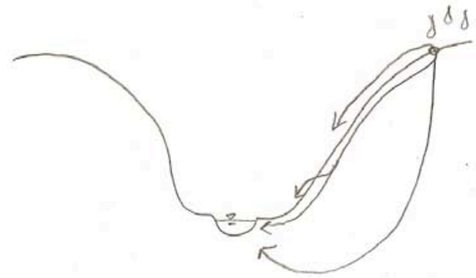
Rivers
T. Perron – 12.001

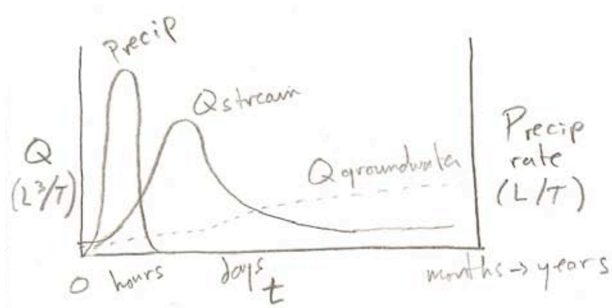
After our discussions of large-scale topography, how we represent topography in maps, and how topography interacts with geologic structures, you should be frothing at the mouth with curiosity about how topography forms. We now begin our all-too-brief tour of surface processes, in which we will review the main mechanisms that shape topography.

- Why are rivers important?
    - Rivers are everywhere [PPT: Allegheny Plateau DEM]
        - Most continental landscapes are the product of river erosion and sediment transport
        - Even form on other planets & moons
            - Networks on Mars & Titan [PPT: Mars, then Titan]
            - Long, sinuous lava flows on Moon, Venus, Io
            - Clearly this is a universal geologic process
    - Rivers are responsible for most of the mass fluxes across the continents
        - Water, rock (as solid particles or in solution), nutrients
        - Vital for geology, ecology, human society
    - How much water and sediment?
        - Freshwater is a rare resource
        - Distribution:
            - Fraction of earth's water that is fresh (non-saline): 3%.
            - Of freshwater, ~1/3 is groundwater, 2/3 is ice. Only 0.3% is surface water, and most of this is in lakes.
        - Yet rivers do most of the work carrying rock mass.
- Why do rivers form?
    - P > ET leads to runoff, infiltration, groundwater flow.
        - These flows are directed downslope by pressure gradients induced by gravity. Many paths, surface or subsurface, eventually lead to river channels.
        - Flow paths
            - Surface overland flow

- Shallow subsurface flow and return flow
- Deep groundwater flow, including flow up to stream channels



- Hydrographs
  - Precip, stream discharge, groundwater discharge
  - Streamflow response to a precip event depends on drainage basin size & runoff characteristics
  - Effects of urbanization
  - What determines the size of a river channel (which in turn determines how much flow it can convey before it spills over its banks)? Small, frequent flows, or large, rare flows?
  - Your lab explores flood frequency analysis, which is one way to answer this question empirically: what is the recurrence interval of a flow that just fills the banks?

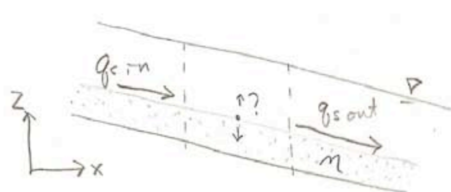


Note that Precip is really recharge (=P-ET), and units are volume/area/time

- Formation of channels, valleys and networks [PPT: Gabilan]
  - If erosion rate depends on flux of water, land surface is unstable with respect to water erosion → channelization [PPT]
  - The positive feedback makes rivers cut valleys, and the rest of the landscape slopes toward them

- Other processes prevent channels from forming everywhere
  - Thresholds: Finite strength of land surface and river banks due to cohesive sediment, ice, vegetation roots, etc.
  - Smoothing by mass movement of soil/sediment
    - Soil creep
    - Small landslides
    - Rain splash
- The larger the spatial scale, the more dominant the positive feedback is → river networks [PPT: Model, then Allegheny]

- How do rivers evolve over time? Erosion and deposition: processes that control changes in river bed elevation depend on whether bed is exposed bedrock, or always covered by sediment
  - Flow in rivers is driven by downslope component of weight of water, and is balanced by resistance associated with shear stress on the bed
  - Exposed BR: what controls the rate at which rivers erode rock?
    - Plucking: water removes pieces of the bed. Rate depends on flow stress (and therefore velocity), rock strength. But this is thought to be slower than erosion by sediment
    - Impact wear by saltating (rolling, hopping) grains
  - Sediment cover: What controls the rate of aggradation or degradation of an "alluvial" bed, with no exposed bedrock?
    - Conservation of mass (aka the Exner equation) for bed sediment with a volume fraction η:



$$\frac{\Delta V}{\Delta t} = \frac{w \Delta x \Delta z}{\Delta t} = \frac{1}{\eta}\left(Q_{s,in} - Q_{s,out}\right) = \frac{w}{\eta}\left(q_{s,in} - q_{s,out}\right)$$

$$\frac{\Delta z}{\Delta t} = -\frac{1}{\eta}\frac{\left(q_{s,out} - q_{s,in}\right)}{\Delta x}$$

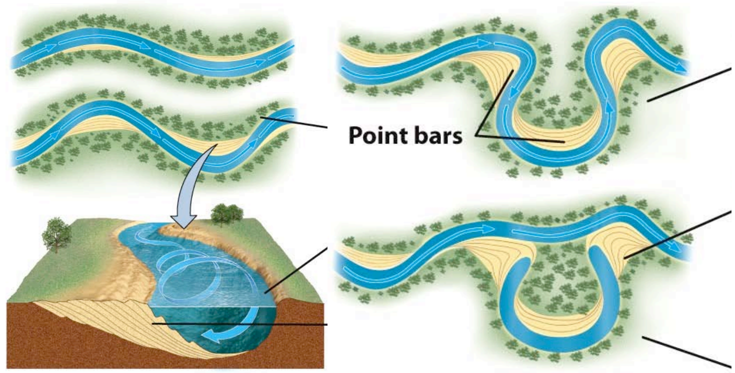
$$\frac{\partial z}{\partial t} = -\frac{1}{\eta}\frac{\partial q_s}{\partial x}$$

(In 2D, for conservation of a quantity ϕ, you will often see $\frac{\partial \phi}{\partial t} + \nabla \cdot \phi = 0$)

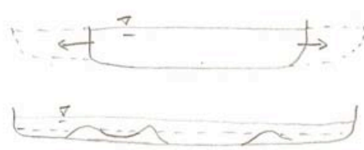
        - In general, sediment flux scales with (a power of) bed shear stress. Relationships determined from field monitoring, experiments

- How do rivers change along their path from headwaters to ocean? [PPT: Brahmaputra]
    - If you walked down a river starting from a topographic divide, what changes in channel geometry, sediment and processes would you see? [Sketch concave-up long profile]
        - Slopes become gentler, until eventually reaching base level (can be sea level, an inland water body, or even a dry basin)
        - No channel → channel
        - Less exposed bedrock
        - Fining sediment (boulders → gravel → sand → silt)
    - Why does sediment get (exponentially) finer downstream?
        - Abrasion breaks down grains, so the farther they travel, the smaller they get
        - Selective transport: as slope, and therefore stress, decrease downstream, the maximum transportable grain size shrinks
- Planform morphology of alluvial rivers [PPT: meandering vs. braided]
    - Rivers that have little or no exposed bedrock shape their own geometry through erosion & sediment deposition
    - Why do some rivers meander?
        - Flow-steering instability
            - Perturbation in flow path or bed topography steers flow to one side
            - Superelevation of water surface along outer part of bend alters pattern of shear stress
            - Stress decreases downstream on inside of bend → point bar deposition; stress increases downstream on outside of bend → bed and bank erosion. Requires stabilization of point bar by vegetation, cohesive sediment, ice, etc.
            - The river bend becomes more curved, which creates a stronger superelevation → positive feedback

- Meander bends grow until cut off during floods [PPT: Birch Creek, Alaska]



- Why do others braid? [PPT: Waimakariri]
  - Easily eroded bank material (little or no cohesion)
  - Channel widens during high flow, and medial bars are deposited as flow recedes and sediment transport capacity declines
  - Why don't braided streams widen indefinitely? Eventually flow depth gets so small that stress is insufficient to transport sediment, especially at banks.



  - Illustration of importance of bank cohesion: [PPT: Tal movie]. Diminished occurrence of braided channels in the rock record may be a signature of the rise of life on the continents.

- Depositional systems: What happens when a river meets a body of water?
  - Deltas [PPT: Lena, Nile, Eberswalde Delta, Mars]
    - Slopes decline to zero, so there's a downstream decrease in shear stress → deposition
    - River can build outward along the same path, but this leads to a further decrease in slope
    - Eventually the difference in slope is large enough that river changes course during a flood: avulsion.
    - Over time, occupation of, and deposition along, many different flow paths builds a fan-shaped delta