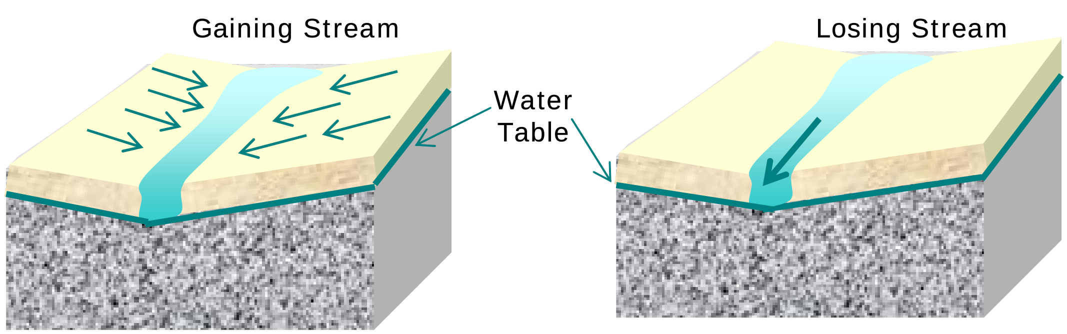
Lecture Packet #6: Groundwater-Surface Water Interactions

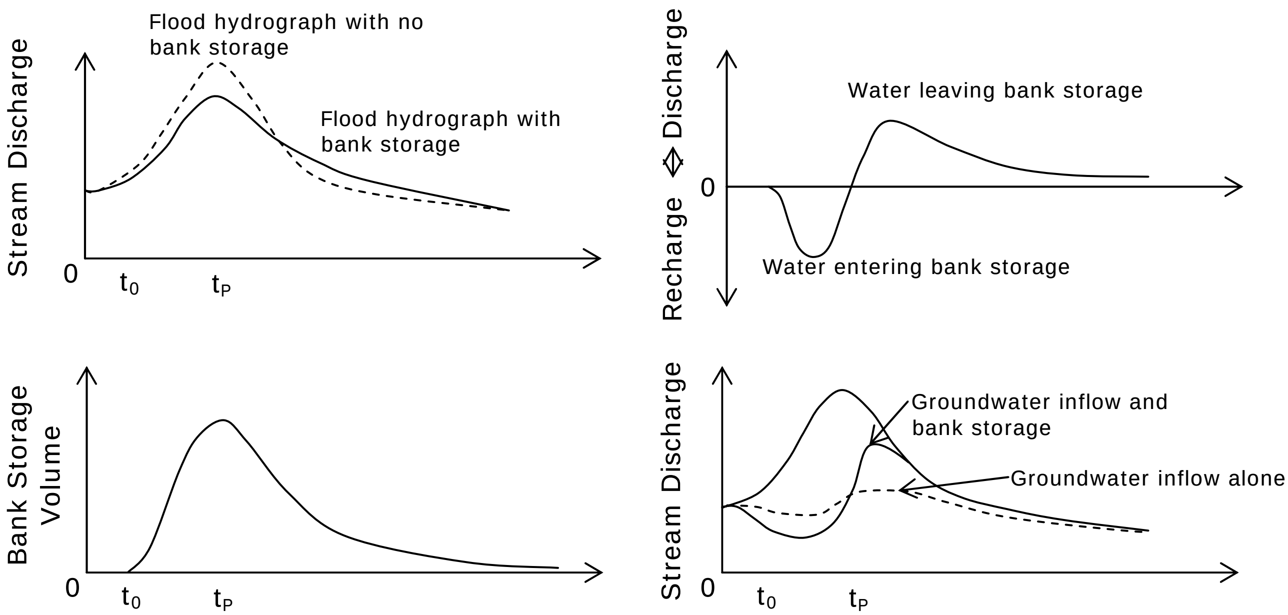
Streams

- Streamflow is made up of two components:
    - Surface water component
        - Surface Runoff
        - Direct Rainfall
    - Groundwater component (baseflow)
        - Seepage through the streambed or banks
- Definitions
    - Losing or influent stream → Stream feeds aquifer
    - Gaining or effluent stream → Aquifer discharges to stream



Stream-Aquifer Interactions

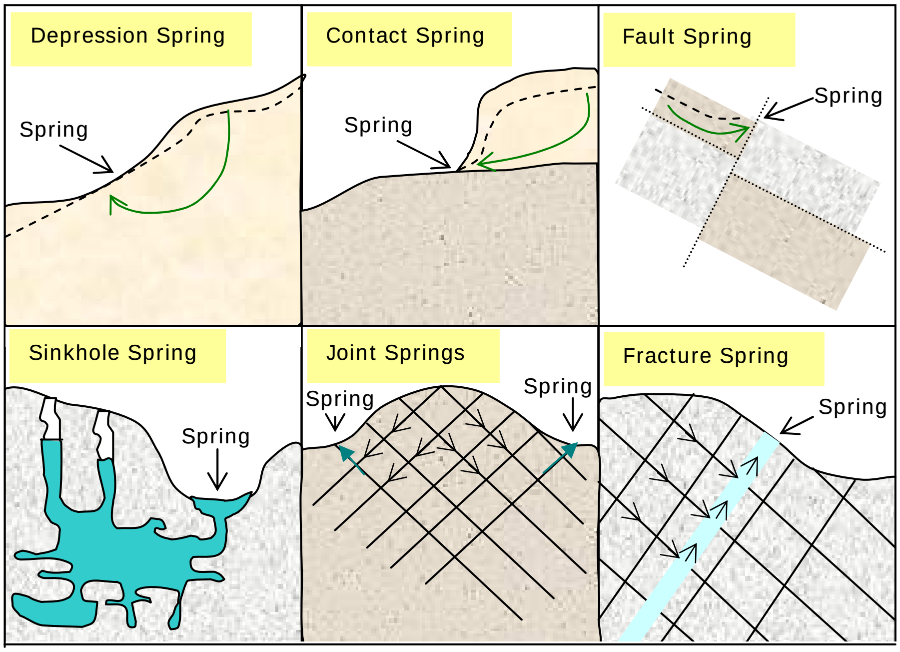
Base Flow – Contribution to streamflow from groundwater
- Upper reaches provide subsurface contribution to streamflow (flood wave).
- Lower reaches provide bank storage which can moderate a flood wave.



Springs
- A spring (or seep) is an area of natural discharge.
- Springs occur where the water table is very near or meets land surface.
  - Where the water table does not actually reach land surface, capillary forces may still bring water to the surface.
- Discharge may be permanent or ephemeral
- The amount of discharge is related to height of the water table, which is affected by
  - Seasonal changes in recharge
  - Single storm events

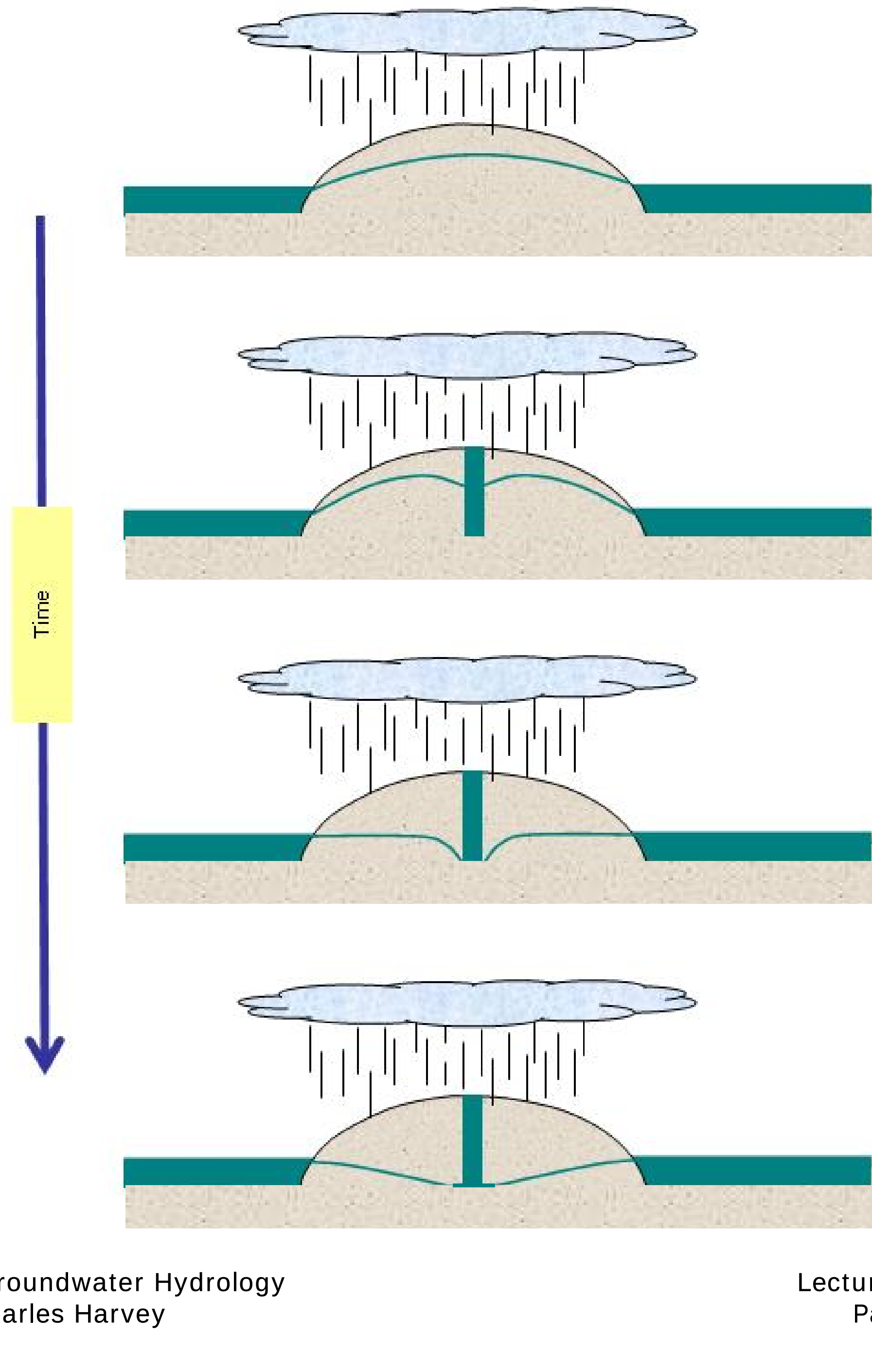
Types of Springs	
• Depression spring	Land surface dips to intersect the water table
• Contact spring • Fault spring	Water flows to the surface where a low permeability bed impedes flow
• Sinkhole spring • Joint spring • Fracture spring	Similar to a depression spring, but flow is limited to fracture zones, joints, or dissolution channels

Regional Groundwater Flow



Where does water come from when pumping?

- Initial rate of recharge balances initial rate of discharge.
- Water pumped comes from storage and recharge within cone of depression.
- Water pumping creates cone of depression reaches shoreline.
- Ultimate magnitude of pumpage (before well dries up – at the well) is dependent on hydraulic conductivity, thickness, available drawdown.
- Ultimate production of water depends upon how much rate of recharge can be changed and/or how much water can be captures. Steady-state production is not dependent on S_y.
- Although rate of recharge = discharge is interesting, it is almost irrelevant in determining the sustained yield of the aquifer. (Here, think of case where rainfall is small or does not exist – water source is ultimately the lake.)



General Conclusions: Essential factors that determine response of the aquifer to well development

- Distance to, and character of, recharge (precip vs. pond)
- Distance to, and character of, natural discharge
- Character of cone of depression (function T and S)

Prior to development aquifer is in equilibrium.
"All water discharged by wells is balanced by a loss of water from somewhere."
-Theis (1940)

When pumping occurs, water comes from storage until a new equilibrium is reached. Accomplished by:

- Increase in recharge → capture of a water source
- Decrease in discharge → reduction of gradient → outflow
- Both

Some water must always be **mined** (taken from storage) to create groundwater development.

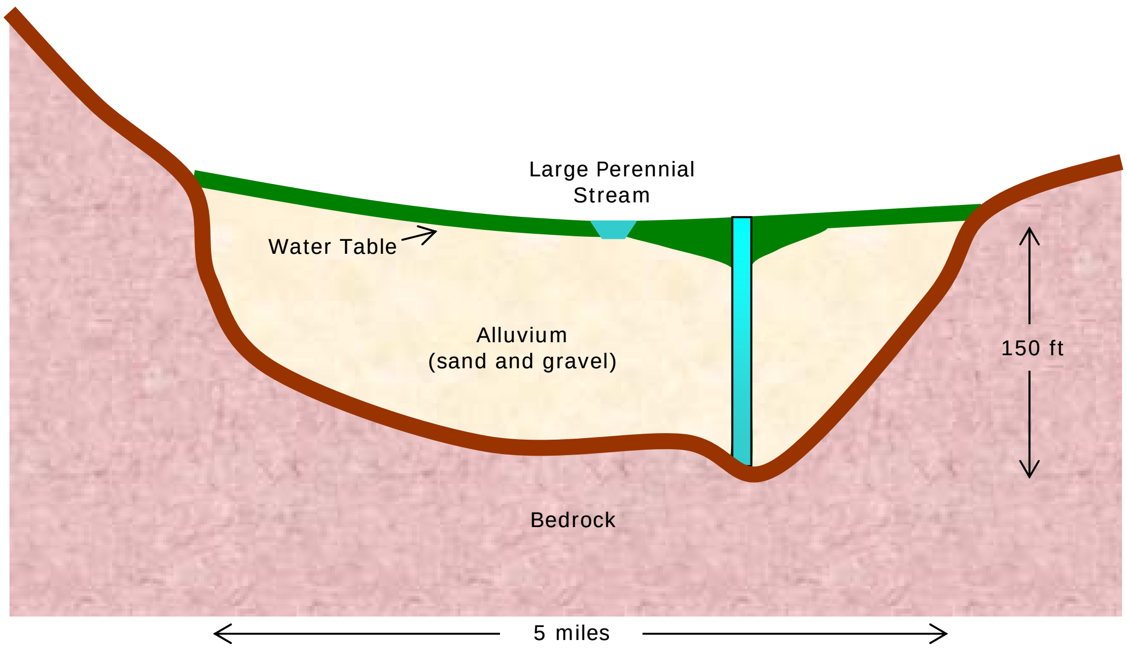
Mathematically the pumping water balance is:

$Q = (R + \Delta R) - (D + \Delta D) - S(\Delta h/\Delta t)$

If over the years R = D, and a new equilibrium (new steady state) is reached ($\Delta h/\Delta t = 0$)

$$Q = \Delta R - \Delta D$$

Valley of Large Perennial Stream in Humid Region



Setting – East Coast

- Thick, permeable alluvial valley cut into shale
- Large perennial stream
- Shallow water table with many phreatophytes (trees that can stick roots below water table and saturate their roots)
- Moderately heavy precipitation

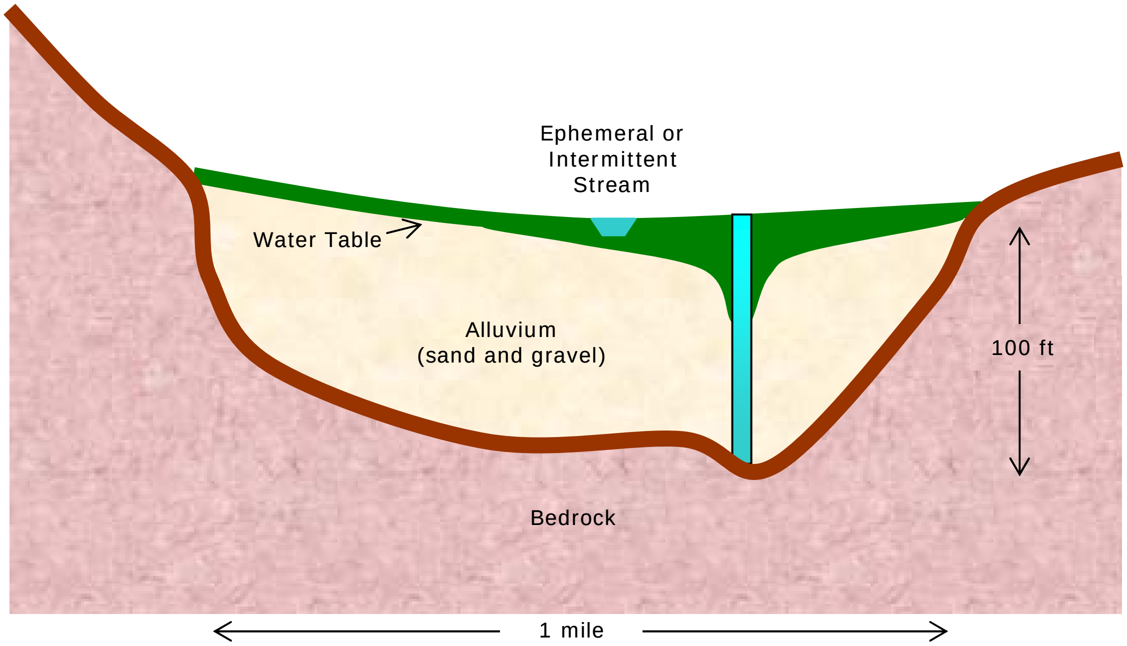
Sources of Water

- Withdrawal from storage (cone of depression)
- Salvaged rejected recharge (prevention of runoff to stream by making more room for recharge from precipitation – water goes to groundwater rather than stream – only some of stream water recharges.
- Salvaged natural discharge (natural discharge w/o pumping)
  - o Lowering water table beneath phreatophytes
  - o Decreasing gradient toward stream decreasing base flow (for low development rates) – river is a GW sing – a gaining stream under natural conditions
- Over long term at steady state

$$Q = \Delta R + \Delta D$$

Small developments ΔR source ← Room for precipitation
Large developments, stream capture, ΔD, source.

Valley of Ephemeral Stream in Semiarid Region



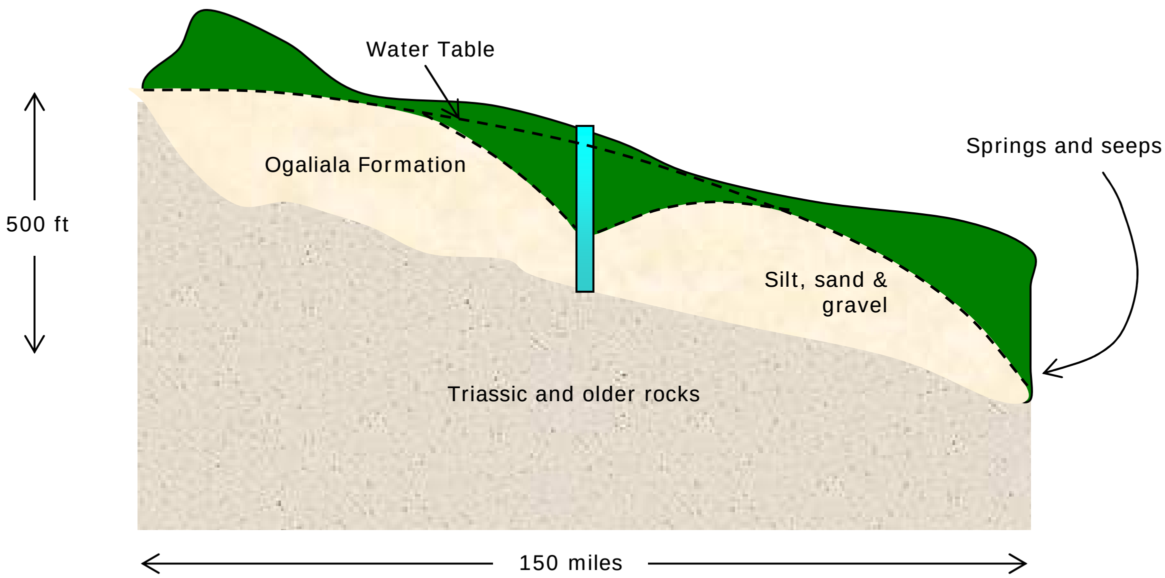
Setting – West Coast (not northwest)

- Moderately thick, permeable alluvial valley cut into shale
- Large ephemeral stream
- Water table beneath stream channel, below vegetation
- Precipitation like in Palo Alto, about 15 in/yr
- Stream dry most of year, floods in heavy rains

Sources of Water

- Withdrawal from storage (cone of depression)
- No salvaged rejected recharge (enough room for all recharge from low precipitation)
- Little salvaged natural discharge (no phreatophytes)
- Recharge directly from stream (water table low enough so that there is room for flood waters – evaporation-free-control reservoir) – can guarantee this with pumping
- $\Delta D = 0$
    - Capture floodwaters and get + S $\Delta h/\Delta t$
      When $\Delta R = 0$ loss from storage is only source
      $Q = -S\, \Delta h/\Delta t$ (water can be pumped seasonally for irrigation and later replenished)

High Plains of Texas and New Mexico



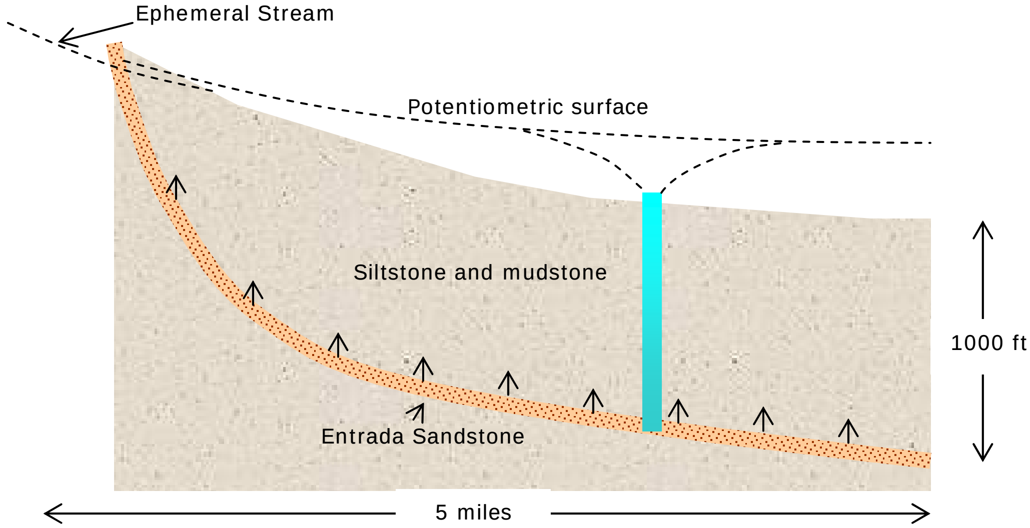
Setting

- Remnant high plain sloping, cut off from external sources of water by escarpments both upgradient and downgradient
- Thick (300 ft to 600 ft) permeable rocks on impermeable rocks
- Recharge from precipitation is 1/20 to 1/2 in/yr
- Discharge from springs about the same
- Water table (>50 ft)

Sources of Water

- Withdrawal from storage (cone of depression)
- No salvaged rejected recharge (ample space – 50 ft. unsaturated)
- Little salvaged natural discharge (gradient unchanged, but even if not, aquifer flow would only account for 1 to 2% of the withdrawal rate)
- $Q = -S \Delta h/\Delta t$ water from storage – mining only $S_y = 0.15$
- Big difference with Entrada Sandstone $S = 5 \times 10^{-5}$ per square foot for each foot of head decline

Productive Artesian Aquifer System



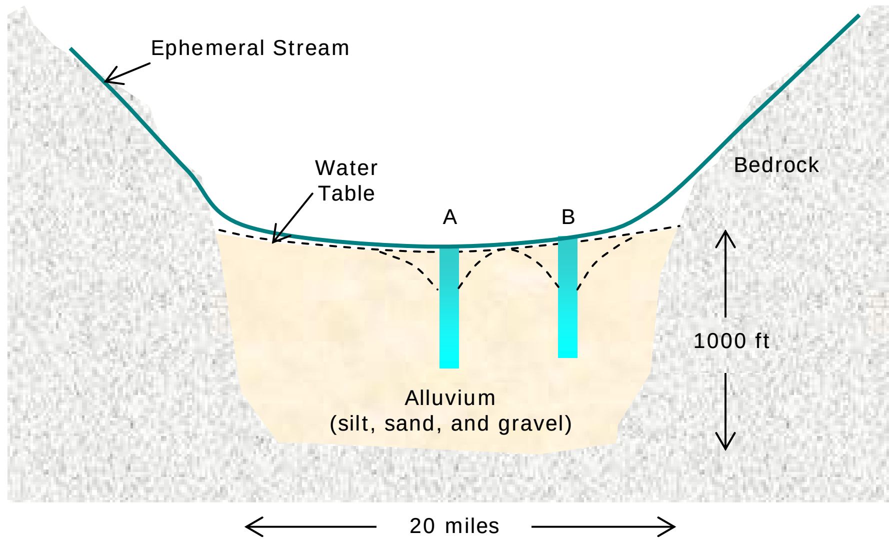
Setting

- Grand Junction Artesian Basin, Colorado
- Typical low conductivity artesian aquifer
- Fine-grained sandstone, party cemented with calc. carb.
- 150 ft. thick → T = 20 ft^2/d, S = 5 x 10^{-5}
- Recharge from precipitation (7-8 in/yr) where outcrops are in contact with alluvium
- Discharge small and from upward leakage through relatively impermeable siltstone 500 to 1000 ft thick
- Artesian conditions, as much as 160 ft above land surface

Sources of Water

- Withdrawal from confined storage (large overlapping cones of depression)
- No salvaged rejected recharge – already room for recharge water; no extra would enter aquifer if water table in recharge area were lowered. (limiting unit is artesian aquifer)
- Little salvaged natural discharge (limited upward leakage)
- Acts like confined “bathtub” with little ΔD due to pumping.
- $Q = -S\,\Delta h/\Delta t$ water from storage – mining only – mining artesian storage and not dewatering storage

Closed Desert Basin



Setting

- Thick coalescing alluvial fans, gradational from mountains
- Basin receives precipitation of 3-5 in/yr, mountains 20-30 in/yr
- Very shallow water table near playa, deep near mountains
- Streams are ephemeral
- Phreatophytes near playa

Sources of Water

- Withdrawal from storage (create cone of depression)
- Salvaged rejected recharge (center none – precip in valley evaporates or transpires) (border some recharge from small ephemeral streams near surrounding mountains)
- Salvaged natural discharge
    - Lowering water table near playa may reduce ET (roots)
    - Near borders of basin discharge toward playa can be reduced (stop flow to center where ET occurs)
- **Operation** – increase rejected recharge and prevent existing discharge:
  $Q = \Delta R + \Delta D - (+/- S \Delta h/\Delta t)$
- Retention dams to capture flood waters for recharge