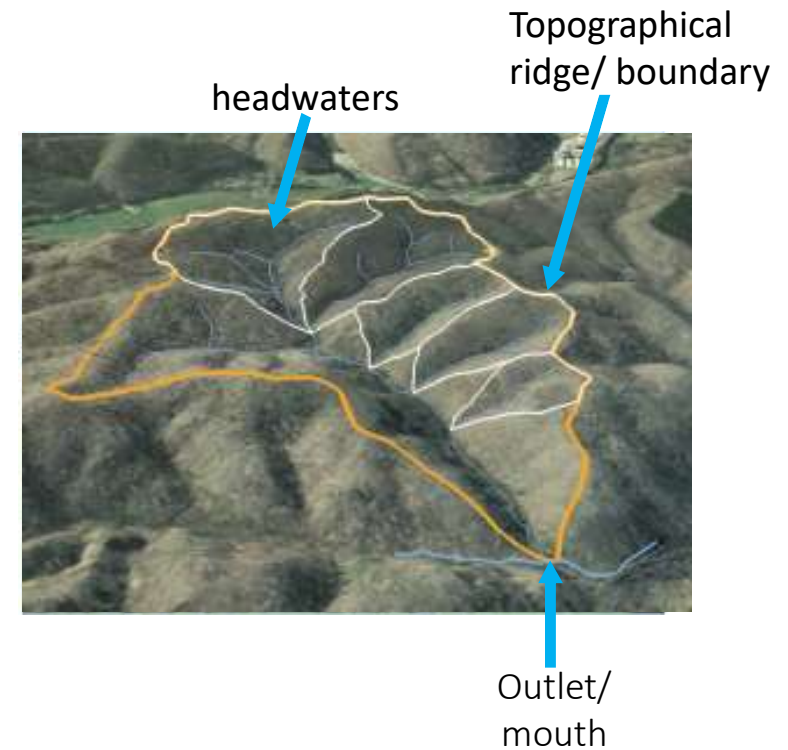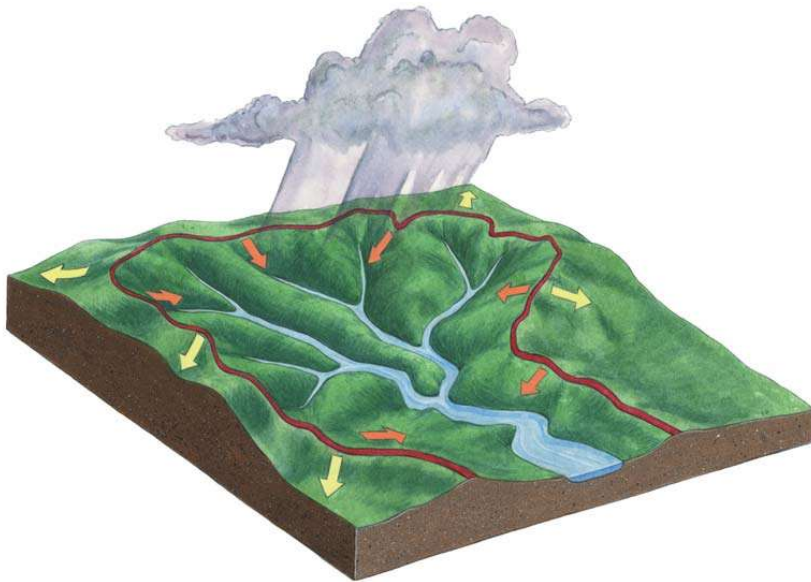# Water Balance and Budyko Framework

Early graduate/ Senior undergraduate level

What is a Watershed

- A land area that channels precipitation to a common outlet such as reservoirs, bays, and the ocean.
- An area of land that drains or "**sheds**" water into a specific waterbody

headwaters

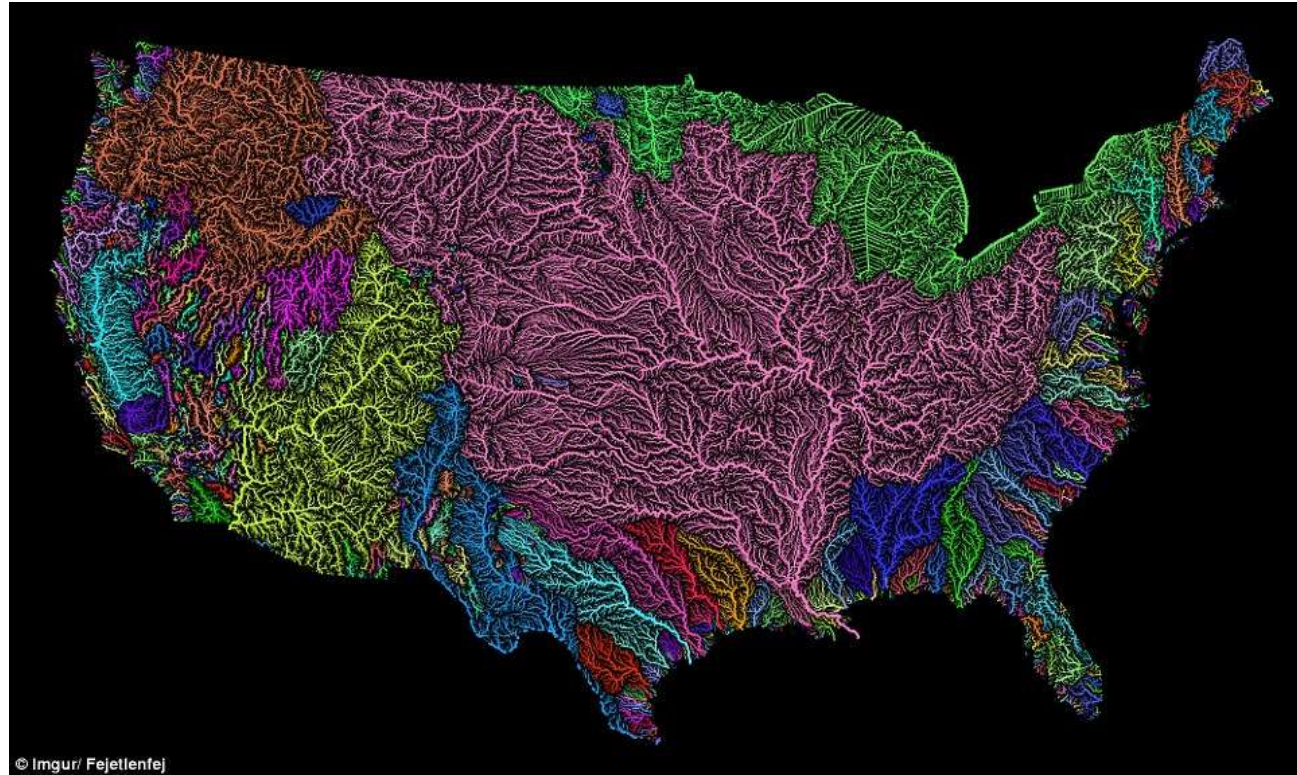Topographical ridge/ boundary

Outlet/ mouth

- Watersheds are defined based on topography
- Topography is the arrangement of the natural and artificial **physical** features of an area.

Image courtesy: Edwards et. al 2015

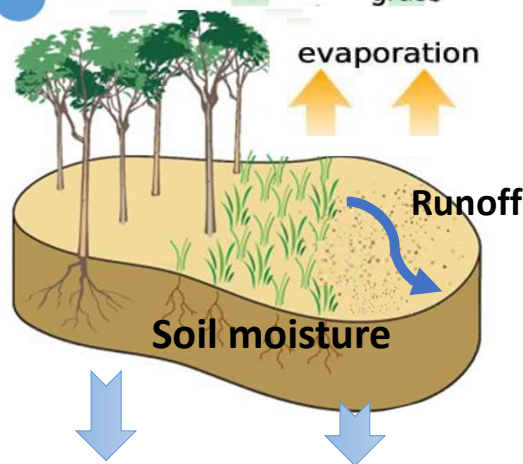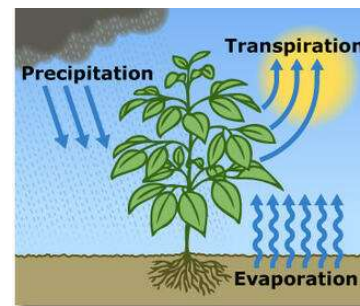# No Matter Where You Are, You Are in a Watershed

Nature's arteries to transport water, nutrients & sediments

© Imgur/ Fejetlenfej

Know your watershed: https://mywaterway.epa.gov/

Components of Hydrological Cycle

evapotranspiration = transpiration + evaporation

transpiration

trees   grass

evaporation

Precipitation

Runoff

Soil moisture

Groundwater recharge

Transpiration

Precipitation

Evaporation
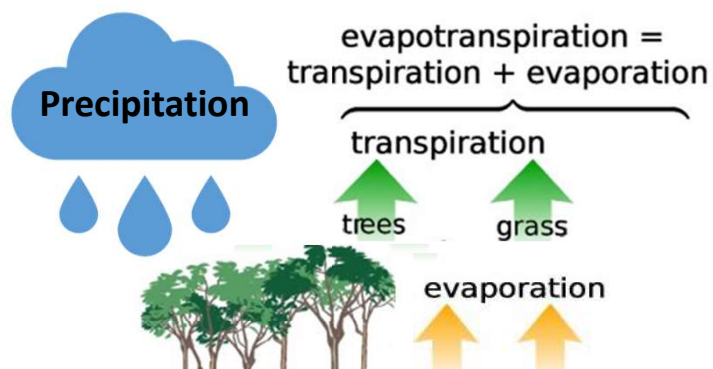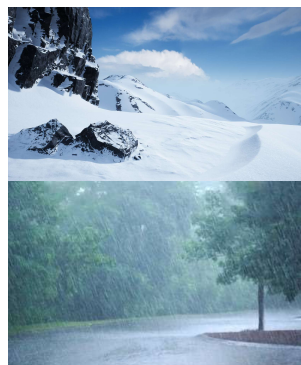
Question 1 What type of system is Earth's hydrological cycle?

1. A Closed system?
2. An Open System?

➤ Earth's water/hydrological cycle is a closed system
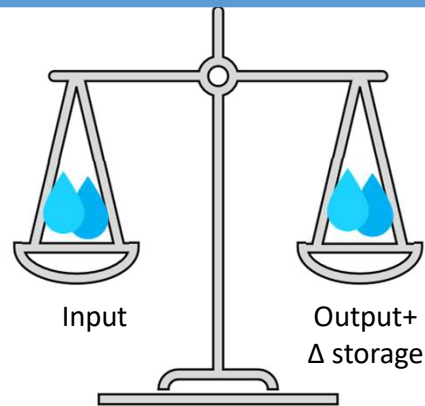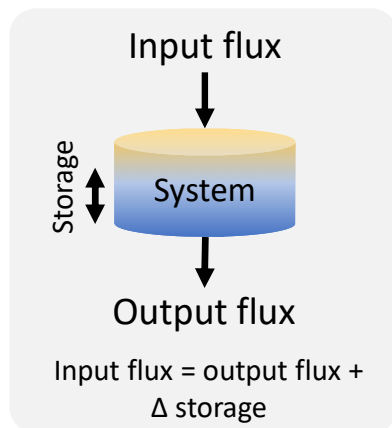➤ No water escapes or enters the system.

Conservation of Mass & Energy

Input flux

Storage

System

Output flux

Input flux = output flux + Δ storage

Input

Output+ Δ storage

Redistribution matters

Hydrological Water Balance

evapotranspiration = transpiration + evaporation

transpiration
trees   grass

ET

evaporation

Precipitation

P

Runoff

Q

Soil moisture

S

R

Groundwater recharge

Input flux

Δ Storage

Output flux

Input flux

Storage

System

Output flux

Input flux = output flux + Δ storage

P

Loss+Δs

P

$(Q + ET + R)$+ Δs

Static

$$P = Q + ET + R + \Delta s$$

Water Balance

Trenberth, 2011, *Journal of climate*

Units: Thousand cubic km for storage, and *thousand cubic km/yr for exchanges*   *1990s

$$P = Q + ET + GW + \Delta s$$

If a sample watershed receives **500 mm** of precipitation per year, what would be the estimated amount of annual evapotranspiration for that watershed?

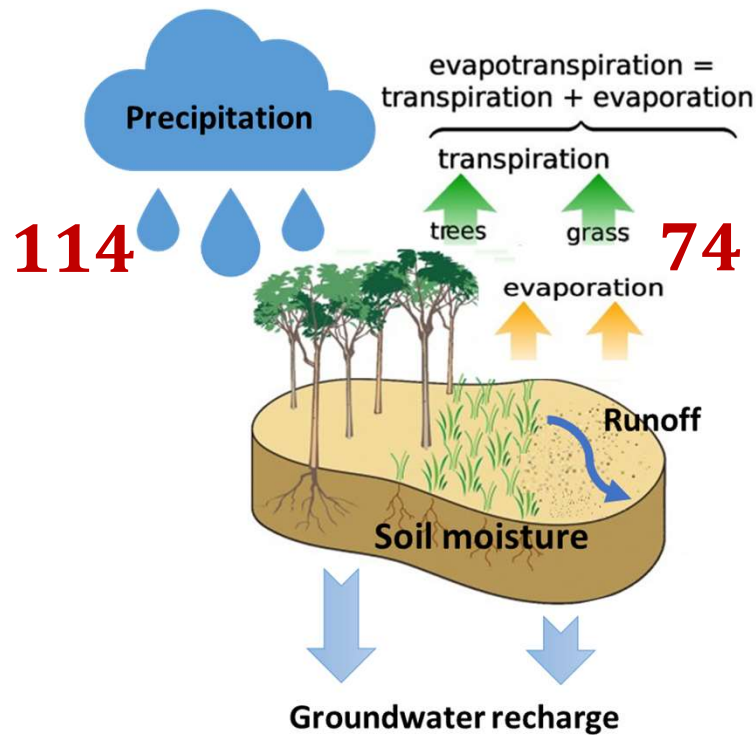Evapotranspiration $(ET) = ?\,?\,?$

Water Balance

$$P = Q + ET + GW + \Delta s$$

114 **74**

If a sample watershed receives **500 mm** of precipitation per year, what would be the estimated amount of annual evapotranspiration for that watershed?

$$\text{Evapotranspiration (ET)} = 500 * \frac{ET_{Global}}{P_{Global}} = 500 * \frac{74}{114} = \sim \mathbf{324\ mm}$$

$$\frac{ET}{P} = \frac{74}{114} = \text{evaporative index (EI)}$$
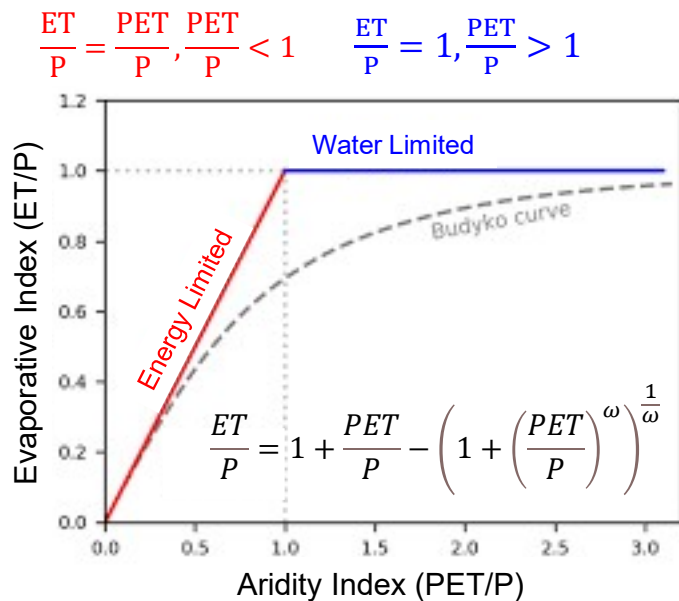
Question 2 Will water balance estimates change, based on the location of watershed?

1. Estimates may NOT change significantly
2. Estimates will change

Hint: Think in terms of the governing driver of the water cycle on Earth.

Budyko Curve

$$\frac{ET}{P} = \frac{PET}{P}, \frac{PET}{P} < 1 \qquad \frac{ET}{P} = 1, \frac{PET}{P} > 1$$

$$\frac{ET}{P} = 1 + \frac{PET}{P} - \left(1 + \left(\frac{PET}{P}\right)^{\omega}\right)^{\frac{1}{\omega}}$$

$\omega =$ fitting parameter linked to watershed characteristics such as topography, soil, vegetation, and geographic location of watersheds

ET/P ratio depends on aridity (climate) and watershed characteristics, ω

Climate

Aridity: ■ Hyper-arid ■ Arid ■ Semi-arid ■ Dry sub-humid ■ Humid
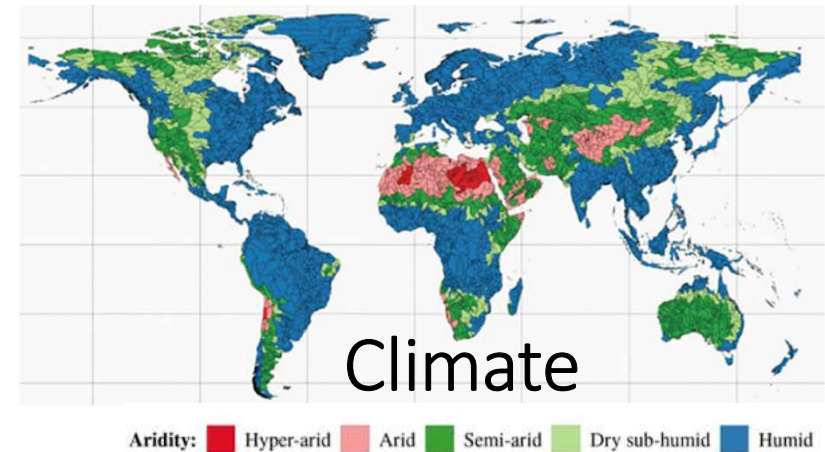
❑ **Aridity Index:** Indicator of climate (arid, humid, etc.).

$$\text{Aridity Index} = \frac{\text{Potential Evapotranspiration}}{\text{Precipitation}}$$
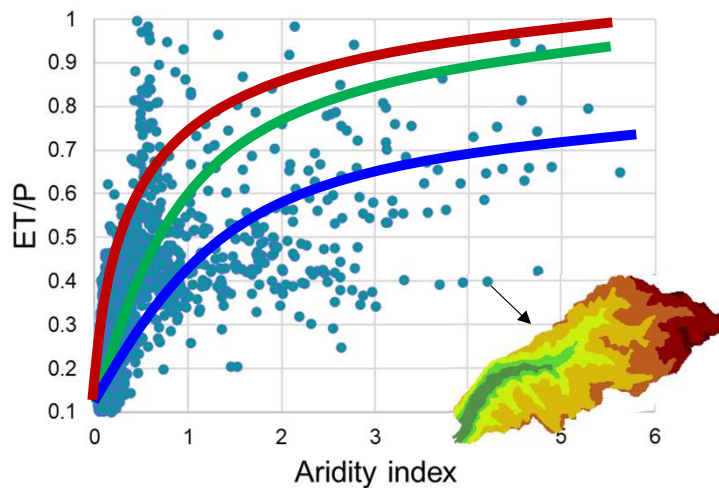
❑ **Potential Evapotranspiration (PET):** Maximum amount of water that can be removed from land assuming abundant moisture supply.

❑ PET depends on availability of solar radiation and weather conditions (relative humidity, temperature, wind speed etc).

Koppa, A., et. al 2021. Budyko-Based Long-Term Water and Energy Balance Closure in Global Watersheds From Earth Observations. *Water resources research*
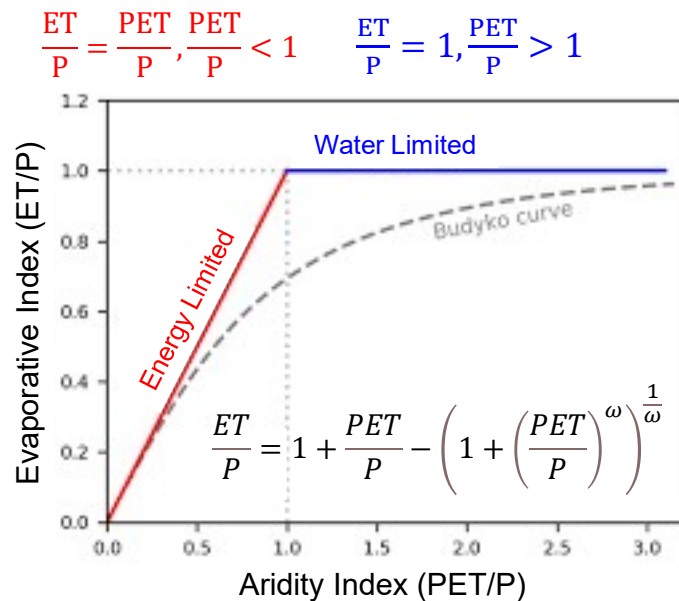
Summary

Static $P = Q + ET + R + \Delta s$

1. Global hydrological cycle is a closed system. Redistribution matters!

1. Budyko Curve gives relationship between aridity and evaporative index of a watershed.

2. Climate and watershed characteristics govern the evaporative index of watersheds.

Thank you!

Assignment Exercise

$$\frac{ET}{P} = \frac{PET}{P}, \frac{PET}{P} < 1 \qquad \frac{ET}{P} = 1, \frac{PET}{P} > 1$$

$$\frac{ET}{P} = 1 + \frac{PET}{P} - \left(1 + \left(\frac{PET}{P}\right)^\omega\right)^{\frac{1}{\omega}}$$

$\omega =$ fitting parameter linked to watershed characteristics such as topography, soil, vegetation, and geographic location of watersheds
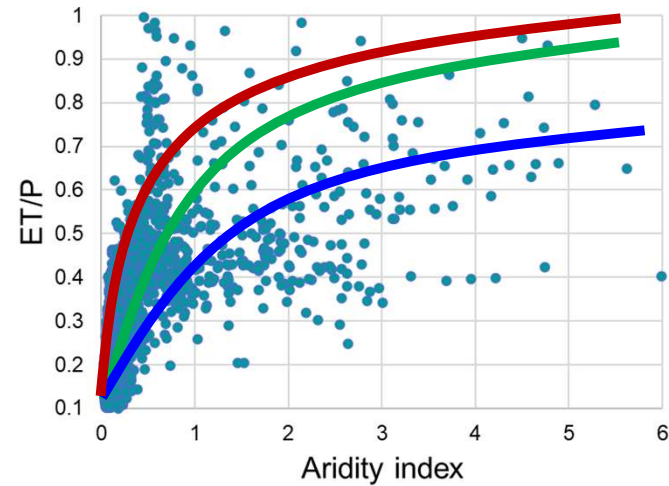
1. Size
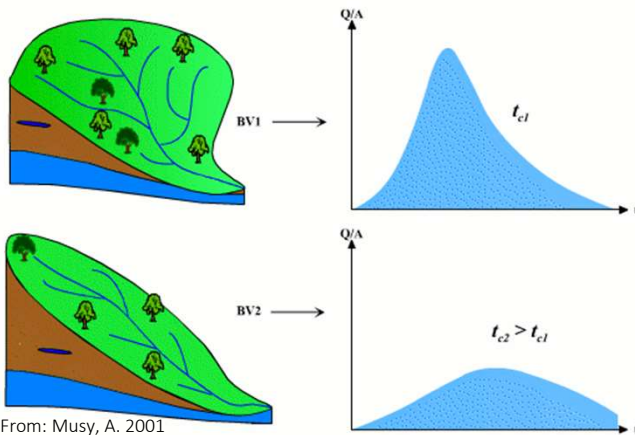2. Slope
3. Shape
4. Drainage density
5. Land use/land cover
6. Geology and soils
7. Vegetation

Open class GIT repository:
https://github.com/Vinit-Sehgal/hydrology

Useful terms and resources:

Watershed slope reflects rate of change of elevation w.r.t distance along principal flow path.

From: Musy, A. 2001

NDVI (Normalized Difference Vegetation Index) is an index that detects and quantifies live green vegetation using multi-spectral remote sensing.

For more details:
https://gisgeography.com/ndvi-normalized-difference-vegetation-index/