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

<table>
<thead>
<tr>
<th>Types of Springs</th>
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<tbody>
<tr>
<td>Depression spring</td>
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<tr>
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</tbody>
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Regional Groundwater Flow

Depression Spring

Contact Spring

Fault Spring

Sinkhole Spring

Joint Springs

Fracture Spring
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 captured. 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)
  - Lowering water table beneath phreatophytes
  - 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 \( \Delta R \) source ↩ Room for precipitation
Large developments, stream capture, \( \Delta D \), 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)
- \[ Q = -S \frac{\Delta h}{\Delta t} \] 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**

- **Ephemeral Stream**
- **Potentiometric surface**
- **Siltstone and mudstone**
- **Entrada Sandstone**
- **5 miles**
- **1000 ft**

**Setting**
- Grand Junction Artesian Basin, Colorado
- Typical low conductivity artesian aquifer
- Fine-grained sandstone, partly cemented with calc. carb.
- 150 ft. thick → $T = 20 \text{ ft}^2/\text{d}$, $S = 5 \times 10^{-5}$
- 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 $\Delta D$ 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:
  \[ Q = \Delta R + \Delta D - (\pm S \Delta h/\Delta t) \]
- Retention dams to capture flood waters for recharge