Hydrologic cycle

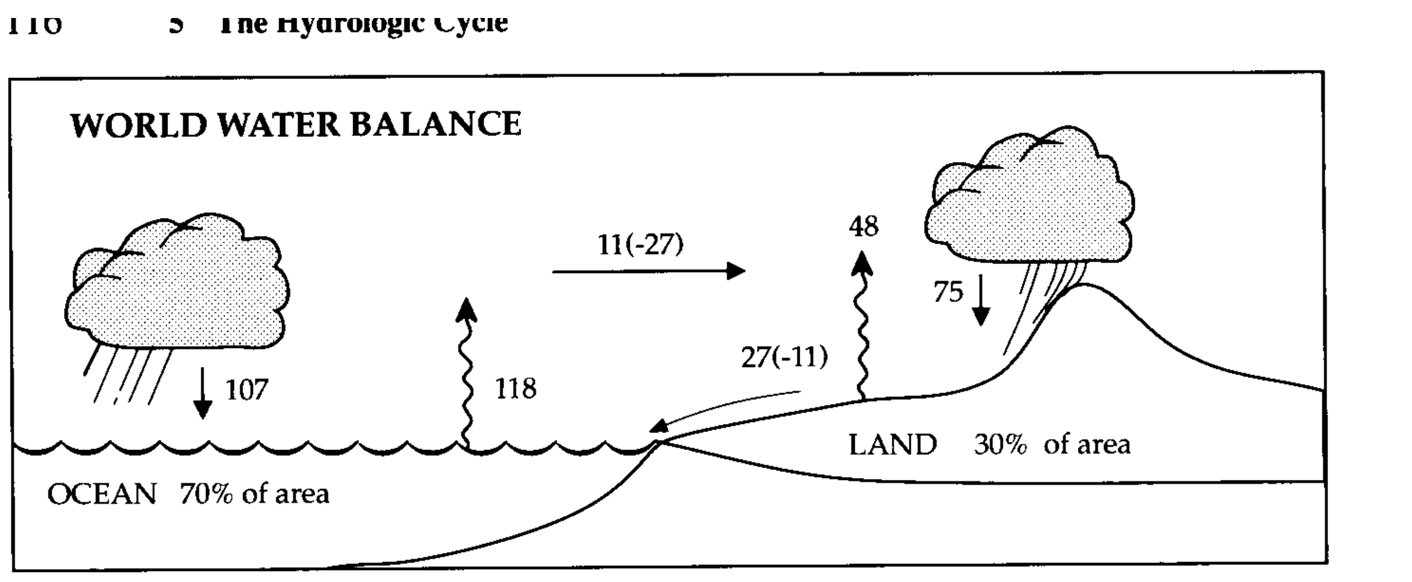
Reading: GPC Ch5. Omit subsections 5.5.1, 5.5.2 and 5.6.1

Outline:

- World water balance and equations for the water balance
- Geographic distribution of P and P-E
- Surface water storage and runoff
- Evaporation, transpiration
- Examples of terrestrial water budgets

Hydrologic cycle: movement of water among the reservoirs of ocean, atmosphere and land.
Total amount of water on Earth constant on time scales of thousands of years.

Basic fluxes of water in the global hydrological cicle



Units: cm/yr spread over the surface in question

Table 5.1

Water Volumes of Earth

Category	Volume (10^6 km^3)	Percent
Oceans	1348.0	97.39
Polar ice caps, icebergs, glaciers	227.8	2.010
Groundwater, soil moisture	8.062	0.580[a]
Lakes and rivers	0.225	0.020
Atmosphere	0.013	0.001
Total water amount	1384.0	100.0
Freshwater	36.00	2.60
Freshwater reservoirs as a percent of total freshwater		
Polar ice caps, icebergs, glaciers		77.2
Groundwater to 800-m depth		9.8[a]
Groundwater 800–4000-m depth		12.3[a]
Soil moisture		0.17[a]
Lakes (freshwater)		0.35
Rivers		0.003
Hydrated earth minerals		0.001
Plants, animals, humans		0.003
Atmosphere		0.040
Sum		100.000

[From Baumgartner and Reichel (1975).]

[a]Numbers uncertain.

Water balance

Surface water balance

$$g_w = P + D - E - \Delta f$$

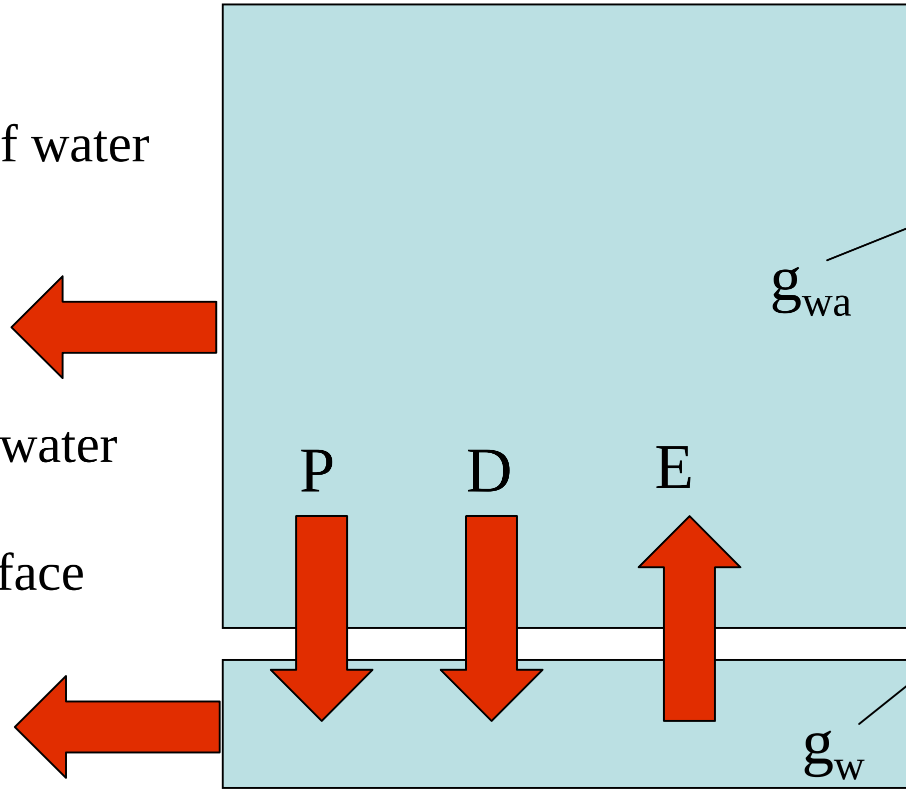
- g_w: Storage at or below surface
- P: Precipitation
- D: Surface condensation (small)
- E: Evaporation
- Δf: Runoff

Over a long term, the balance reduces to $\mathbf{\Delta f = P - E}$
i.e. the excess of precipitation over evaporation is taken by runoff

Atmosphere water balance

$$g_{wa} = -(P + D - E) - \Delta f_a$$

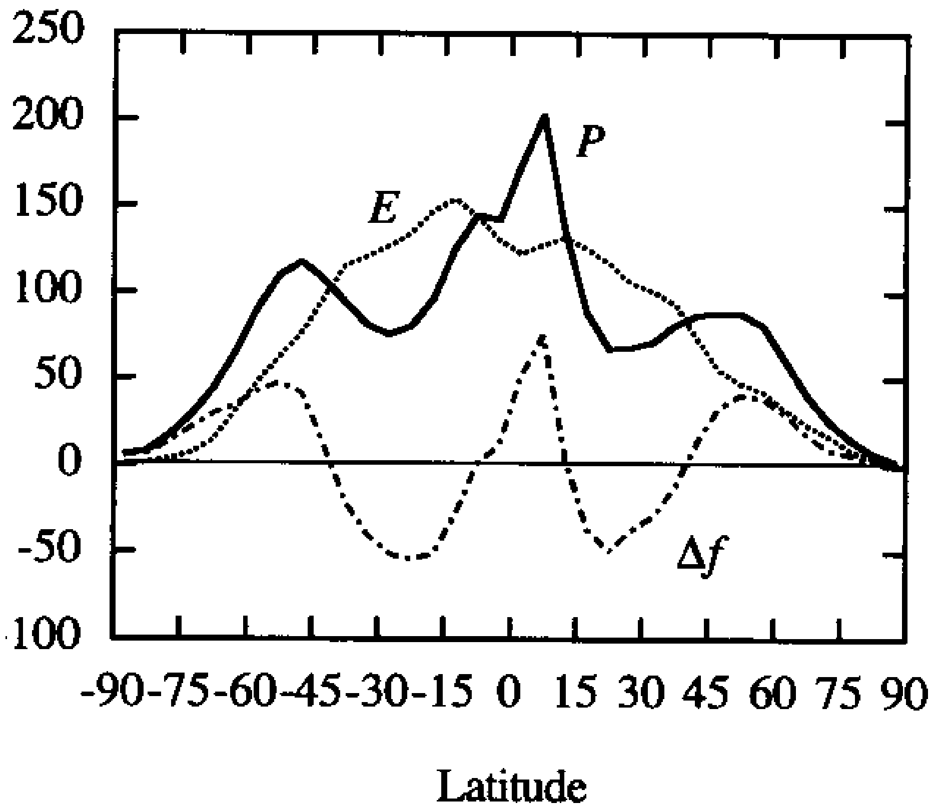
- g_{wa}: Storage in the atmosphere
- P: Precipitation
- D: Surface condensation
- E: Evaporation
- Δf_a: Horizontal atmospheric transport of moisture (export)



Note that $g_w + g_{wa} = -\Delta f - \Delta f_a$ (the exchange of water across the surface disappears)

i.e. net flux of water into atmosphere + ground equals the storage by the atmosphere + ground

Latitude distribution of surface hydrological cycle



- P-E: excess of precipitation over evaporation
- P>E in tropics
- P<E in subtropics
- P>E for latitudes polewards of ~40 degrees N/S
- Horizontal moisture transport balances P-E

When averaged over a year, the storage terms are generally small and the horizontal transport of water out of a region of the atmosphere must be equal and opposite to the net horizontal transport below the surface: water carried to continents by atm. transport must equal the runoff from rivers $\rightarrow$ $\mathbf{\Delta f = P - E}$

The wat. balances of the continents are closely related to their climates

NASA.)

Table 5.2

Water Balance of the Continents and Oceans (in mm/year)

Region	E	P	Δf =P-E	$\Delta f / P$
Land				
Europe	375	657	282	0.43
Asia	420	696	276	0.40
Africa	582	696	114	0.16
Australia	534	803	269	0.33
North America	403	645	242	0.37
South America	946	1564	618	0.39
Antarctica	28	169	141	0.83
All land	480	746	266	0.36
Ocean				
Arctic Ocean	53	97	44	0.45
Atlantic Ocean	1133	761	−372	−0.49
Indian Ocean	1294	1043	−251	−0.24
Pacific Ocean	1202	1292	90	0.07
All ocean	1176	1066	−110	−0.10
Globe	973	973	0	

[From Baumgartner and Reichel (1975).]

Runoff ratio: for land, larger values imply that more precipitation that falls on land flows back into the ocean rather than being re-evaporated

Note P<E for Atlantic (& Indian)

P>E for Pacific, Arctic

Impacts ***salinity*** of ocean

Surface water storage and runoff

Ways to store water:

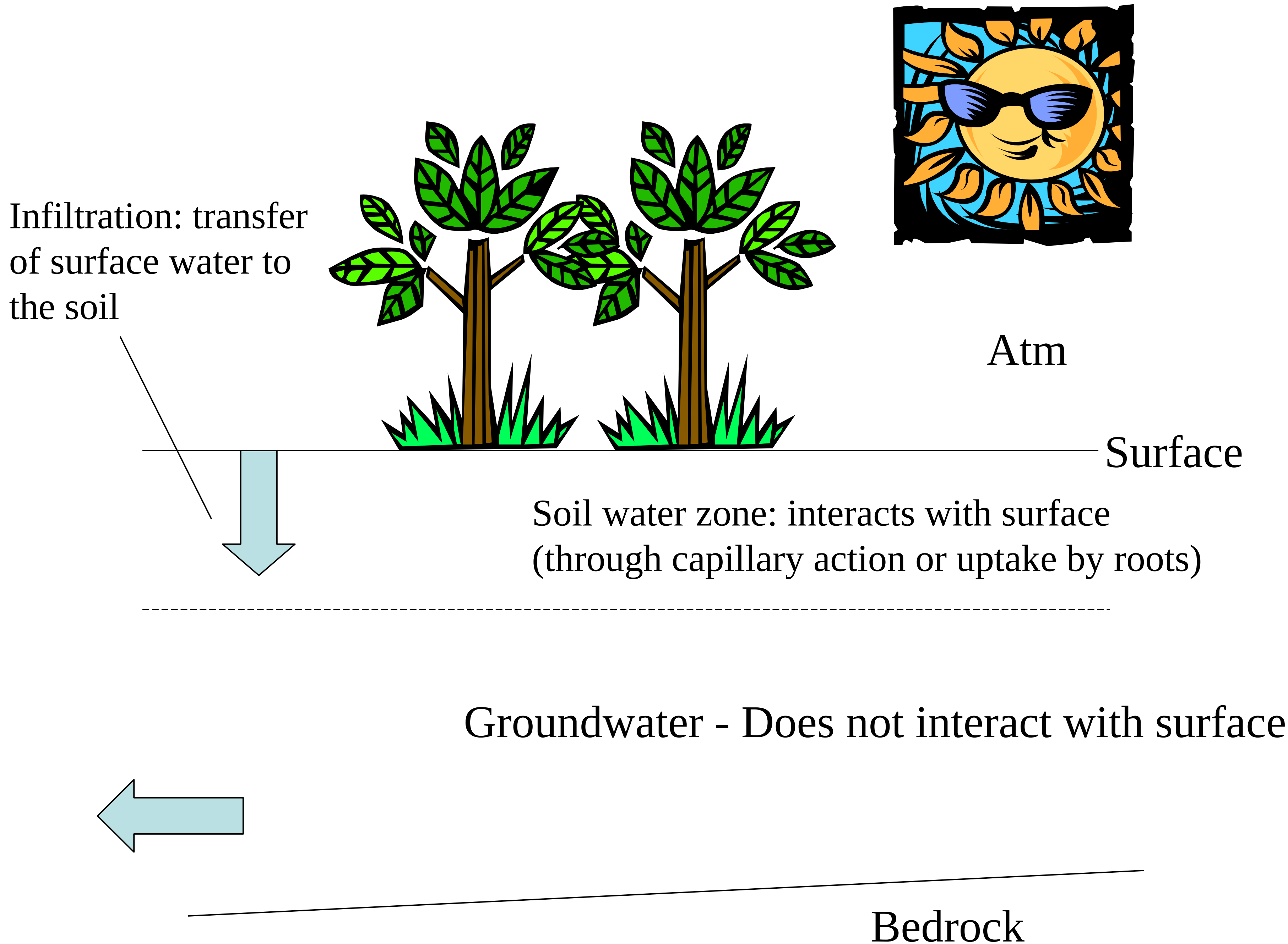
- Surface soil and ground water
- Snowcover - may be important for spring/summer flow in midlatitudes

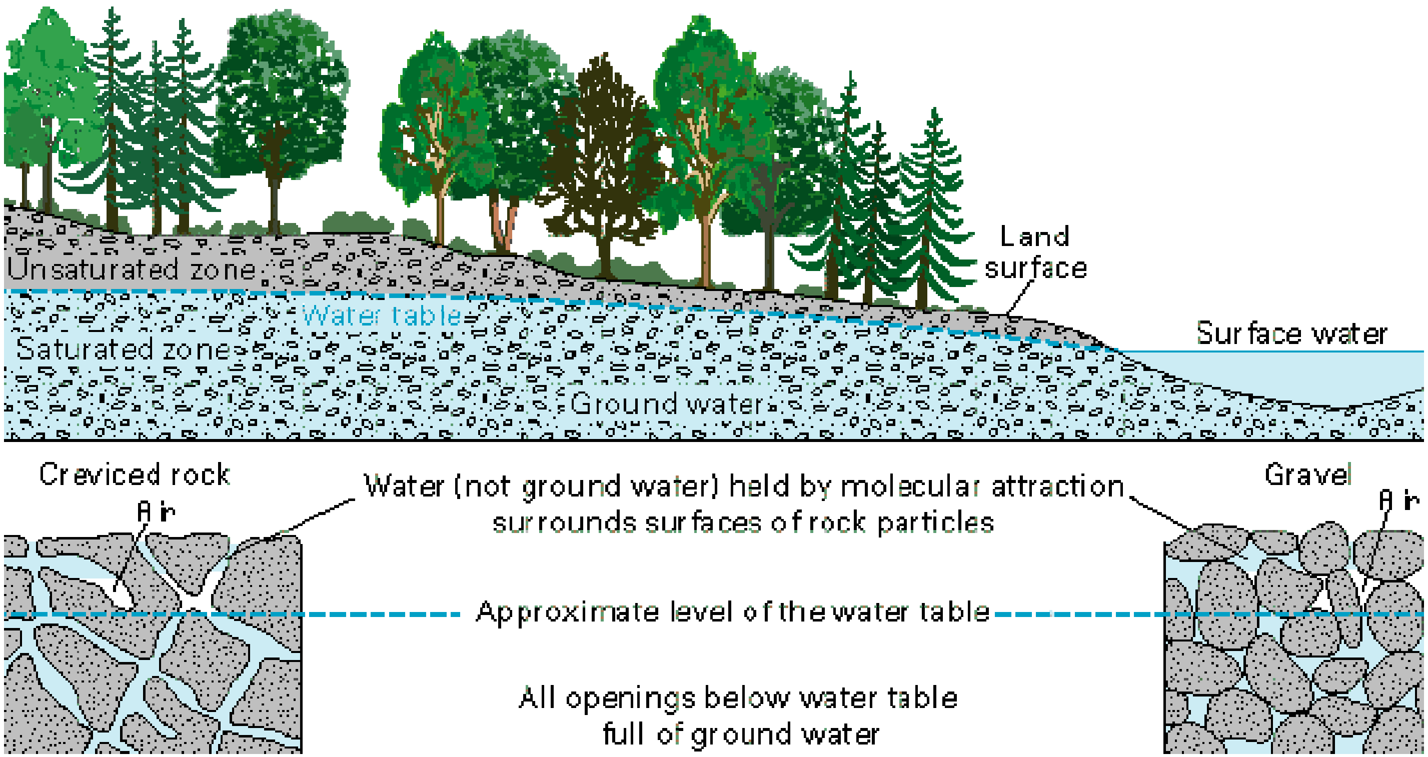
Climate interacts only with water on the surface or in the ***soil water zone -*** the latter being the water that can be brought to the surface by plants, or by diffusion and capillary processes in the soil.

Since plants can bring up water from below more effectively, vegetated region release water to the atmosphere more quickly than bare soil, even if the ground carries the same amount of water in both cases.

Field capacity of soil: amount of water suspended in soil by adherence to soil particles

If soil water > field capacity, then gravity pulls excess downwards to become ***groundwater.***


Infiltration: transfer of surface water to the soil
Atm
Surface
Soil water zone: interacts with surface (through capillary action or uptake by roots)
Groundwater - Does not interact with surface
Bedrock



http://ga.water.usgs.gov/edu/earthgwaquifer.html

Evaporation, transpiration

Evapotranspiration = *evaporation + transpiration*
Transpiration = *passage of water from plants to atmosphere via leaf pores (stomata)*
Plant canopy = collection of vegetable matter on surface

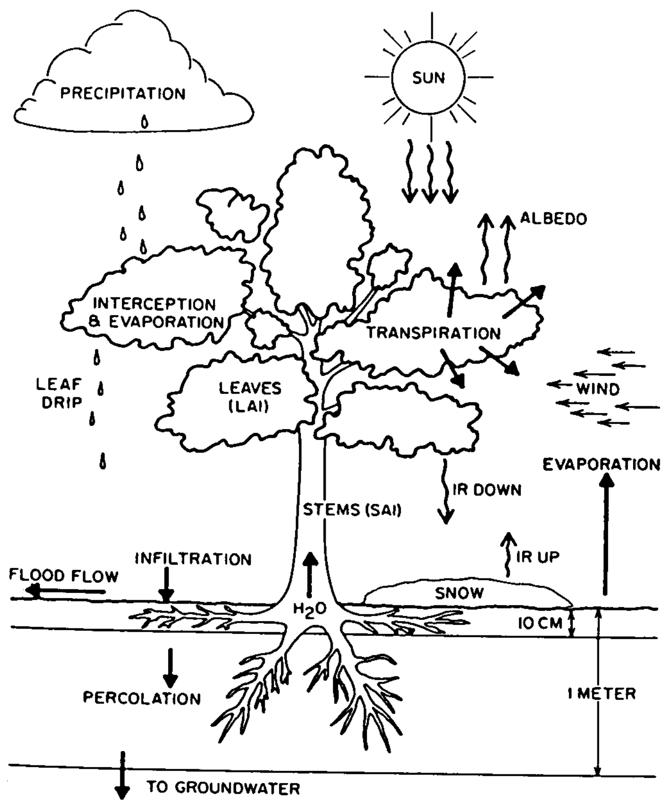


Fig. 5.5 Diagram showing the effects of the vegetation canopy on the water and energy fluxes. [From Dickinson (1984). © American Geophysical Union.]

Interception and evaporation by plant leaves greatly reduce runoff.

Leaf area index (LAI) = ratio of area of top sides of leaves relative to ground area

Some interesting aspects of modeling surface exchange over land:

- Stomatal resistance (in times of drought plants can reduce their transpiration rate)
- Transpiration depends on photosynthesis - radiation, temperature, water availability, plant physiology
- Transpiration also strongly depends on leaf temperature (limiting factor is not water uptake by roots, but rather the vapor phase in the leaves)
- Radiation budget depends on the albedo offered by the plants - depends on surface area (may have many vertical layers of leaves)
- Interception of falling water (storage of water on leaves; facilitation of re-evaporation)
- Soil levels and interaction with the atmosphere
    - Thin layer near surface - determines interaction with atmosphere at the timescale of individual rain events
    - Deeper ‘root zone’ - vegetation draw moisture from these levels
    - Below the root zone - moisture is carried here by gravity if soil is saturated; moisture can be drawn from it by capillary action
- Field capacity of soil (how much can be retained against gravity) depends on soil type: ranges from 10-50%
- Hydraulic conductivity decreases as soils dry out

Evapotranspiration is constrained by the surface water supply, the energy available to provide latent heat of vaporization and the ability of the surface air to accommodate water vapor.
Potential evaporation (PE) = rate of evapotranspiration that would occur if the surface was totally wet (maximum possible evapotranspiration for prevailing atmospheric conditions).

Note one way to estimate potential evaporation is to ***assume that the surface specific humidity is at saturation*** (so it is purely a function of surface temperature):

$$\mathrm{PE} = \rho_a \, C_{\mathrm{DE}} \, U \left(q^*(T_s) - q_a\right)$$

where ρ_a is air density, C_{DE} is transfer coeff. for humidity, q_a is air humidity and U is wind speed.

The difference between the potential evaporation and the actual evaporation gives a measure of the moisture deficit in the soil.

Evaporation can be measured in these ways:

Flux tower measurements : eddy covariance measurements of evaporation (remember w'q'?)

Also from residual of energy balance:

$$E = \frac{1}{L}\left(R_s - \mathbf{SH} - \Delta F_{eo} - G\right)$$

Net radiation (usually the largest term – must be measured accurately)

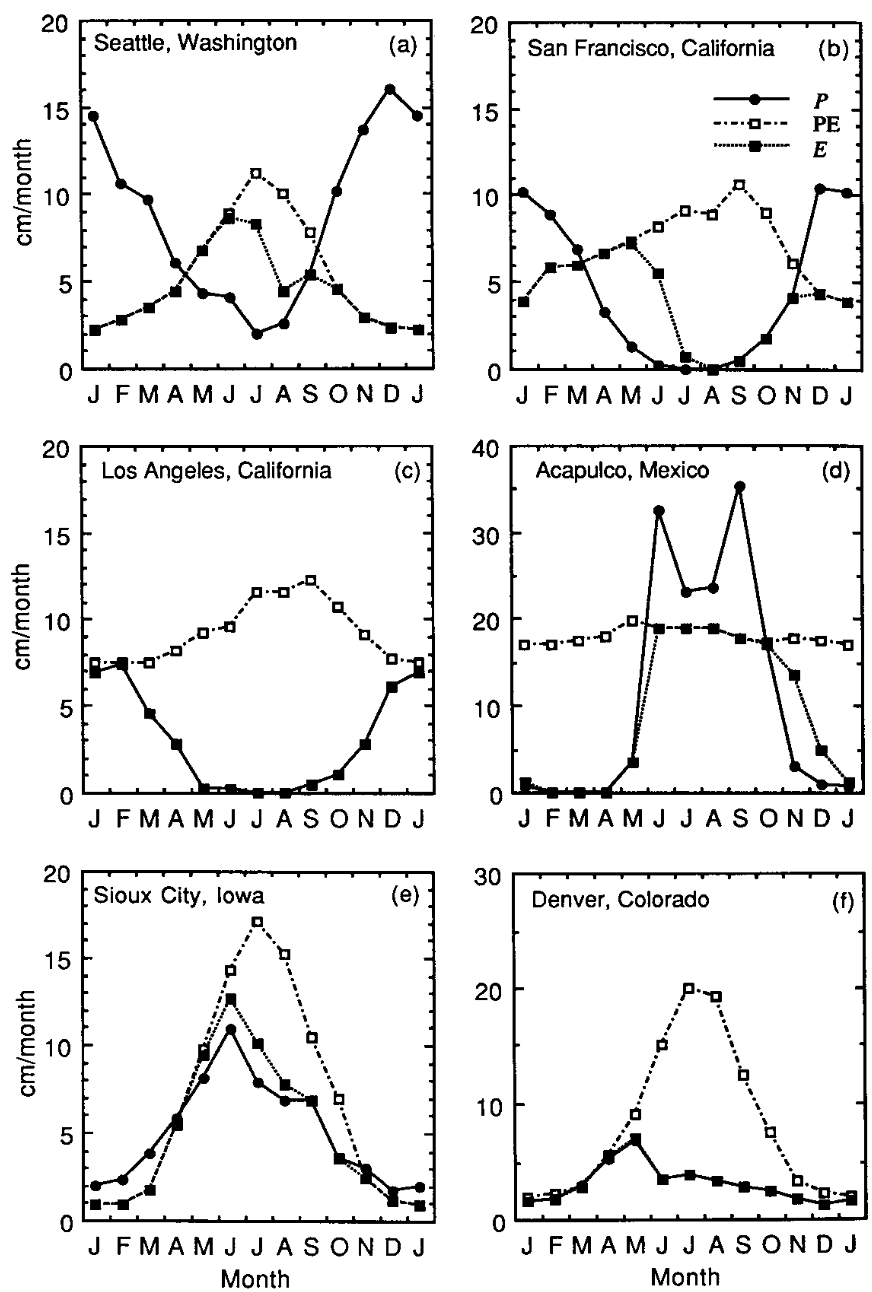
Sensible ht flux (can be small)

Horizontal energy transport (usually small)

Energy storage below sfc (small)

Runoff via streams can be measured using current meters to measure the velocity of the streamflow, and a tape measure to measure the depth and width of the stream cross-section. The average stream flow velocity times the cross-sectional area of the stream determines the stream flow measurement. Units are in unit volume per unit time (typically m^3/s)

Annual variation of terrestrial water balance (related to local climate)



Annual cycle of the water balance at various locations. Where precipitation does not

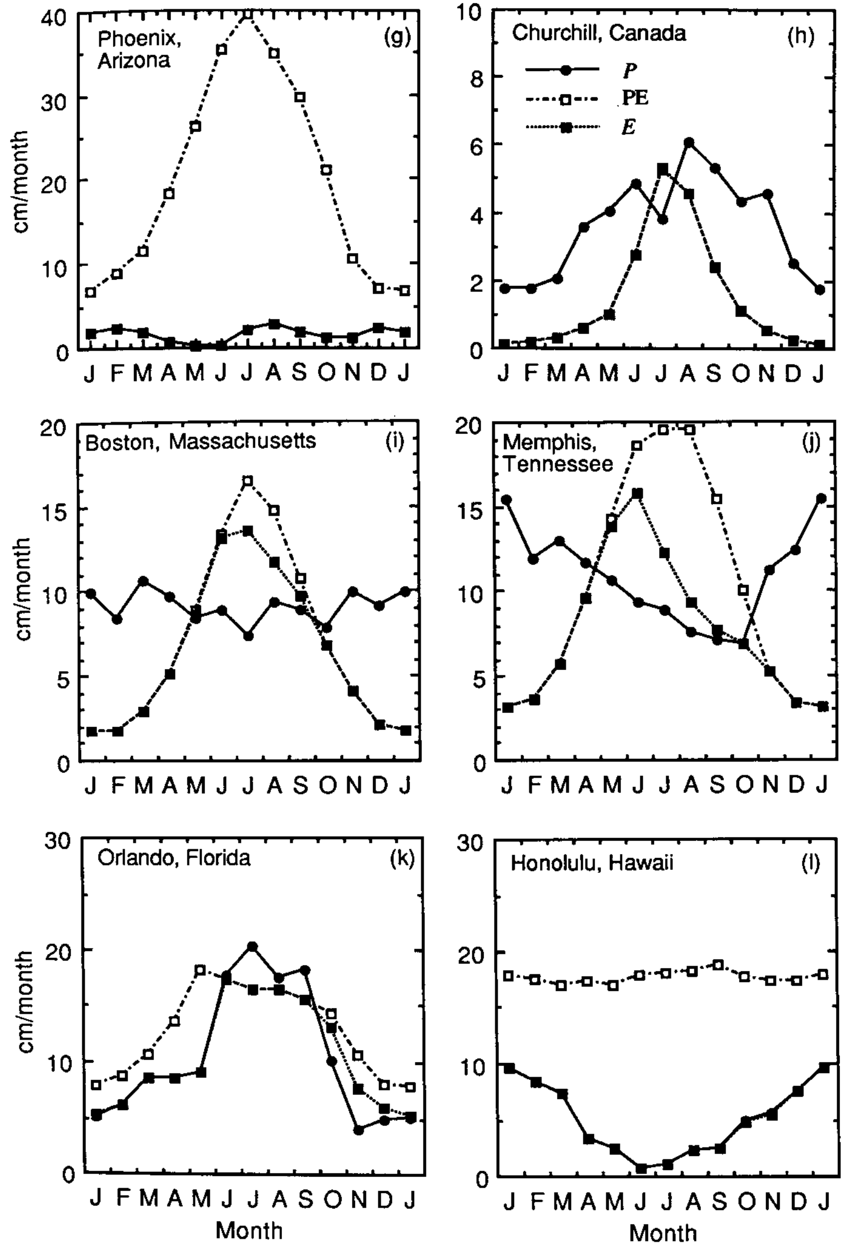


Fig. 5.6—*Continued*