow system
  - Water in intermediate and regional flow systems has a higher mineral content

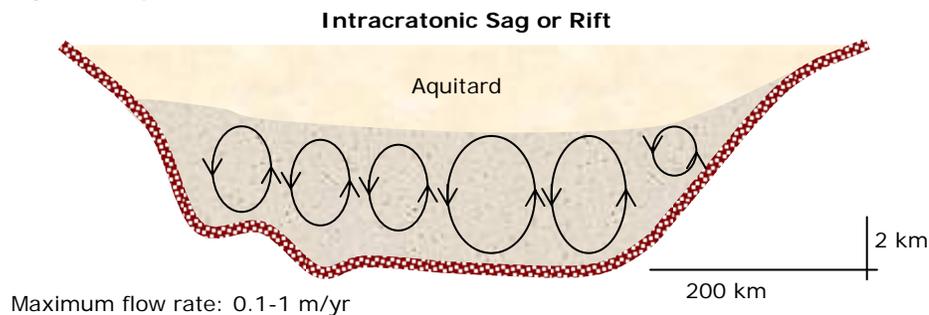
## Geologic Processes Controlling Regional Flow

Flow controlled by single or coupled processes:



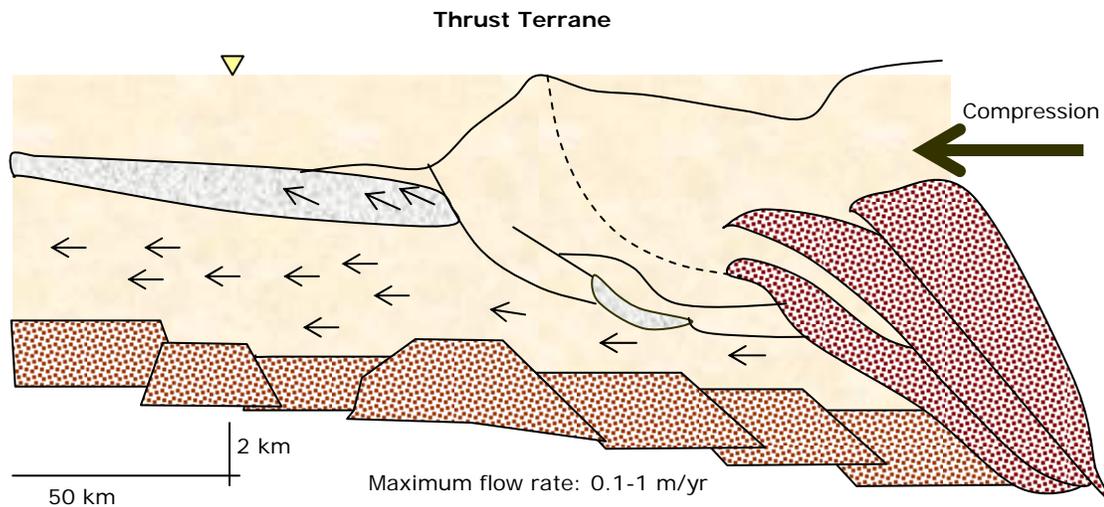
### 1) Topographically driven flow (gravity driven)

- Dominant mechanism for shallow and deep groundwater flow systems
- Water table subdued replica of landscape
- Deep groundwater migrates 1 to 10 m/y in aquifers and much less in aquitards
- Key factors: topography, conductivity, heterogeneity, anisotropy, and basin geometry



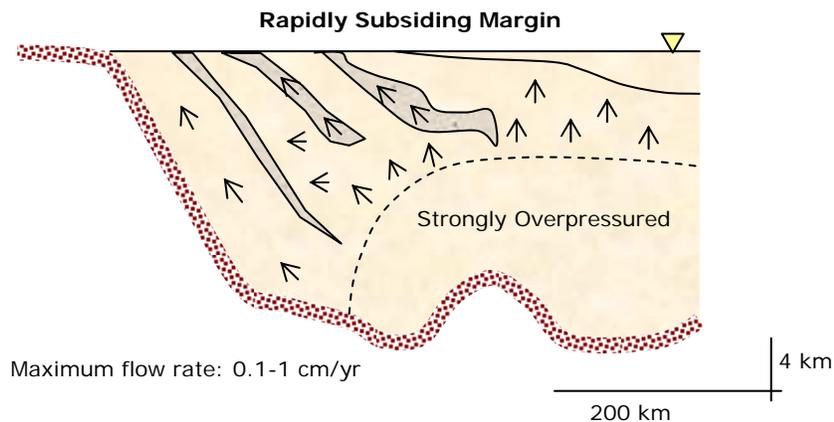
### 2) Free convection

- Circulation cells develop with or without regional horizontal flow (can coexist with gravity-driven flow)
- Driven by buoyancy forces associated with thermal and salinity fields
- Flow rates are on the order of 1 m/y
- Key factors: fluid-density gradient, aquifer thickness, and conductivity



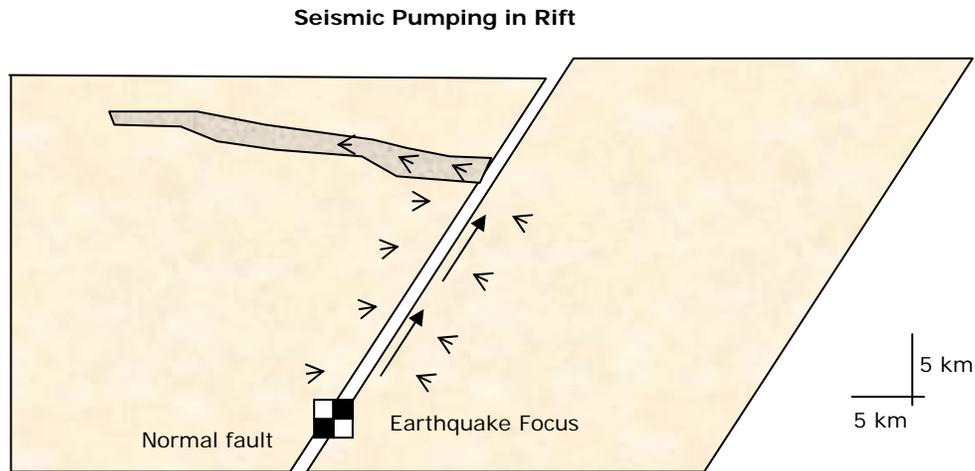
3) Tectonically-driven flow

- Compression and thrusting during mountain building produces large overpressures in orogenic belts
- Regime characteristic of accretionary wedges (subduction zones) with flow rate of cm/y
- Theoretical flow (high) rates of 0.5 m/y

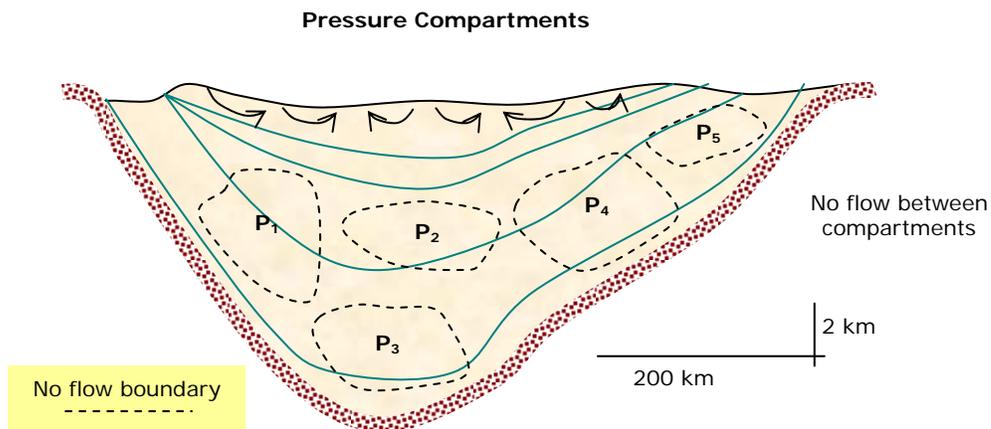


4) Overpressure buried continental margin

- Fluid pressures can approach weight of overburden (lithostatic load)
- Overpressuring typically occurs in young, low K basins
- Also contributing to overpressure are: dehydration reactions and hydrocarbon generation
- Flow rates generally < 1 cm/y (due to low K shales)



- 5) Seismic pumping
- Catastrophic faulting vents overpressure



- 6) Pressure compartments
- Permanent impermeable barrier maintains pressures forever; seals into isolated compartments
  - Not believed by most hydrogeologists who feel there is always some permeability and flow over geologic time