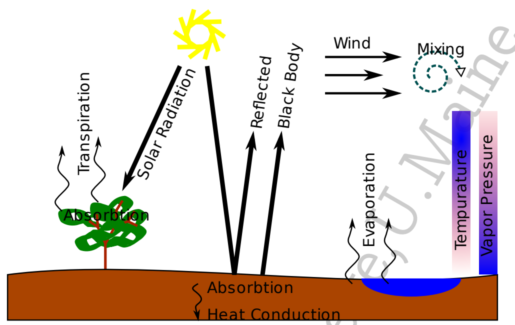
Evapotranspiration: Basics

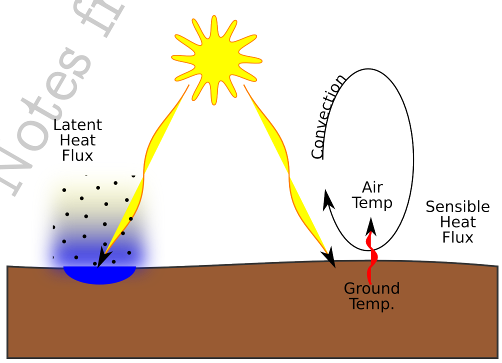
What Controls Evaporation and/or transpiration?

- Evaporation
  - Humidity (diff in vapor pressure of water and air)
  - Energy/Heat (600 cal. to evap. 1 g H_2O)
  - Wind (Mixing)
- Transpiration
  - Plant type (only 1% of water used for growth)
  - Soil Moisture



Evapotranspiration: Sensible and Latent Heat

- Sensible Heat Flux
  - Heat diffusion from ground to air
  - Heat convected through air
- Latent Heat Flux
  - Heat loss through phase change
  - Latent Heat $= \rho_{water} \cdot \lambda \cdot E_r$ λ=latent heat of vaporization [energy/mass] E_r=Evaporation due to radiation



Evapotranspiration: Measurement Overview

- Evaporation Pans
- Mass Transfer Methods
- Energy Balance
- Combination of Energy and Mass Transfer Methods

Evaporation Pans:Open Water

- open water evaporation (no transpiration)
- Standard U.S. Pan
  - 48 inch diameter, 10 inch deep
  - elevated off of ground (12 inches)
  - $E_{Pond} = K \cdot E_{Pan}$ K is pan coeff., approx. 0.7
  - $E_{Pond} = K' \frac{e_{Lake} - e_{air}}{e_{pan} - e_{air}} E_{Pan}$ e is saturated vapor pressureK' is 1.5

Aerodynamic Methods:Open Water

- Diffusion-based method
- $E_a = M \cdot U_z(e_{water} - e_z)$ M is mass-transfer coeff. U is wind speed e is sat. vapor pressure
- M determined through calibration with energy-balance method
- Various attempts to simplify calculation of M
- $M = 0.622 \frac{\rho_{air} C_E}{\rho_{water} P}$ C_E is constant that changes with height (1.15 to $1.4 \cdot 10^{-3}$ at 8 m.)P is air pressure at that height increased pressure condenses gas to liquid

Energy Balance:Open Water

- Energy input from insolation equals losses due to sensible, ground, and latent heat fluxes.
- $R_n = H + G + \rho_{water} \cdot \lambda \cdot E_r$ H is sensible heat fluxG is ground heat flux
- Want to calc. E_r from other parameters
- sensible heat flux through Bowen Ratio ratio of sensible:latent heat

$$\beta = \gamma \frac{T_2 - T_1}{e_2 - e_1} = \frac{H}{\rho_{water} \cdot \lambda \cdot E_r}$$

γ is psychrometric constant, tabulated for different temps, relates vapor pressure to air temp. $gamma$ is also influenced by pressure (important at high altitudes)

- Net radiation R_n at ground is both short-wavelength (solar) and long-wavelength (re-radiated) radiation
- Can measure net radiation
- Can estimate R_n from short-wave and long-wave components from climate data.

Energy Balance Problem, E from pond (2.24)

- Relative humidity is 47%

- Max and min pond temp.: 18 and 15 deg. C
- Mean air temp.: 23 deg C
- Solar radiation is 42.5 $\frac{MJ}{m^2 \cdot day}$
- 70 degrees N latitude (What day does this rad. input represent?)
- Bowen ratio is 0.1 (How is this calculated?)
- Bright sun for 85% of day.
- Negligible ground heat flux

$$S_n = (1-\alpha)\left(.25 + .5 \cdot \frac{n}{N}\right) R_A$$
$$R_b = -(0.1 + 0.9\frac{n}{N})(0.34 - 0.14\sqrt{e_d})\sigma T^4$$

Gupta Eq 2.24 &2.26,Table 2.9,2.10

Evapotranspiration: Combination Method

- Weight aerodynamic and energy balance evaporation
- Based on:
  - psychometric constant (γ)
  - vapor pressure grad. (Δ); slope of vap. press. w.r.t. temp
    - both values tabulated with temp.
    - table 2.9 in Gupta
- $E = E_r \cdot \frac{\Delta}{\Delta+\gamma} + E_a \cdot \frac{\gamma}{\Delta+\gamma}$

Evapotranspiration: Drainage Basin

- Potential ET: If not limited by moisture availability
- Actual ET: True ET (PET⩾AET)
- Lysimeters (Evapotranspirometers)
  - Field based monitoring
  - Monolith of soil and plants in container
  - measure water loss

Evapotranspiration: Drainage Basin

- Penman-Monteith (PET)
  - Aerodynamic method combined with Energy Balance
  - adds plant resistance to water loss (r_s) to turbulence across vegetated surface (r_a)
  - uses *real* vapor pressure(e_z) and saturated vapor pressure at plant surface (e_z^0)

$$E_a = 0.622 \frac{\rho_{air}}{\rho_{water} P} \frac{1}{r_a}(e_z^0 - e_z)$$
$$E_r = \frac{R_n - G}{\rho_{water}\lambda(1+\beta)}$$
$$ET_0 = \frac{\Delta}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} E_r + \frac{\gamma}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} E_a$$

Empirical relationships for PET

Empirical equations to calc. PET from temp.

- Hamon (temp-based) $PET = 29.8 \cdot D \frac{e_s}{T_K}$ D=hours of daylight, e_s based on mean daily temp
- McGuinness-Bordne (temp-based) $PET = \frac{R_A \cdot (T_a + 5.)}{\lambda \cdot \rho \cdot 68}$
- summary of 27 PET models in Oudin et al., 2005, Journal of Hydrology
- PE formulas overestimate catchment scale PE

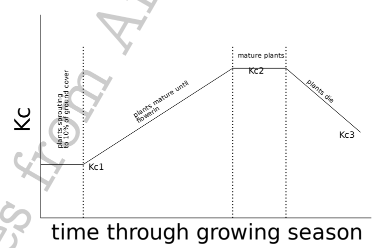
Actual ET

- AET is regulated by precip. and energy
  - arid areas: precip limited
  - wet areas: energy limited
- Empirical relationship between energy(PET) and precip. (Pike, 1964) $AET = \frac{p}{\left[1+(\frac{p}{PET})^2\right]^{\frac{1}{2}}}$ provides reasonable long-term average (monthly)
- Use Penman-Monteith approach, measure T and e at two levels to calc Bowen Ratio.

Actual ET

Crop AET

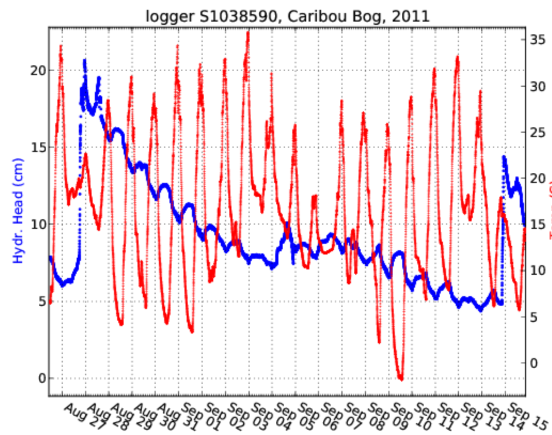
- $AET = K_c \cdot K_a \cdot PET$
- K_c is crop coefficient (from table) for early, middle or late plant growth stage
- K_a adjustment for soil moisture availability $K_a = \frac{\Theta - \Theta_{LL}}{\Theta_t - \Theta_{LL}}$ $\Theta_t = (1 - F_{ns})(\Theta_{DU} - \Theta_{LL}) + \Theta_{LL}$ F_{ns} is available water (no stress), Θ_{DU} is moisture content at field capacity (water held against drainage, 33 KPa suction), Θ_{LL} is moist. cont. at lower limit of extractable water (permanent wilting point,1500KPa suction). (Doorenbus and Kassam, 1979)



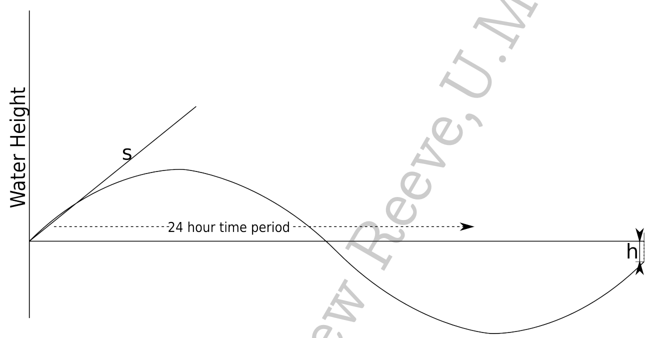
Actual ET

TABLE 4.8. General Averages and Ranges of Soil Water Parameters for Agricultural Soils (Jensen et al., 1990).

	WATER CONTENT, VOLUME BASIS, $m^3 m^{-3}$					
	Drained upper limit		Lower limit of extractable water		Available water	
Texture Class	Average	Range	Average	Range	Average	Range
Coarse						
Sand	0.12	0.07-0.17	0.04	0.02-0.07	0.08	0.05-0.11
Loamy Sand	0.14	0.11-0.19	0.06	0.03-0.10	0.08	0.06-0.12
Moderately Coarse						
Sandy Loam	0.23	0.18-0.28	0.10	0.06-0.16	0.13	0.11-0.15
Medium						
Loam	0.26	0.20-0.30	0.12	0.07-0.16	0.15	0.11-0.18
Silt Loam	0.30	0.22-0.36	0.15	0.09-0.21	0.15	0.11-0.19
Silt	0.32	0.29-0.35	0.15	0.12-0.18	0.17	0.12-0.20
Moderately Fine						
Silty Clay Loam	0.34	0.30-0.37	0.19	0.17-0.24	0.15	0.12-0.18
Fine						
Silty Clay	0.36	0.29-0.42	0.21	0.14-0.29	0.15	0.11-0.19
Clay	0.36	0.32-0.39	0.21	0.19-0.24	0.15	0.10-0.20



Air Temperature and water level in Caribou Bog. Note daily oscillations in water level. Time scale is shifted by 12 hours.



$$ET = S_y(24 \cdot s + h)$$

s=hourly change in water level from midnight to 4 am h=decrease in water level over 24 hour period