Evaporation

GG22A: GEOSPHERE & HYDROSPHERE
Hydrology

Some definitions

- Evaporation
  - *conversion of a liquid to a vapour*
- Transpiration
  - *that part of evaporation which enters the atmosphere through plants*
- Total Evaporation
  - *the combined processes of evaporation and transpiration*
  - this has been referred to as evapotranspiration (*an ugly word)*
- Potential evaporation (PE)
  - *evaporation that would occur from an extensive well-watered surface*
- Actual evaporation (AE)
  - *evaporation that actually occurs, given water availability*

Factors affecting evaporation

- Several factors affect the rate of evaporation from surfaces:

1. Energy availability.
2. Humidity.
3. Rate of turbulent diffusion.
4. Water availability.
5. Vegetation characteristics.

Energy availability

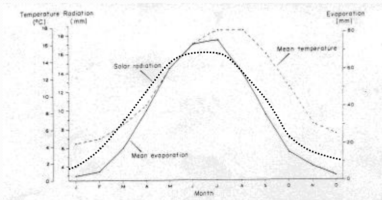


Figure 4.2 Mean monthly evaporation, temperature and solar radiation (mm evaporation equivalent) for Camden Square, London (evaporation and temperature data from Miller, 1953).

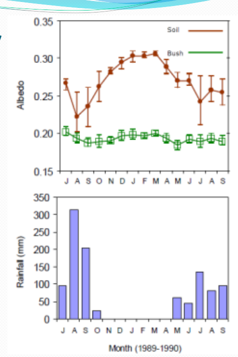
Camden Square, London

- Solar Energy: the relationship between mean monthly evaporation and solar radiation appears to be closer than the relationship to temperature.

Energy availability

- Albedo affects the reflectance of solar energy available:
  - High albedo = high reflectance
  - Low albedo = low reflectance

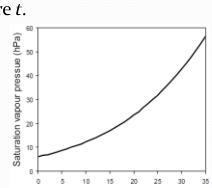
Land cover	Albedo
Snow and ice	0.2 (old) to 0.8 (new)
Open water	0.08
Bare soil	0.1 to 0.35
Tall trees	0.11 to 0.16
Grass and pasture	0.2 to 0.26



Allen *et al.* (1994)

Humidity

- *Actual Vapour Pressure* (e)
  - The density of water vapour within the air.
- *Saturation Vapour Pressure* (e_s)
  - The limit to the density of water vapour which may be contained in the air, at temperature *t*.
- *Relative humidity*
  - e/e_s
- *Saturation Deficit* or *Vapour Pressure Deficit* (VPD)
  - $e_s - e$, or the extra water that can be held in the air at temperature *t*.



Humidity

- Evaporation is greatest in **warm and dry** atmospheric conditions, and least in **cold and humid** conditions.
- In warm and dry conditions:
  - the Vapour Pressure Deficit (e_s -e) is large, which promotes evaporation.
- In cold and humid conditions:
  - the Vapour Pressure Deficit is low, which limits evaporation.

Turbulent diffusion

- The Vapour Pressure Deficit soon reaches zero in calm conditions, as evaporation occurs.
  - This would have the effect of stopping evaporation, so a mixing of air by **turbulence** is required.
  - Air movement is needed to remove the lowest moist layers in contact with the water surface and to mix them with the upper drier layers.

Turbulent diffusion

- The stronger the wind, the greater will be the turbulence, so there will be more convection and more evaporation.
- There is some relationship between evaporation and wind speed, but a critical speed may be reached where no additional evaporation takes place.

Water availability

- Evaporation from free water bodies
  - Water availability is *not* a problem. Evaporation is mainly controlled by the drivers of energy, humidity and windspeed
  - Additional energy may come from heat stored in the water.
- Evaporation from bare soil
  - Water availability *is a problem.* Evaporation is limited by amount of water available
  - Sensitivity to lack of water varies with soil type
  - Additional energy may come from heat stored in the soil

Evaporation from free water bodies

- In addition to meteorological factors, the physical characteristics of a lake, pond or reservoir also influence the rates of evaporation from the surface:

1. Salinity of the Water Body.
2. Depth of the Water Body.
3. Size (Area) of the Water Body Surface.

Evaporation from free water bodies

- Salinity of the Water Body:
  - evaporation decreases by about 1% for each 1% increase in salinity. This is due to the reduced vapour pressure of saline water.
- Water Depth: has an effect on the seasonal distribution of evaporation.

Evaporation from free water bodies

- Shallow water bodies have a similar seasonal temperature regime to the air temperature above them
  - maximum rates of evaporation occurs during the summer; minimum rates in winter.

Evaporation from free water bodies

- Deep lakes have a greater capacity for heat storage and many exhibit thermal stratification which also influences evaporation.
  - Deep lakes may slowly release stored heat during the autumn and winter months.

Evaporation from free water bodies

- In deep lakes, water temperatures tend to be:
  - cooler than the air above the lake in summer
  - warmer than air temperatures in the winter.
- The Vapour Pressure Deficit (e_s-e) is calculated from:
  - The saturation vapour pressure (e_s) at the temperature of the water surface
  - The actual vapour pressure (e) of the overlying air.
- It follows that the VPD is higher in winter than summer, leading to greater evaporation.
- Turbulent diffusion is also greater in winter
  - In summer, the warmer overlying air will tend to be cooled by the water body, which would tend to stabilise it.

Evaporation from free water bodies

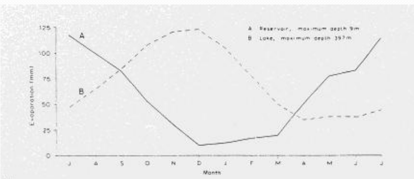


Figure 4.4 *The trend of evaporation through the year from Kempton Park reservoir near London (curve A) and Lake Superior (curve B) (based on data from Lapworth, 1956, and Hickman, 1940).*

Evaporation from free water bodies

- Size of the Surface (Area): Large lakes have a greater effect on their local atmosphere – they can produce a vapour blanket which reduces the VPD.

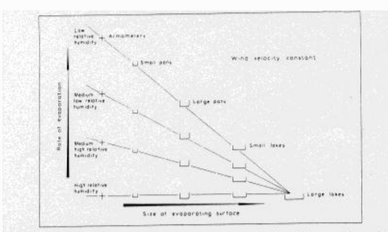


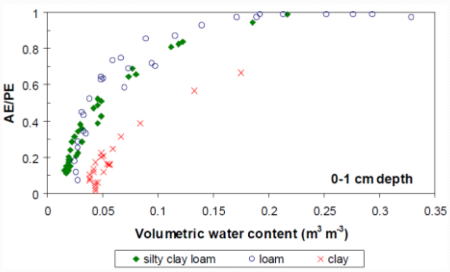
Figure 4.5 *The relationship between the rate of evaporation, the size of the evaporating surface and the relative humidity (from an original diagram by Thornthwaite and Mather, 1955).*

Evaporation from soils

- Meteorological factors apply.
- Also depends on the **water availability** at the evaporating surface (*evaporation opportunity*), influenced by:

1. Soil Moisture Content.
2. Soil Capillary Characteristics.
3. Soil Colour and Temperature.

Evaporation from bare soil when water is limiting



Chanzy & Bruckler, 1993

Evaporation from soils

- **Soil Moisture Content**: surface layers particularly important.
  - Water vapour movement from the subsoil to the surface less important.
  - A rough soil surface comprises a larger evaporating surface than an identical area of water: the *evaporation opportunity* may be >100%.
  - Soil evaporation increases if the soil surface is re-wetted by frequent and intermittent showers than from a soil surface which is thoroughly soaked by a single storm with the same quantity of rain.

Evaporation from soils

- **Soil Capillary Characteristics**: where rainfall is infrequent, evaporation opportunity can depend on the capillary rise of moisture from depth.
  - In finer-textured soils: capillary movement is effective over larger vertical distances than for coarse-textured soils, but it is slower.
- Capillary activity becomes important to evaporation where shallow groundwater exists:
  - Soil evaporation is maximum when the water table is at the surface.
  - Below about 1m depth, any further drop in the height of the water table leads only to a very slight change in the rate of evaporation.
  - This critical depth (c.1m) is influenced by the capillary characteristics of the soil
    - depends on the texture and grain size of the soil.
    - deeper for fine-textured soils than for coarse-textured soils.

Evaporation from soils

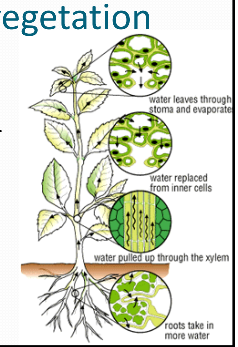
- **Soil Colour and Temperature**:
  - soil colour affects albedo: darker soils tend to absorb more heat
  - soil temperature: warmer soils may have higher rates of evaporation as they have more energy available.

Evaporation from vegetation

- Evaporation from vegetation occurs by two processes:
  - Evaporation of intercepted water from wet vegetation (Interception Loss).
  - Transpiration.

Evaporation from vegetation

- Transpiration:
  - Loss of water from the stomata (and to a lesser extent from leaf cuticles and lenticels in the stems).
  - Main role of transpiration is to bring a stream of water and dissolved nutrients from the root hairs to the stem vessels (xylem) and up to the leaves.



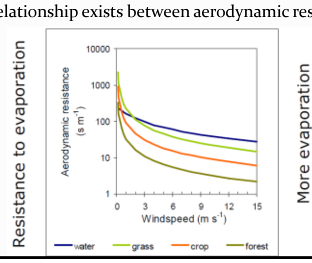
Evaporation from vegetation

- Meteorological factors apply.
- Evaporation from vegetation also depends on:

1. Aerodynamic characteristics of the vegetation.
2. Vegetation factors.
3. Soil factors.

Evaporation from vegetation

- Aerodynamic characteristics: tall trees have a lower aerodynamic resistance than grasses and they also have a rougher surface (trees have a higher aerodynamic roughness) generating eddy currents.
- An inverse relationship exists between aerodynamic resistance and wind speed.



Evaporation from vegetation

- Vegetation Factors: relate to physiological resistances imposed by the vegetation. These factors are:

1. Albedo: influences the energy balance at the evaporating surface.
2. Stomata conductance: more important than aerodynamic resistance.
3. Root Control.

Evaporation from vegetation

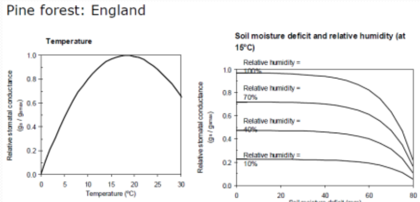
- Stomatal conductance:
  - Rate at which water can leave plant varies with vegetation type

	maximum stomatal conductance (mm s^{-1})
Temperate grass	8
Cereals	11
Conifers	5.7
Deciduous	4.6
Tropical rainforest	6.1

Evaporation from vegetation

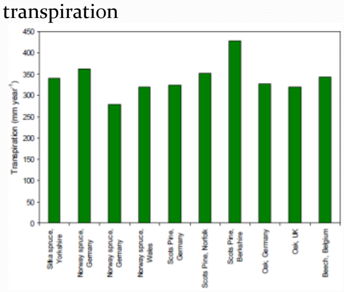
- Stomatal conductance varies with temperature, water availability, relative humidity, light and CO_2 concentrations

Pine forest: England



Evaporation from vegetation

- Forest transpiration



Roberts (1983)

Transpiration when water is limiting

- Field capacity: water held in soil against gravity
- Wilting point: minimum water content at which plants can extract water

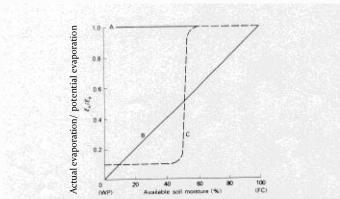


Figure 4.15 *The relationship between actual and potential evaporation through the range of drying from field capacity (FC) and wilting point (WP) according to Veihmeyer and Hendrickson (line A), Thornthwaite (line B) and Penman (curve C). See text for explanation.*

- Line A: water loss in young prune trees were the same when the soil moisture was reduced almost to the wilting point as when the soil was at field capacity.
- Line B: evaporation decreases as soil moisture decreases through a range of drying conditions to the wilting point.
- Line C: "root constant" model.

Total evaporation from an area

- Total evaporation =

  Evaporation from open water +

  Evaporation from bare soil +

  Transpiration +

  Evaporation of intercepted water

Relative importance of different components

	Precipitation (mm)	Transpiration (mm)	Evaporation of intercepted water (mm)	Interception / transpiration
UK conifers:				
Balquihidder (Scotland)	2500	280	710	2.5
Plynlimon (Wales)	1820	310	520	1.7
Stocks (NW England)	980	340	370	1.1
Thetford (E England)	600	350	210	0.6
Japanese conifers				
Mature	1343	333	182	0.5
Young	1480	294	83	0.3
Beech woodland, France[1]	462	255	120	0.5
Heather (Scotland)	2500	170	350	2.1
Grass (Scotland)	2500	160	200	1.3
Rainforest	2640	990	330	0.3

[1] *over the growing season only*

Total evaporation

- Which is the most important component?
  - It depends on the availability of moisture and whether the vegetation is wet or dry.
  - If the vegetation is frequently wet, evaporation from the surfaces will be normally greater than transpiration and interception loss will dominate the evaporation total.
  - Evaporation of intercepted water can also occur at night.
- The relative importance of evaporation by interception and transpiration will vary over a year based on the length of time the vegetation is either wet or dry and on atmospheric conditions.

Summary

- Factors affecting evaporation:
  1. Energy availability.
     - Solar energy; albedo
  2. Humidity.
     - Actual & saturated vapour pressure; vapour pressure deficit (VPD).
  3. Rate of turbulent diffusion.
     - Wind speed; surface roughness
  4. Water availability.
     1. Open water; soil moisture deficit
  5. Vegetation characteristics.
     1. Albedo; stomatal conductance; root control.
- Total evaporation
  - Evaporation from open water, soil, interception; transpiration