Czech University of Life Sciences Prague, Czech Republic

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The potential evapotranspiration as a key component in water balance.

Bachelar course of "Topics in Geography"

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Definition

- The terms potential evaporation and potential evapotranspiration are to be differentiated.

combines the rate at which water is removed from wet soils with that from plant surfaces

measure for the atmospheric demand

- Evaporation - the primary pathway that water moves from the liquid state back into the water cycle as atmospheric water vapor.

Free-water evaporation

"Potential evaporation"

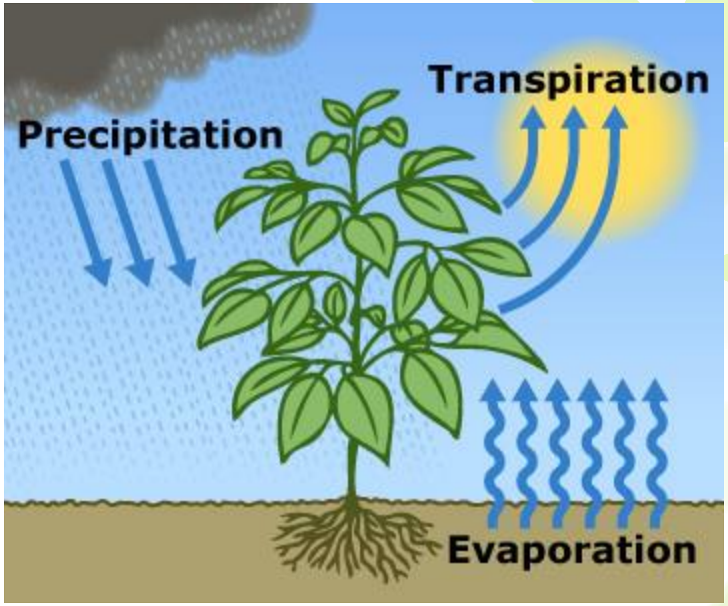
- Evaporation that would occur from an open-water surface in the absence of advection and changes in heat storage

Depends only on climate/meteorology

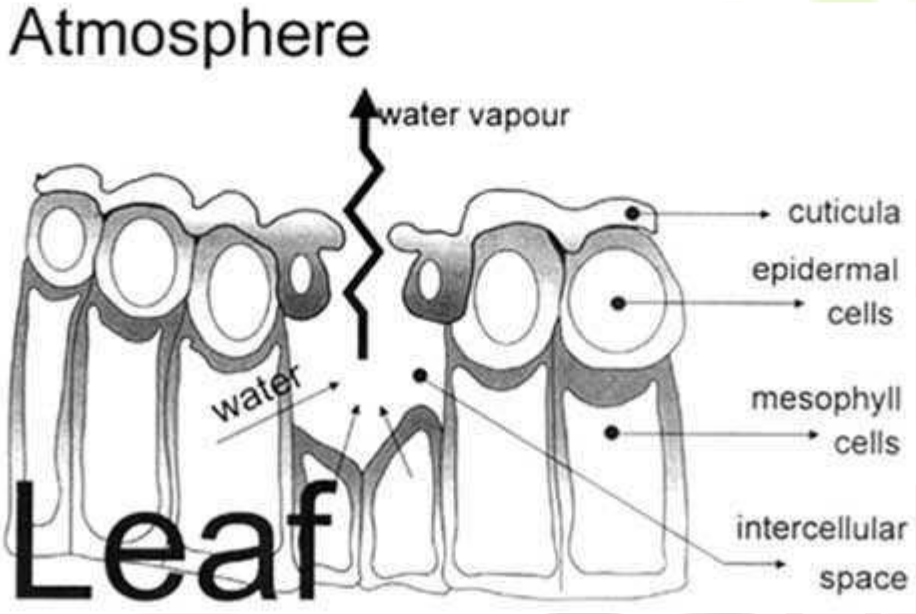
Evaporation: net loss of water from a surface resulting from a change in the state of water from liquid to vapor and the net transfer of this vapor to the atmosphere

Transpiration

Transpiration:
evaporation of water
from the
vascular system of plants
into the atmosphere



- ✓ Vaporization occurs in intercellular spaces of the plant tissue, while exchange with the atmosphere occurs through and is controlled by plant stomata.



Definition

❖**Evapotranspiration (ET)**☞the sum of plant transpiration and evaporation;

❖ **Evaporation** ☞ process to convert liquid water into a gas.

✓ accounts for the movement of water to the air from sources such as the soil, canopy interception and water bodies.

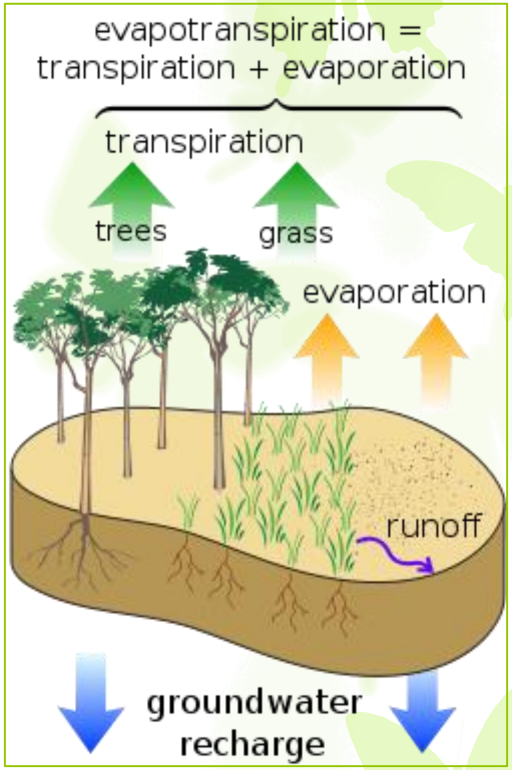
❖**Transpiration** ☞ process involving water loss from plants.

❖Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes.

❖Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface.

❖This fraction decreases over the GS as the crop develops and the crop canopy shades more and more of the ground area.

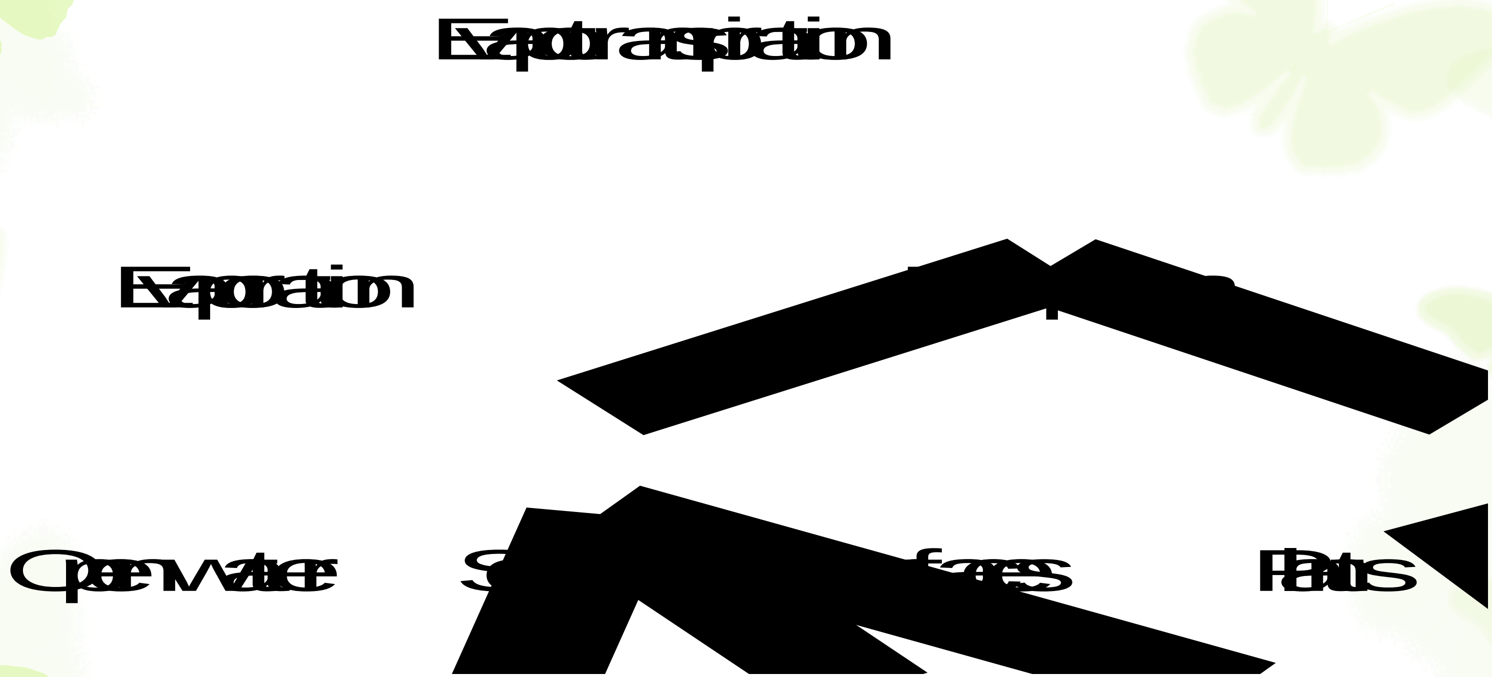
❖When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process.



Evapotranspiration - an important part of the water balance (water cycle)

ET divided into sub-processes:

- Studies have shown that the oceans, seas, lakes, and rivers provide 90% of the moisture in the atmosphere via evaporation, with the remaining 10% being contributed by plant transpiration.



- ET is a complicated process because it is the product of the different processes, such as evaporation of water from the soil, and water intercepted by the canopy, and transpiration from plant leaves.
- Physiological, soil and climatic variables are involved in these processes.

Definition

- **ET**⇨ an important variable in drought identification to determine evaporative demand of the atmosphere.
- Recent drought studies have enhanced the debate on the effect of actual evapotranspiration (ETa), reference evapotranspiration (ETo) and/or potential evapotranspiration (PET) on drought quantification!!!
  - **We can distinguish between two aspects of ET:**

1) PET - the amount of evaporation that would occur if a sufficient water source were available.

   - ✓ It is a reflection of the energy available to evaporate water, and of the wind available to transport the water vapour from the ground up into the lower atmosphere.

2) ETa - the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration.

   - ✓ the water lost under real conditions.
   - ✓ **ETa < PET** {except where the surface is continuously moist}.

- ETo - the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, bulk surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, and no moisture stress (Allen et al., 1994).
  - ✓ Estimates of ETo are largely applied in irrigation schemes to define crop water requirements.

Units

- ET rate is normally expressed in **mm per unit time**.
- **Time unit** can be an hour, day, decade, month or even an entire growing period or year!!!
- Rate expresses the amount of water lost from a cropped surface in units of **water depth**.
- **Water depths** can also be expressed in terms of energy received per unit area.
  - heat required to vaporize free water.
- This energy, known as the **latent heat of vaporization** (λ) ☞ λ = **2.45 MJ kg^{-1}** ⇨ **2.45 MJ** are needed to vaporize 1 kg.

☞ an energy input of **2.45 MJ per m^2** is able to vaporize 1 mm of water,

⇨ **1**mm of water is equivalent to **2.45 MJ m^{-2}**.

☞ ET rate expressed in units of **MJm^{-2}day^{-1}** is represented by l ET.

Table 1. Conversion factors for evapotranspiration

	depth	volume per unit area		energy per unit area *
	mm day^{-1}	m^3 ha^{-1} day^{-1}	l s^{-1} ha^{-1}	MJ m^{-2} day^{-1}
1 mm day^{-1}	1	10	0.116	2.45
1 m^3 ha^{-1} day^{-1}	0.1	1	0.012	0.245
1 l s^{-1} ha^{-1}	8.640	86.40	1	21.17
1 MJ m^{-2} day^{-1}	0.408	4.082	0.047	1

* For water with a density of 1000 kg m^{-3} and at 20°C.

As one hectare has a surface of 10000 m^2 and 1 mm is equal to 0.001 m, a loss of 1 mm of water corresponds to a loss of 10 m^3 of water per hectare. In other words, 1 mm day^{-1} is equivalent to 10 m^3 ha^{-1} day^{-1}.

On a summer day, net solar energy received at a lake reaches 15 MJ per square metre per day. If 80% of the energy is used to vaporize water, how large could the depth of evaporation be?

From Table 1:	1 MJ m^{-2} day^{-1} =	0.408	mm day^{-1}
Therefore:	0.8 x 15 MJ m^{-2} day^{-1} = 0.8 x 15 x 0.408 mm d^{-1} =	4.9	mm day^{-1}

The evaporation rate could be 4.9 mm/day

Processes

For the process of evapotranspiration, three basic physical requirements in the soil-plant-atmosphere system must be met:

1) Continuous supply of water;
2) Energy to change liquid water into vapour;
3) Vapour pressure gradient (E-e) between the evaporating surface and the air.

⇓

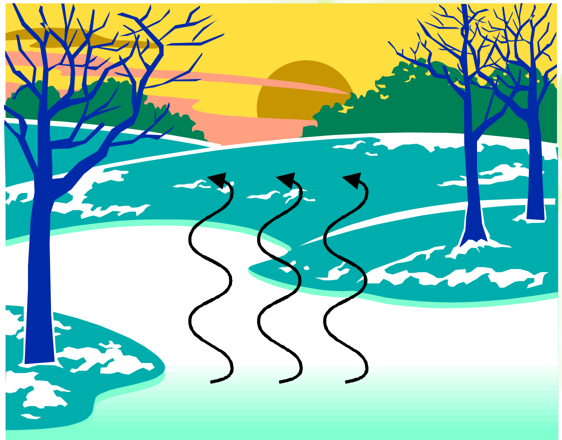
- ET is an energy controlled process requiring the conversion of available radiation energy (sunshine) and sensible energy (***H*** - heat contained in the air) into latent energy (λ - energy stored in water vapor molecules).

Classification of ET processes

- Surface type:
  - Open water
  - Bare soil
  - Leaf/canopy type
  - Crop type
  - Land region
- Water availability
  - Unlimited vs. limited
- Stored energy use, ΔQ
- Water-advected energy, A_w

} **often assumed negligible**

Physics of evaporation



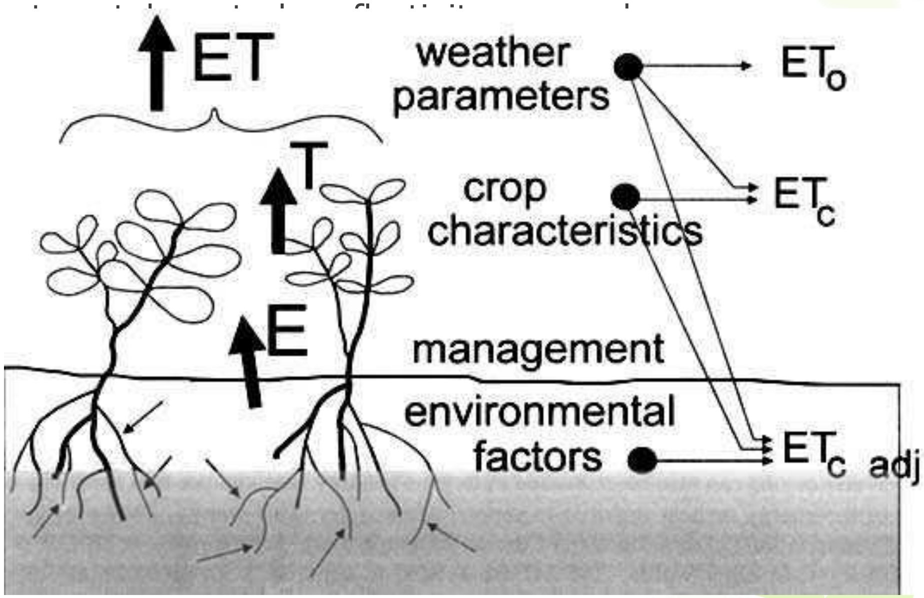
- Energy is required to change the state of the molecules of water from liquid to vapour.
- Direct solar radiation and the ambient temperature of the air provide this energy.
- The driving force to remove water vapour from the evaporating surface is the difference between the water vapour pressure at the evaporating surface and that of the surrounding atmosphere.
- As evaporation proceeds, the surrounding air becomes gradually saturated and the process will slow down and might stop if the wet air is not transferred to the atmosphere.
- The replacement of the saturated air with drier air depends greatly on wind speed.

⇓

- solar radiation, air temperature, air humidity and wind speed are climatological parameters to consider when assessing the evaporation process.

Factors Affecting Evapotranspiration

- **Weather**:
  - Solar radiation,
  - Air temperature,
  - Relative humidity,
  - Wind speed
- **Crop characteristics**:
  - Crop type and variety (Height, roughness, rooting characteristics)
  - Stage of development
- **Management**:
  - Irrigation management
  - Irrigation method
  - Cultivation practices
  - Fertility management
  - Disease and pest control
- **Environmental conditions**:
  - Soil type, texture, water-holding capacity
  - Soil salinity
  - Soil depth and layering
  - Poor soil fertility



Factors Affecting transpiration

❖ **Temperature T:**

- ✓ Transpiration rates go up as **T** goes up, especially during the GS, when the air is warmer due to stronger sunlight and warmer air masses.
- ✓ Higher **T** cause the plant cells which control the openings (stoma) where water is released to the atmosphere to open.

❖ **Relative humidity r:**

- ✓ As the **r** of the air surrounding the plant rises the transpiration rate falls.
- ✓ It is easier for water to evaporate into dryer air than into more saturated air.

❖ **Wind and air movement:**

- ✓ Increased movement of the air around a plant will result in a higher transpiration rate.
- ✓ If there is no wind, the air around the leaf may not move very much, raising the humidity of the air around the leaf.
- ✓ Wind will move the air around, with the result that the more saturated air close to the leaf is replaced by drier air.

❖ **Soil-moisture availability:**

- ✓ When moisture is lacking, plants can begin to premature ageing, which can result in leaf loss and transpire less water.

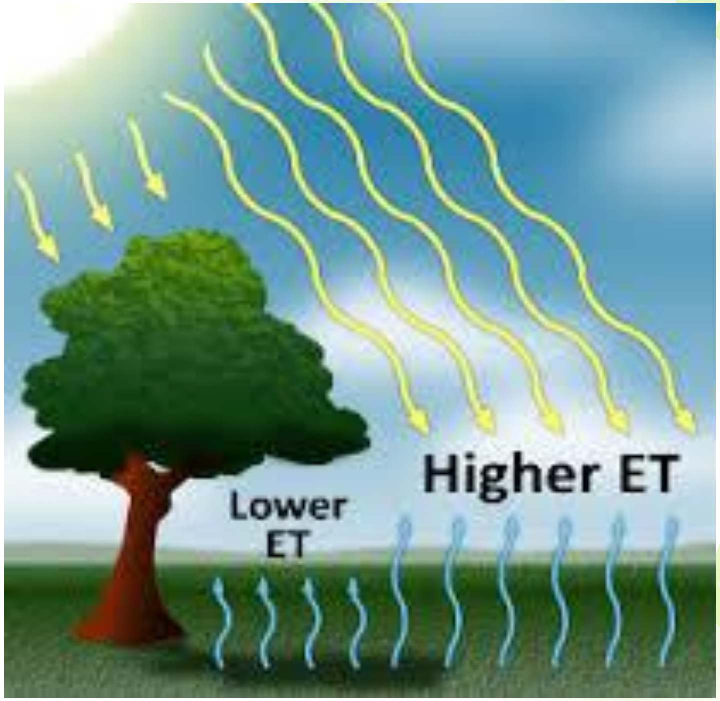
❖ **Type of plant:**

- ✓ Plants transpire water at different rates.
- ✓ Some plants which grow in arid regions, conserve precious water by transpiring less water than other plants.

Factors Affecting Evapotranspiration

Energy inputs: Solar radiaton

- ET process is determined by the amount of energy available to vaporize water.
- Solar radiation reaching the evaporating surface depends on the turbidity of the atmosphere and the presence of clouds which reflect and absorb major parts of the radiation.



Factors Affecting Evapotranspiration

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Air temperature

- The sensible heat of the surrounding air transfers energy to the crop and exerts as such a controlling influence on the rate of evapotranspiration.
  - In sunny, warm weather the loss of water by evapotranspiration is greater than in cloudy and cool weather.

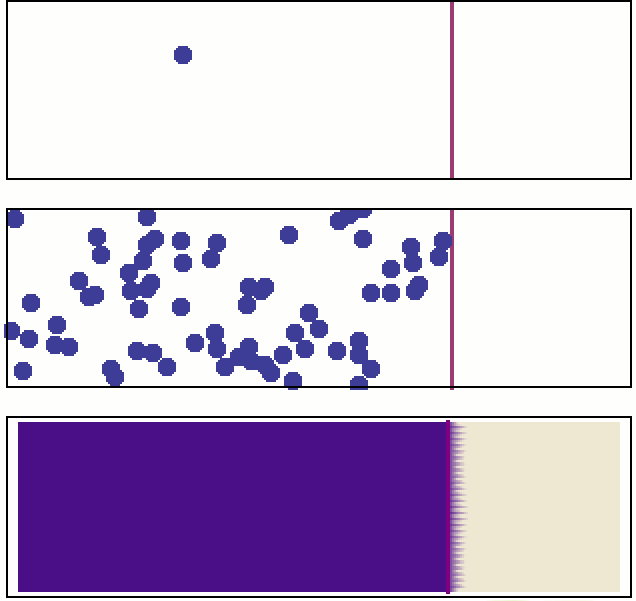
Factors Affecting Evapotranspiration

Air humidity

- While the energy supply from the sun and surrounding air is the **main driving force** for the vaporization of water,
  - the difference between the water vapour pressure at the evapotranspiring surface and the surrounding air is the **determining factor for the vapour removal**.

$$e_s^* - e_a^*$$

- Evaporation require that the humudity of the atmosfere be less than that of the ground.
  - ☞ when the air reaches saturation r = 100 % ⇨ **evaporation cannot take place.**
- Well-watered fields in hot dry arid regions consume large amounts of water due to the abundance of energy and the desiccating power of the atmosphere.
  - In humid tropical regions, still the high energy input, the high humidity of the air will reduce the evapotranspiration demand.
    - In such an environment, the air is already close to saturation, so that less additional water can be stored and hence the evapotranspiration rate is lower than in arid regions.

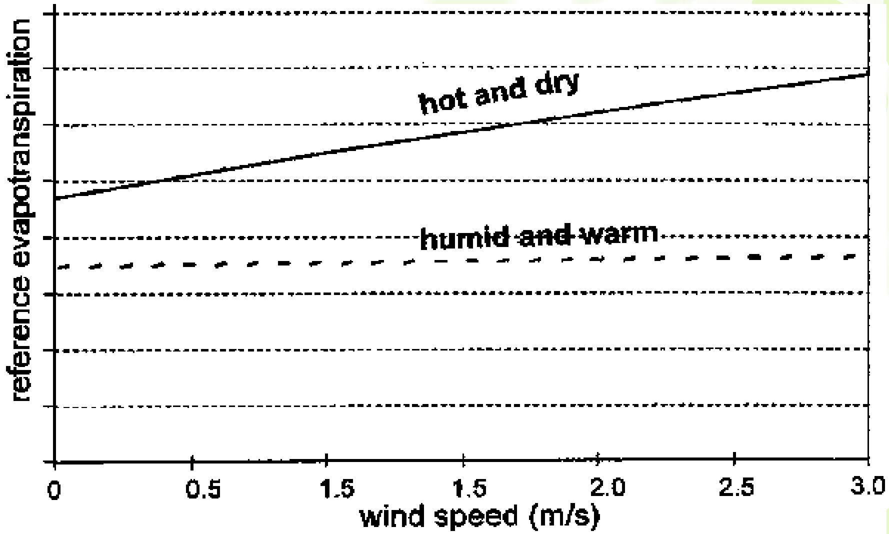


Factors Affecting Evapotranspiration

Wind speed

- The process of vapour removal depends to a large extent on wind and air turbulence which transfers large quantities of air over the evaporating surface.
- If this air is not continuously replaced with drier air, the driving force for water vapour removal and the ET rate decreases.

The effect on ET of increasing wind speeds for the two different climatic conditions

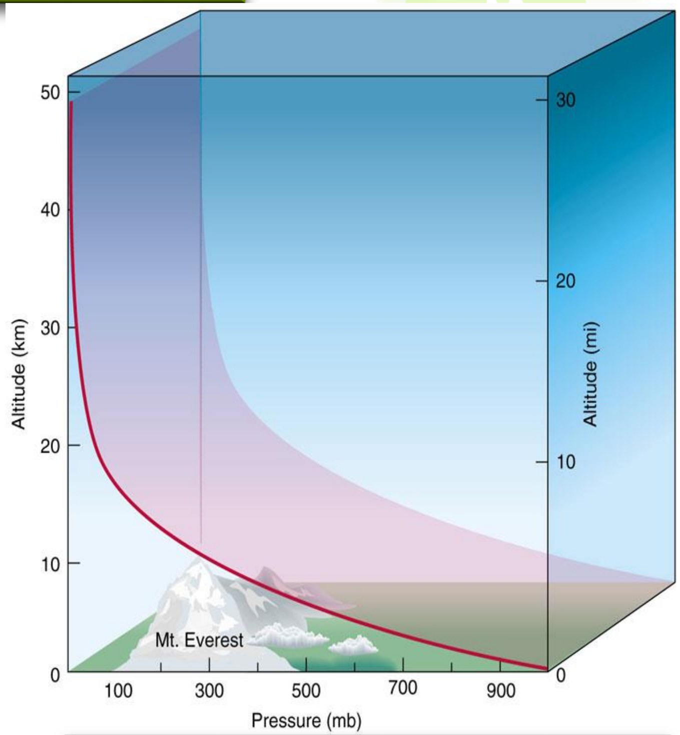


(1) The drier the atmosphere, the larger the effect on ET and the greater the slope of the curve.
(2) For humid conditions, the wind can only replace saturated air with slightly less saturated air and remove heat energy.

Atmospheric parameters affecting Evapotranspiration

Atmospheric pressure (P, hPa)

- Evaporation at high altitudes is promoted due to low atmospheric pressure as expressed in the psychrometric constant.
- The effect is, however, small and in the calculation procedures, the average value for a location is sufficient.



1mm Hg = 1 torr = 133,322 Pa
760 mmHg (torr) = 1013,25 hPa
1 atm = 1013,25 hPa
1 mbar=1hPa

Latent heat of vaporization (λ)

- the energy required to change a unit mass of water from liquid to water vapour in a constant pressure and constant temperature process.
- varies as a function of temperature ⇨ at a high temperature, less energy will be required than at lower temperatures.
- varies only slightly over normal temperature ranges a single value of **2.45 MJ kg^{-1}** is taken in the simplification of the FAO Penman-Monteith equation.

⇨ This is the latent heat for **t = 20°C**.

Latent heat exchange, *LE*

- Occurs whenever there is a vapor pressure difference between water and air

$$LE = \rho_w \lambda_v E$$

where

ρ_w = water density 1000 kg m^{-3}

λ_v = latent heat of vaporization

$$\lambda_v = 2.50 - 2.36 \times 10^{-3} T$$ [MJ kg^{-1}]

surface water temperature (°C)

Sensible heat exchange, *H*

- Occurs whenever there is a temperature difference between water and air

$$B = \frac{H}{LE} \Rightarrow H = B \times LE$$

where

B = Bowen ratio

Depends on air pressure
→ constant at a particular site

Psychrometric constant (γ)

The γ is given by:

$$\gamma = \frac{c_p P}{\varepsilon \lambda} = 0.665 \times 10^{-3} P \quad (8)$$

$$\gamma = \frac{c_a P}{0.622 \lambda_v}$$

where

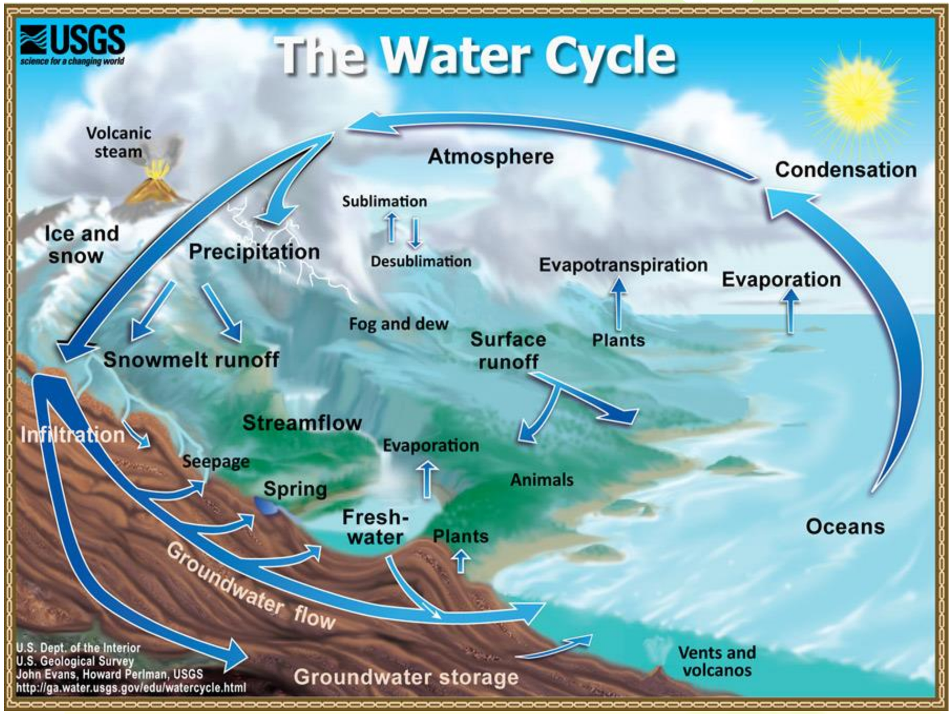
γ psychrometric constant [kPa °C^{-1}],
P atmospheric pressure [kPa],
λ latent heat of vaporization, 2.45 [MJ kg^{-1}],
c_p specific heat at constant pressure, 1.013 10^{-3} [MJ kg^{-1} °C^{-1}],
ε ratio molecular weight of water vapour/dry air = 0.622.

- The specific heat at constant pressure is the amount of energy required to increase the temperature of a unit mass of air by one degree at constant pressure.
- Its value depends on the composition of the air, i.e., on its humidity.
- For average atmospheric conditions a value c_p = 1.013 10^{-3} MJ kg^{-1} °C^{-1} can be used.

ET as part of Global water cycle

✍ a major component of the hydrologic water budget, but one of the least understood.
✍ permits the return of water to the atmosphere and induces the formation of clouds, as part of a never-ending cycle.

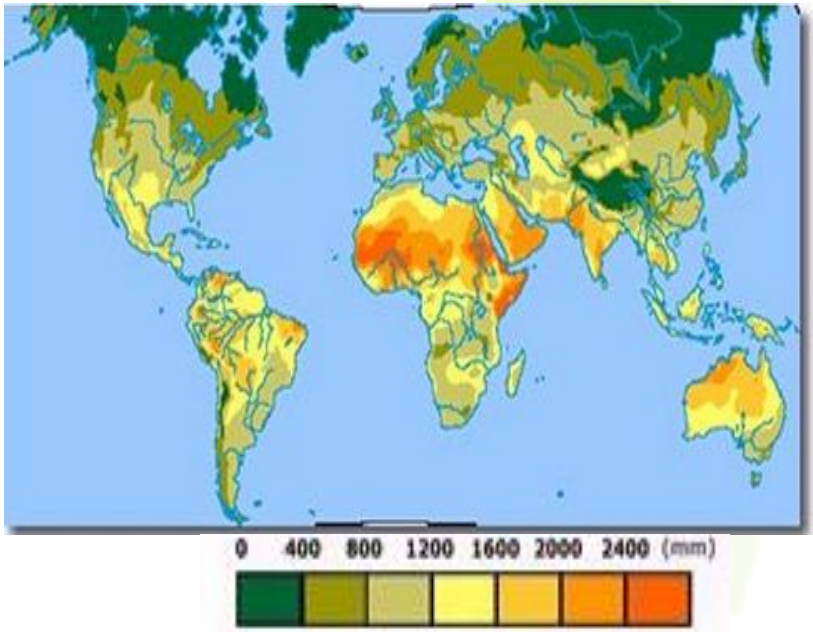
- There are three basic steps in the global water cycle:
  1. water precipitates from the atmosphere
  2. travels on the surface and through groundwater to the oceans
  3. evaporates or transpires back to the atmosphere from land or evaporates from the oceans
- Water vapor redistributes energy from the sun around the globe through atmospheric circulation.
- This happens because water absorbs a lot of energy when it changes its state from liquid to gas.
- Atmospheric circulation moves this latent heat around Earth, and when water vapor condenses and produces rain, the latent heat is released.



- A water molecule can travel to many parts of the globe as it cycles.
- During their constant cycling between land, the oceans, and the atmosphere, water molecules pass repeatedly through solid, liquid, and gaseous phases (ice, liquid water, and water vapor), but the total supply remains fairly constant.

Geographical patterns of evapotranspiration

- varies with latitude, season, time of day, and cloud cover;
  - maximum under the clear skies and long hot days of tropical areas;
  - minimum in the cold, cloudy polar regions;
- in temperate regions - water stores rise and fall with seasonal evaporation rates, ☞ net atmospheric input (**Precipitation minus Evaporation**) can vary from positive to negative.
- temperatures are more constant in tropical regions where large seasonal differences in precipitation, such as monsoon cycles, are the main cause of variations in the availability of water.
- most of the ET of water occurs in the subtropical oceans;
  - In these areas, high quantities of solar radiation provide the energy required to convert liquid water into a gas.
- ET generally exceeds precipitation on middle and high latitude landmass areas during the summer season;
  - reaches a peak during the summer months and declines during the winter.
- daily variation -very little ET occurs at night;



Mean Annual Potential Evapotranspiration.

Methods and Models Review

☝ During the last sixty year several methods and models to measure ET in agroecosystems have been developed.

☝ The estimation of ET from vegetated areas is a basic tool for computing water balances and to estimate water availability and requirements for plants.

☝ Measurement of ET is needed for many applications in agriculture, hydrology and meteorology.

Methods and Models Review

🕮The first vapor flux measurements were initiated by Thornthwaite and Holzman in 1930s, but that works was interrupted by World War II.

🕮 In the late 1940s Penman (1948) published the paper "**Natural Evaporation from open Water, Bare Soil and Grass**" in which he combined a thermodynamic equation for the surface heat balance and an aerodynamic equation for vapor transfer.

🕮 The "Penman equation" is one of the most widely used equations in the world.

🕮 The equation was later modified by Monteith (1965; 1981) and is widely known as the "**The Penman-Monteith Model**".

🕮 It is also necessary to introduce a review of the work of Bowen, who in 1926 published the relationship between the sensible and latent heat fluxes, which is known as the "**Bowen ratio**".

🕮 Measurement of the water vapour flux became a common practice by means of the "**Bowen ratio energy balance method**" (Tanner, 1960).

Measuring evapotranspiration

- One of the main needs of the farmers or irrigation engineer is to be able to predict when the plants will suffer from moisture stress and how much water must be applied.
- Knowledge of ET losses is required by the hydrologist who wishes to plan water management policies;
  - he needs to know what proportion of the precipitation will be available to replenish groundwater.
- This involves being able to measure or calculate the rate of ET.
- The measurement of ET is therefore important, but it is also difficult!!!
- Several systems of measurement have been developed:

(1) Direct measurement
(2) Meteorological formulae
(3) Moisture budget methods.

Direct measurement

- ❖ Evaporation pans
- ❖ Lysimetry
- ❖ Soil water depletion
- ❖ Energy balance and micro-meteorological methods — **research applications only:**
  - ✓ Mass transfer / Bowen ratio (Vertical gradients of air temp and water vapor
  - ✓ Eddy correlation (gradients of wind speed and water vapor)

1. Direct measurement

"Potential evaporation"

Evaporimeter, mm

$$E_{pan} = W - (V_2 - V_1)$$

where

- W = precipitation during time Δt
- V_1 = storage at beginning of period Δt
- V_2 = storage at end of period Δt

	Evaporation, mm	rainfall, mm	r (%)
05/27/2014	+148.3	35.7	92.8
05/28/2014	+168.6	10.0	94.3
05/29/2014	+76.2	3.4	93.2
05/30/2014	+7.6	0.3	78.6
05/31/2014	-32.8	0.0	63.4
06/01/2014	-45.0	0.0	57.2
06/02/2014	-46.9	0.0	60.1
06/03/2014	-38.5	0.0	64.6
06/04/2014	-33.6	0.1	66.8

☞ The rate at which the water is lost through evaporation is measured with a evaporimeter.

☞ This procedure measures only potential evaporation, for it does not allow for limitations moisture supply, nor does it directly determine transpiration losses.

☞ The results seem to vary according to the size, depth, position of the pan.

☞ It is not always easy to compare results from different sites.

1. Direct measurement

📖 The word ‘**lysimeter**’ is derived from the Greek root ‘**lysis,**’ which means movement, and ‘**metron**,’ which means to measure.

- Lysimeters:
  - ✓ Difficult and expensive to construct
  - ✓ Require careful operation and maintenance
  - ✓ Primarily research application
  - ✓ Primary tool for evaluating weather effects on ET and evaluation of estimating methods

- ✍ Regular weighing allows the moisture content to be determined.
- ✍ If the amount of precipitation is known, the moisture loss through ET can be calculated.

Table 13.2 *Calculation of evapotranspiration through lysimeter moisture measurements*

1 *Date*	2 *Precipitation (cm)*	3 *Weight of precipitation (g)*	4 *Weight of lysimeter (g)*	5 *Previous weight of lysimeter (g)*	6 *Change in weight (g) (4–5)*	7 *Weight transpired and evaporated (g) (3–6)*	8 *Water transpired and evaporated expressed in cm (7÷surface area)*
1.8.81	0.24	75.36	9110.35	9062.75	+47.60	27.80	0.09
2.8.81	–	–	9097.21	9110.35	−13.14	13.14	0.04
3.8.81	–	–	9042.94	9097.21	−54.27	54.27	0.17
4.8.81	–	–	8986.32	9042.94	−56.62	56.62	0.18
5.8.81	0.51	160.14	9124.67	8986.32	+138.35	21.79	0.07

Note: Surface area of lysimeter – 314 cm^2.

✍ Lysimeters are tanks filled with soil in which crops are grown under natural conditions to measure the amount of water lost by evaporation and transpiration.

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break

2. Estimating ETa, ETo, PET by meteorological formulae

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- greatly dependent upon atmospheric conditions, it is possible to derive good estimate of ET from meteo data
- problem of obtaining data ⇨ wide variety of empirical, semi-empirical, and physically-based equations/models
- these are much easier to use; however, based not on physical principles but on observed relationships between ET and one or more climatological variables
- the relationships have usually been obtained under one particular climatic regime and they may not be applicable elsewhere

Based on the principal climatic element or physical process involved in the formula of its calculation these methods can be grouped into five categories:

(1) water budget (Guitjens, 1982)

(2) mass-transfer (Harbeck, 1962)

(3) combination (Penman, 1948)

(4) radiation (Priestley and Taylor, 1972)

(5) temperature-based (Thornthwaite, 1948)

Food and Agriculture Organization of the United Nations (**FAO**) and American Society of Civil Engineers (**ASCE**) have adopted the Penman-Monteith (PM) method as the standard for computing ET from climate data (Allen et al., 1998; Penman, 1948).

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Potential evapotranspiration (PET)

- Thornthwaite method

The best known of these empirical equations is the one developed by Thornthwaite to assess PET.

Index must be adjusted for # days/mo and length of day

2. Estimating PET

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- In this formula, he is using temperature as a substitute for radiation, and it therefore works reasonably well.
- In tropics, however, the equation underestimate PET because temperatures lag behind radiation inputs.
- Nevertheless, the relative simplicity of the method makes it popular, and despite its shortcomings and its inevitable inaccuracies, it is one of the more widely used methods of assessing PET.

Thornthwaite method

$$PET = 1.6\left[\frac{10T_a}{I}\right]^a$$

where

PET = potential evapotranspiration [mm mo^{-1}]

T_a = mean monthly air temperature [°C]

I = annual heat index → $\sum_{i=1}^{12}\left[\frac{T_{ai}}{5}\right]^{1.5}$

a = $0.49 + 0.0179I - 0.000077I^2 + 0.000000675I^3$

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Free-water evaporation

"Potential evaporation"

- Penman equation
  - Standard hydrological method

K = shortwave (solar) radiation input
L = longwave radiation
H = turbulent exchange of sensible heat with atmosphere
LE = turbulent exchange of latent heat with atmosphere

Δ slope vapour pressure curve

$$E = \frac{K + L - H}{\rho_w \lambda_v}$$

$$\Delta = \frac{e_s^* - e_a^*}{T_s - T_a}$$

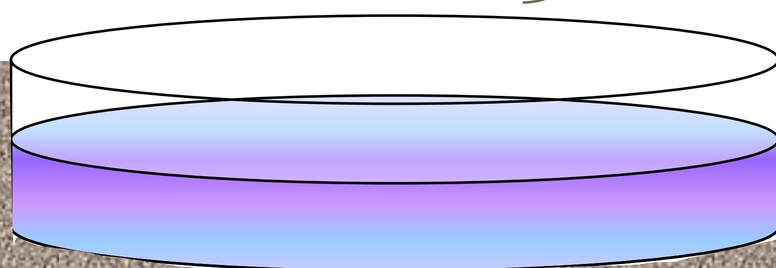
psychrometric constant

$$\gamma = \frac{c_a P}{0.622 \lambda_v}$$

$$\gamma \approx 0.066 \text{ kPa K}^{-1}$$

recall: $LE = \rho_w \lambda_v E$

$$E = \frac{H\Delta + \gamma E}{\Delta + \gamma}$$



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Water balance of crops

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FAO Penman-Monteith model used to estimate ETo

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Firstly, the FAO model is used to estimate the reference evapotranspiration (ETo):

$$ETo = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

ETo for hypothetical standardized reference crop: short reference crop, like 12 cm tall grass

where,

R_n	net radiation at the crop surface [MJ m^{-2} d^{-1}],
G	soil heat flux density [MJ m^{-2} d^{-1}],
T	mean air temperature at 2 m heght [°C],
u_2	wind speed at 2m height [m s^{-1}],
e_s	saturation vapour pressure [hPa],
e_a	actual saturation vapour pressure [hPa],,
$e_s - e_a$	saturation vapour pressure deficit [hPa],
Δ	slope vapour pressure curve [hPa °C^{-1}],
γ	psyhrometric constant [hPa °C^{-1}],

Secondly, crop evapotranspiration is calculated by multiplying K_c and ETo:

$$\mathbf{ET_c = K_c * ET_o}$$

where,

ET_o	reference evapotranspiration [mm d^{-1}],
ET_c	crop evapotranspiration [mm d^{-1}],
K_c	crop coefficient [-],

Thirty, a simple form of water balance of crops (WB) is calculated as following:

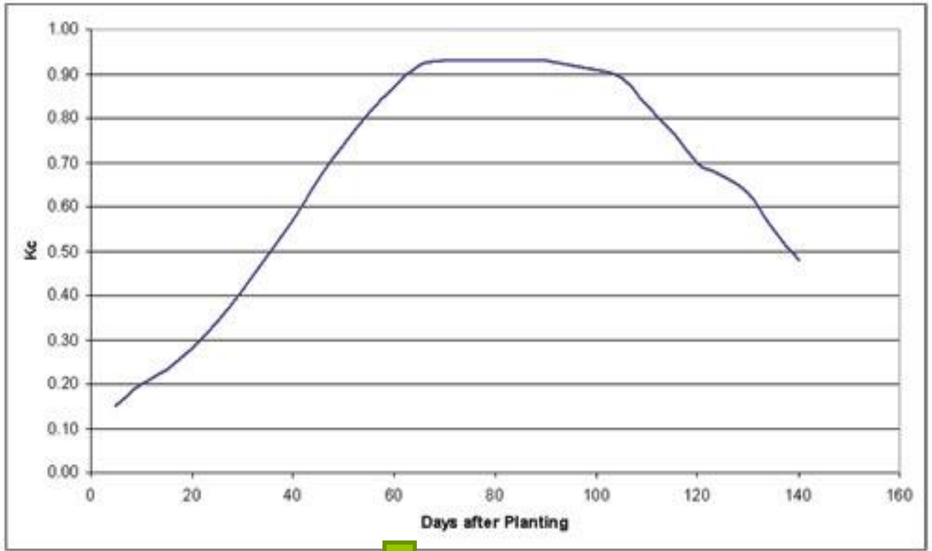
$$\mathbf{WB = P - ETc}$$

where,

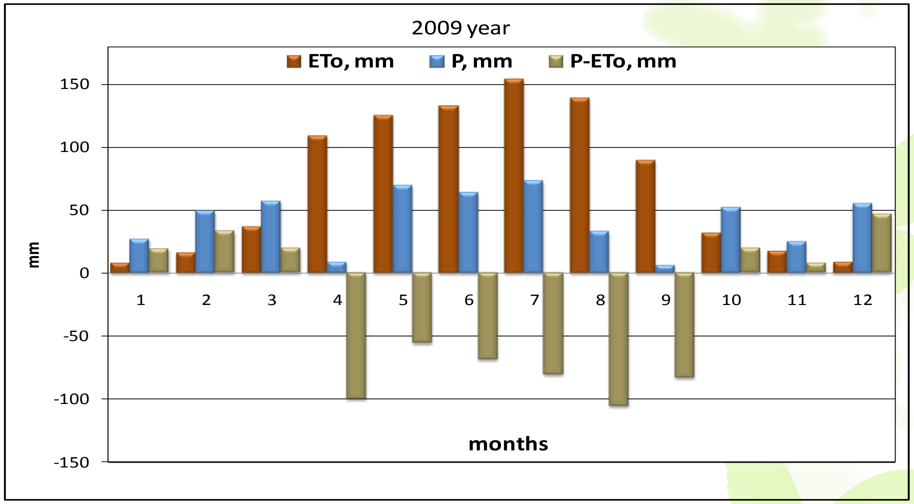
P	precipitation [mm],
ET_c	crop evapotranspiration [mm d^{-1}],
WB	water balance [mm],

Crop coefficient (Kc) for vegetables during stages of development

Type of vegetables		1st Stage	2nd Stage	3rd Stage	4th Stage
Apium graveolens L. var. rapaceum	Celeriac	after transplanting	≥7 leaves	bulb start to develop	100 ground cover
		K_c = 0.5	K_c = 0.8	K_c = 1.1	K_c = 1.4
					



Example crop coefficient curve that shows K_c values that change with crop development



Distribution of monthly reference evapotranspiration, precipitation and water balance

Potopová, ERASMUS (spring 2015, Spain)

Erasmus+

Potential evapotranspiration (PET)

- Blaney-Criddle method

$$PET = (0.142T_a + 1.095)(T_a + 17.8)kd$$

where

PET = potential evapotranspiration [mm mo^{-1}]

T_a = average air temperature [°C]

k = empirical crop factor

d = monthly fraction of annual hours of daylight

Erasmus+

Blaney-Criddle formula
Precautions/Limitations

- Simple, easy to use
- Minimal data requirements—mean monthly air temperature
- Wide application across western US
- Not a reference ET method
- Crop growth stage coefficient, k_c
  - is specific to this method
  - not a true crop coefficient, i.e., shown to be <u>dependent</u> on climate/location
- Should not be used to compute ET on less than a monthly time step
- Underpredicts in arid climates, and under windy or high advection conditions

Erasmus+

Hargreaves Method (1985)

$$ET_o = 0.0023(T_{max} - T_{min})^{0.5}\ (T_{mean} + 17.8)\ R_a$$

- Originally developed in 1975
  - solar radiation and temperature data inputs
- Updated in 1982 and 1985
  - solar radiation estimated from extraterrestrial radiation (Ra)
- Grass reference ET_o
- Can be used to compute daily estimates
    - Simple, easy to use
    - Minimal data requirements—maximum and minimum air temperature
    - Better predictive accuracy in arid climates than Blaney-Criddle

Erasmus+

Priestley and Taylor Method (1972)

- developed as a substitute to the Penman–Monteith equation to remove dependence on observations
- only radiation observations are required
- aerodynamic component was deleted from the P–M equation and the energy component was multiplied by a coefficient, **α = 1.26**

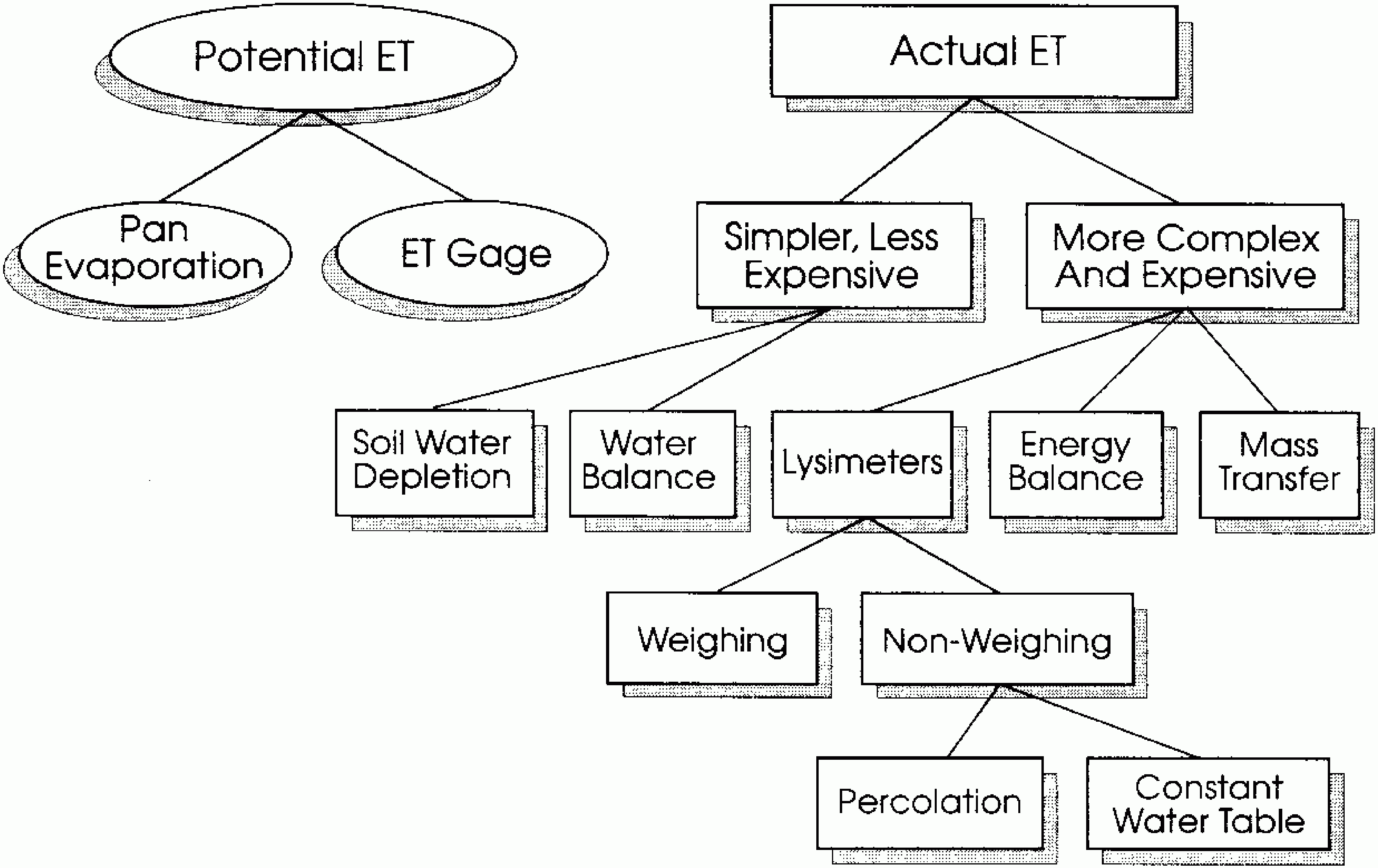
- observations revealed that actual evaporation was 1.26 times greater than potential evaporation, and therefore the equation for actual evaporation was found by taking potential evapotranspiration and multiplying it by **α**

$$PET = \alpha \frac{\Delta}{\Delta + \gamma} \frac{R_n}{\lambda}$$

where,

PET	potential evapotranspiration [mm d^{-1}],
R_n	net radiation at the crop surface [MJ m^{-2} d^{-1}],
λ	soil heat flux density [MJ m^{-2} d^{-1}],
α	coefficient = 1.26,
Δ	slope vapour pressure curve [hPa °C^{-1}],
γ	psyhrometric constant [hPa °C^{-1}],

Summary


Potential ET
Pan Evaporation
ET Gage
Actual ET
Simpler, Less Expensive
More Complex And Expensive
Soil Water Depletion
Water Balance
Lysimeters
Energy Balance
Mass Transfer
Weighing
Non-Weighing
Percolation
Constant Water Table

Conclusion

- ET provides a vital link between the surface waters and the atmosphere, a link operating at almost every stage of the hydrological cycle.
- In the process of returning water to the atmosphere, ET involves a major exchange of energy; thus it a vital part of the energy cycle of the atmosphere.
- PE has an overriding influence upon vegetation growth.
- Transpiration provides the means by which plant temperatures and turgidity are maintained.
- When ET is prevented, as for example when the plant is kept in totally saturated atmosphere or when there is no available moisture in the soil, plant growth ceases.
- Through the control ET exerts on the hydrological cycle, and through its effects on plants, it also has a fundamental influence upon man.
- In many parts of the world high rates of ET constrain agriculture, and man has been forced to adopt to the conditions by using irrigation or by growing drought-resistant crops.
- Excessive ET, like lack of rainfall, is also responsible for the hardship and famine so apparent in many arid areas.
- ET remains one of the most problematic parts of the hydrological cycle to study.