Water Resources Engineering Lecture 3

Hydrologic Budget, Evaporation and Evapotranspiration

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Learning Objectives

- Rainfall Variability and design storm
- Hydrologic Budget
- EVAPORATION
- EVAPOTRANSPIRATION

Hydrologic Cycle Concept

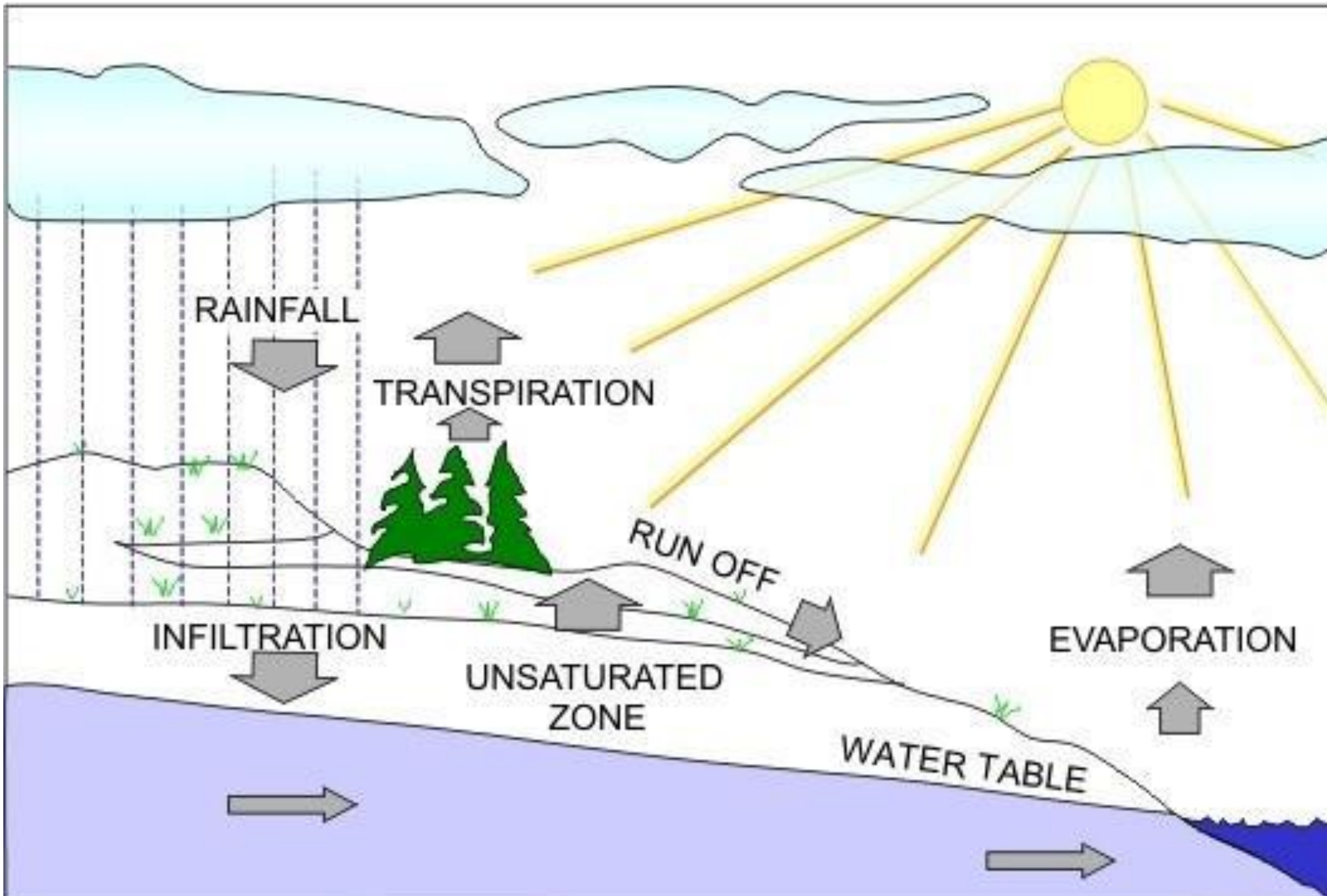
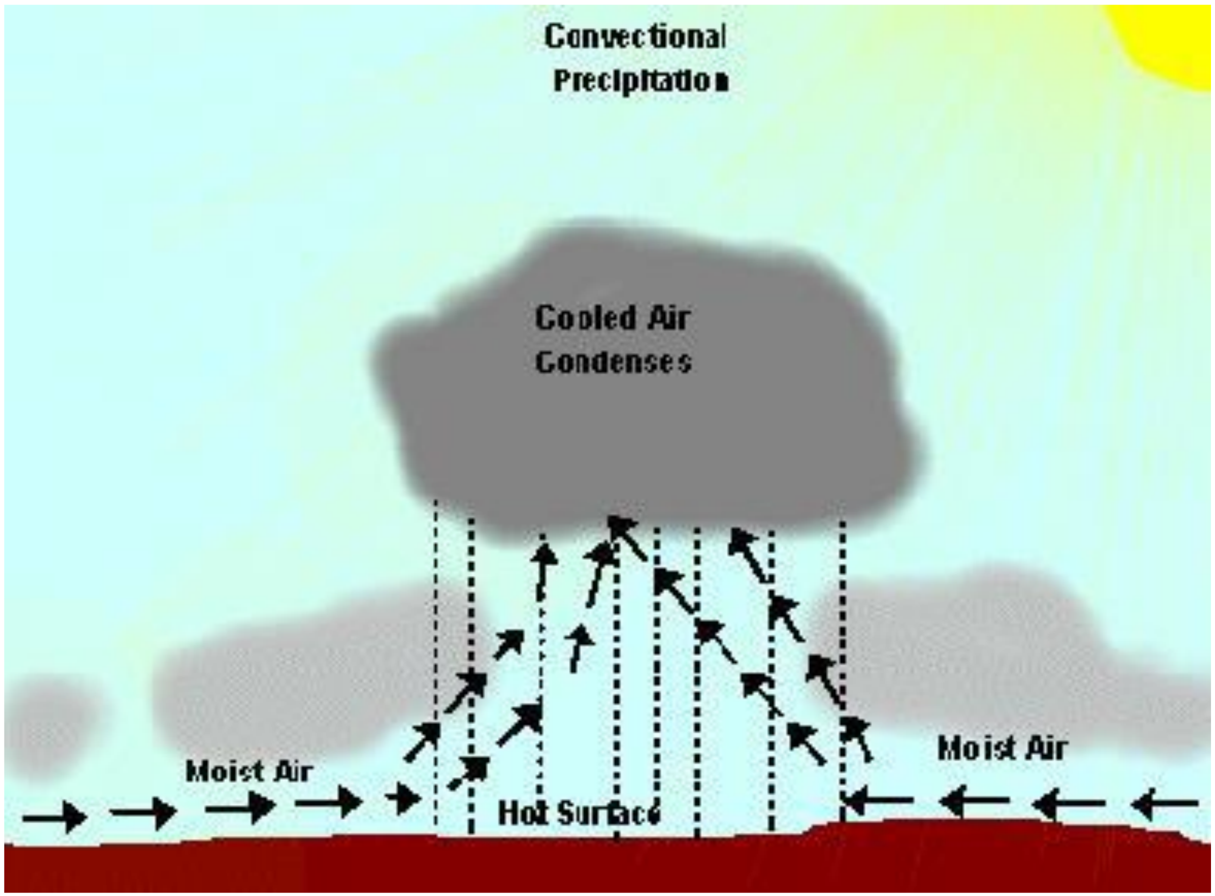
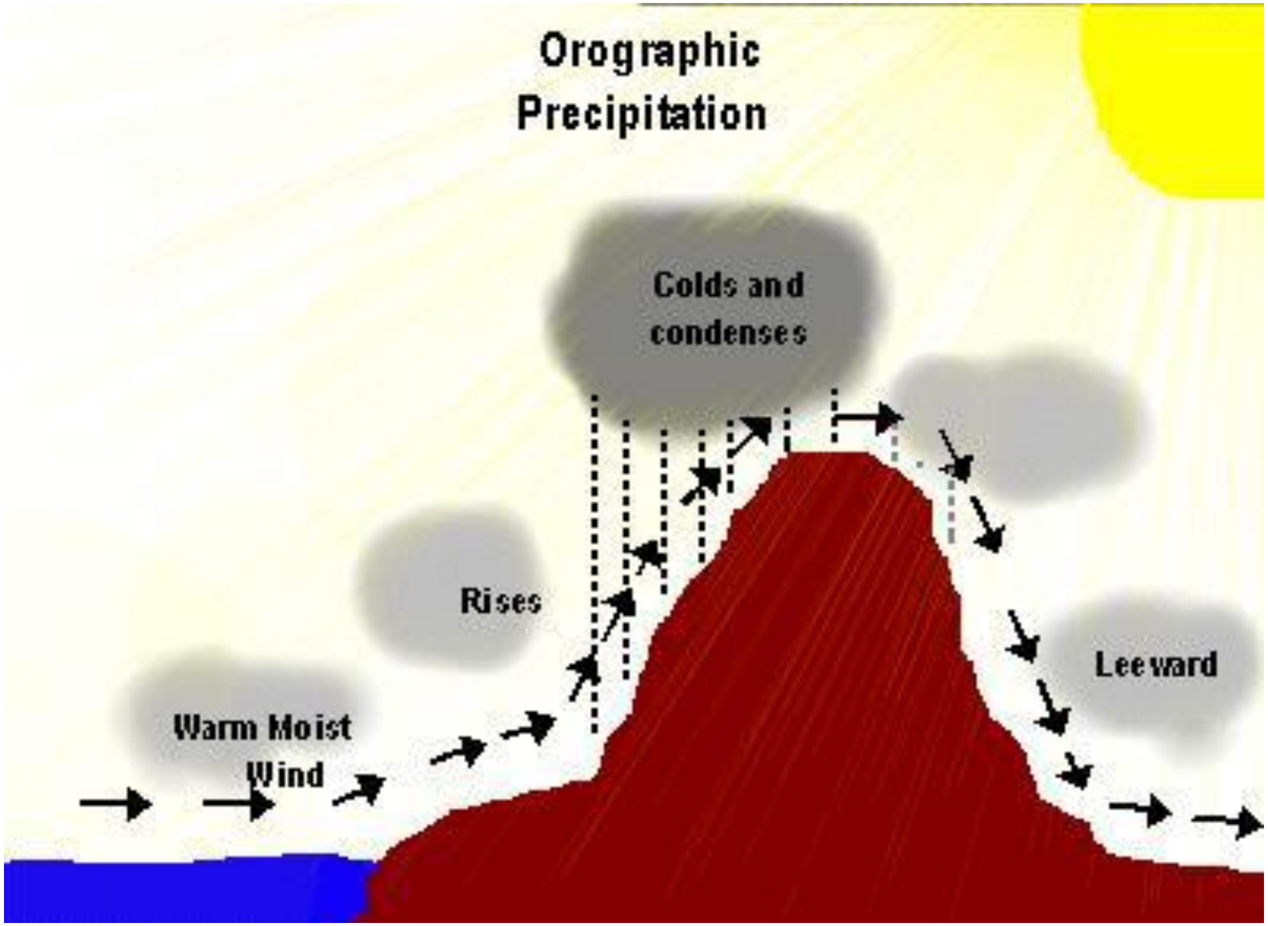


Figure: The Hydrologic Cycle showing major fluxes (Precipitation, Evaporation, Runoff, and Infiltrat

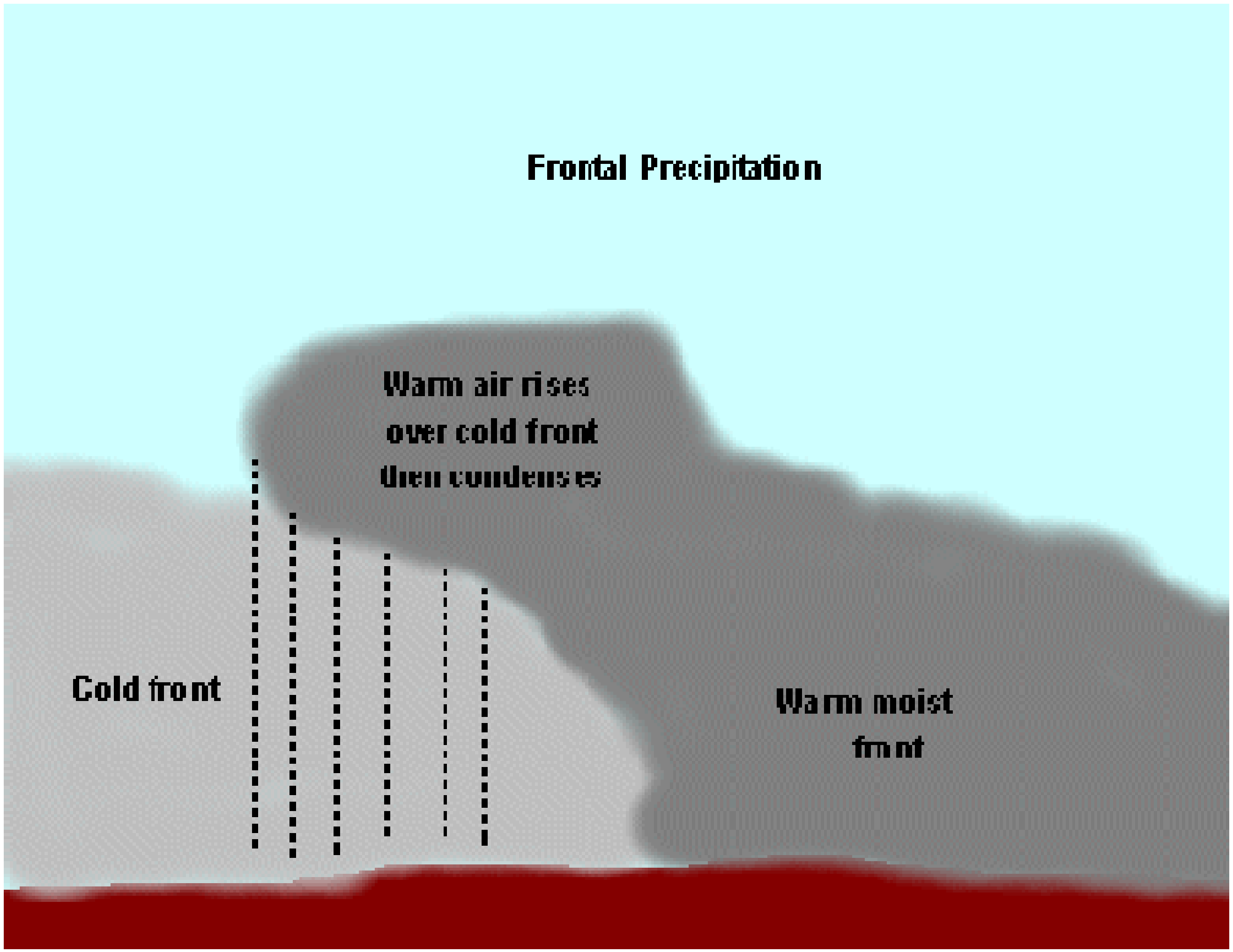
Convectional Precipitation



Orographic precipitation

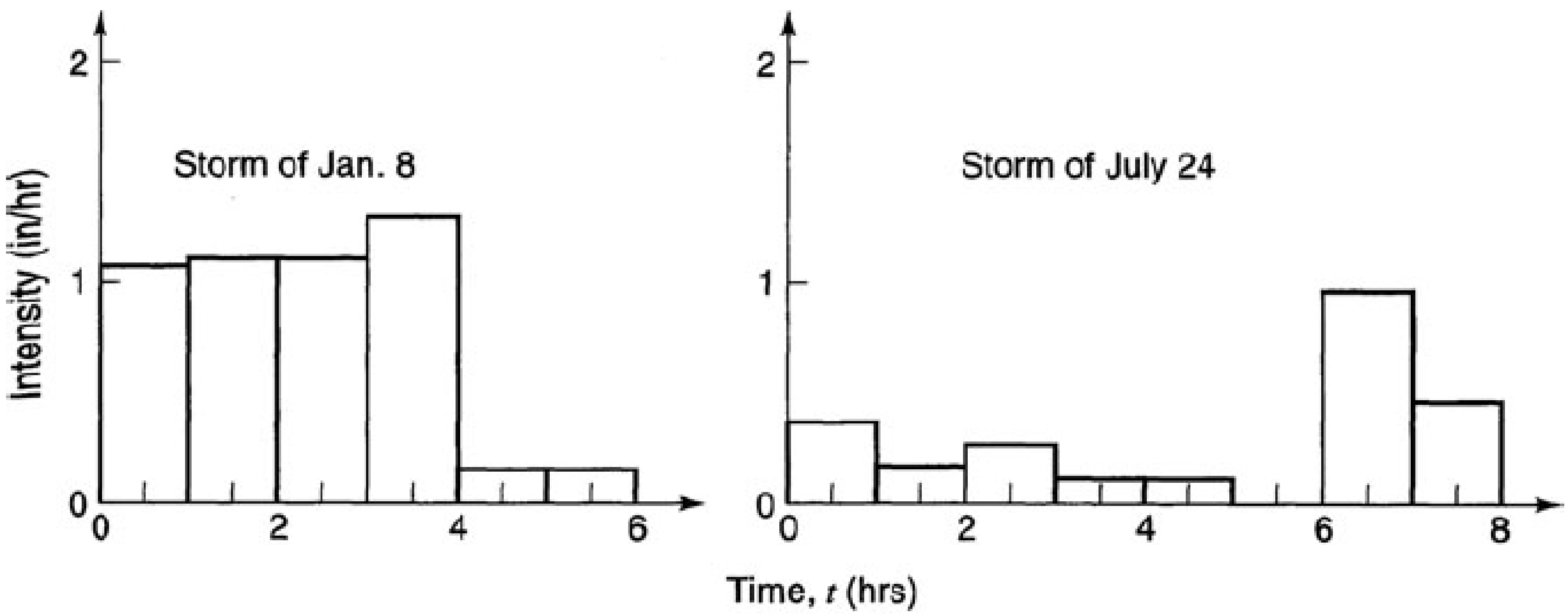


Cyclonic or Frontal Precipitation



Rainfall Variability

- **Rainstorms** can vary significantly in space and time.
- **Rainfall hyetographs** are plots of rainfall depth or intensity as a function of time.



Three methods for determining areal average rainfall using rainfall gauge data. These are the:

1. Arithmetic Mean Method

The central assumption in the arithmetic mean method is that each rainguage has equal weight and thus the mean depth over a watershed is estimated by:

$$\overline{P} = \sum_{j=1}^{N} \frac{P_j}{N}$$

where: Pj = the station j,
N = the total number of rain gauges in and around the watershed.
It is a simple method, and well applicable if the gages are uniformly distributed over the watershed and individual gage measurements do not vary greatly about their mean.

Thiessen Polygon Method

The Thiessen polygon method involves assigning relative weights to the gauges in computing the area average. The assumption in the method is that at any point in the watershed, the rainfall is the same as that at the nearest gauges so the depth recorded at a given gauges is applied out to a distance halfway to the next station in any direction.
The relative weights of each gauge are determined from the corresponding areas of application in a Thiessen polygon network, the boundaries of the polygons being formed by the perpendicular bisectors of the lines joining adjacent gages.

$$\overline{P} = \frac{1}{A}\sum_{j=1}^{J} A_j P_j , \quad A = \sum_{j=1}^{J} A_J$$

Where: Aj = the area of polygon j in the watershed (km2)
Pj = rainfall amount in polygon j (mm)
P = average rainfall (mm)

The disadvantages of the Thiessen method are its inflexibility that is addition of new station implies construction of new polygon, and it does not directly account for orographic influences of rainfall.

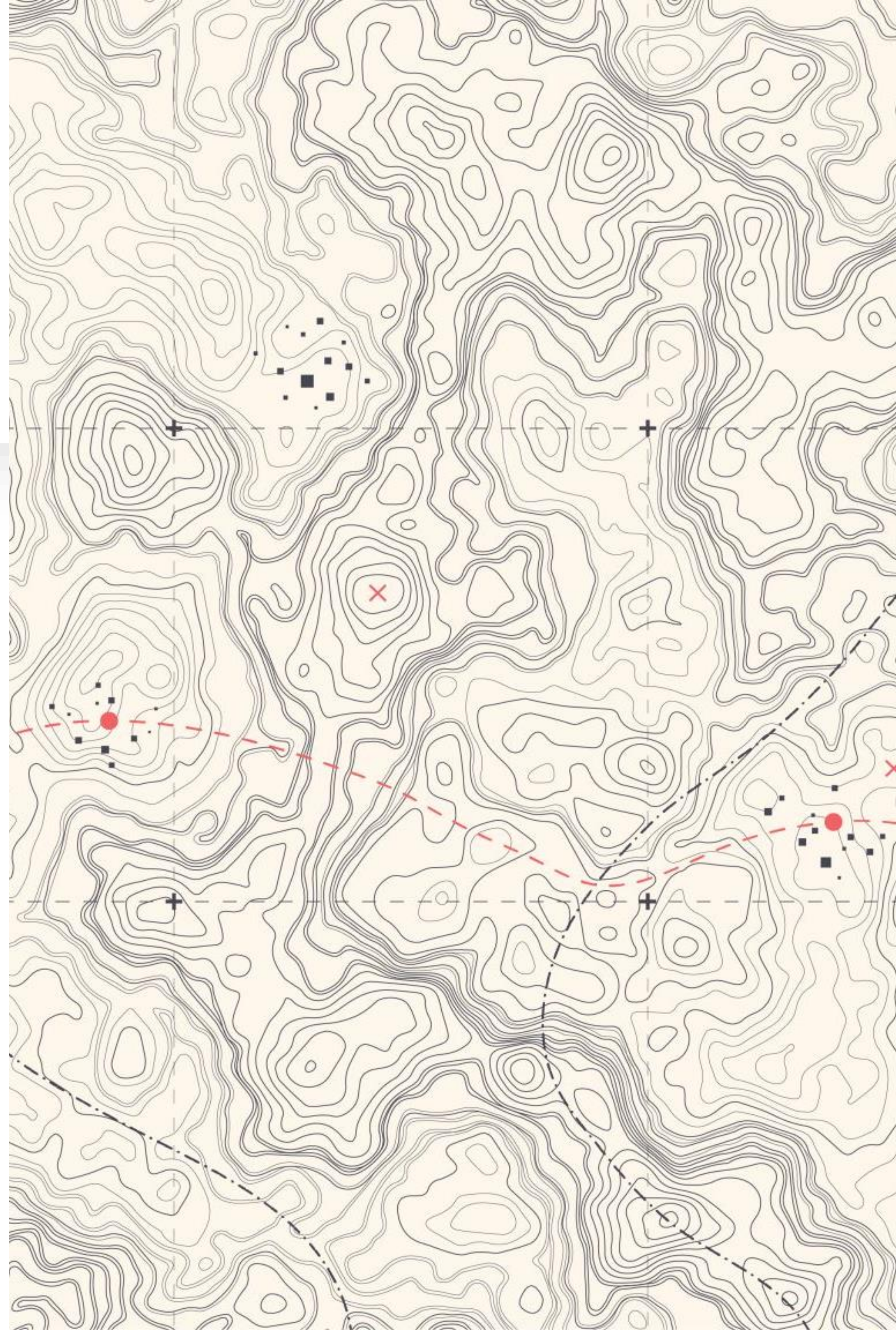
Isohyetal Method

The isohyets are drawn between the gauges over a contour base map taking into account exposure and orientation of both gauges and the catchment surface. The rainfall calculation is based on finding the average rainfall P_i between each pair of isohyets, and the area between them in the watershed A_j.

$$\overline{P} = \frac{1}{A} \sum_{j=1}^{J} A_j P_j , \quad A = \sum_{j=1}^{J} A_J$$

NOAA–Atlas 14

- The new NOAA Atlas 14, Precipitation – Frequency Atlas of the United States, replaces the use of the old NOAA Atlas in the semi-arid region of the southwestern U.S.



Example point precipitation frequency estimates for Phoenix, Arizona:

ARI (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
	Precipitation Frequency Estimates (in)																	
1	0.19	0.29	0.36	0.48	0.59	0.68	0.72	0.88	0.99	1.14	1.23	1.36	1.50	1.63	1.98	2.31	2.67	2.95
2	0.25	0.38	0.47	0.63	0.78	0.88	0.93	1.11	1.26	1.45	1.57	1.74	1.91	2.08	2.54	2.97	3.44	3.80
5	0.34	0.51	0.64	0.86	1.06	1.18	1.22	1.43	1.60	1.88	2.06	2.29	2.52	2.74	3.35	3.91	4.53	4.99
10	0.41	0.62	0.77	1.03	1.27	1.41	1.46	1.68	1.86	2.22	2.45	2.74	3.01	3.27	3.96	4.62	5.33	5.85
25	0.50	0.76	0.94	1.26	1.56	1.72	1.78	2.03	2.22	2.69	3.00	3.37	3.71	4.01	4.79	5.57	6.38	6.97
50	0.57	0.86	1.07	1.44	1.78	1.96	2.04	2.30	2.50	3.06	3.44	3.88	4.26	4.61	5.42	6.30	7.16	7.79
100	0.64	0.97	1.21	1.62	2.01	2.20	2.32	2.58	2.78	3.45	3.89	4.42	4.85	5.24	6.05	7.05	7.95	8.62
200	0.71	1.08	1.34	1.81	2.24	2.45	2.60	2.87	3.07	3.85	4.37	5.00	5.48	5.90	6.70	7.81	8.74	9.42
500	0.81	1.23	1.53	2.06	2.54	2.78	2.99	3.26	3.46	4.40	5.04	5.81	6.36	6.82	7.57	8.82	9.76	10.4
1000	0.88	1.34	1.67	2.24	2.78	3.04	3.31	3.57	3.75	4.84	5.57	6.47	7.07	7.57	8.23	9.60	10.53	11.2

(b) Arizona 33.482 N 112.05 W 1158 feet

Hydrologic System and Water Balance

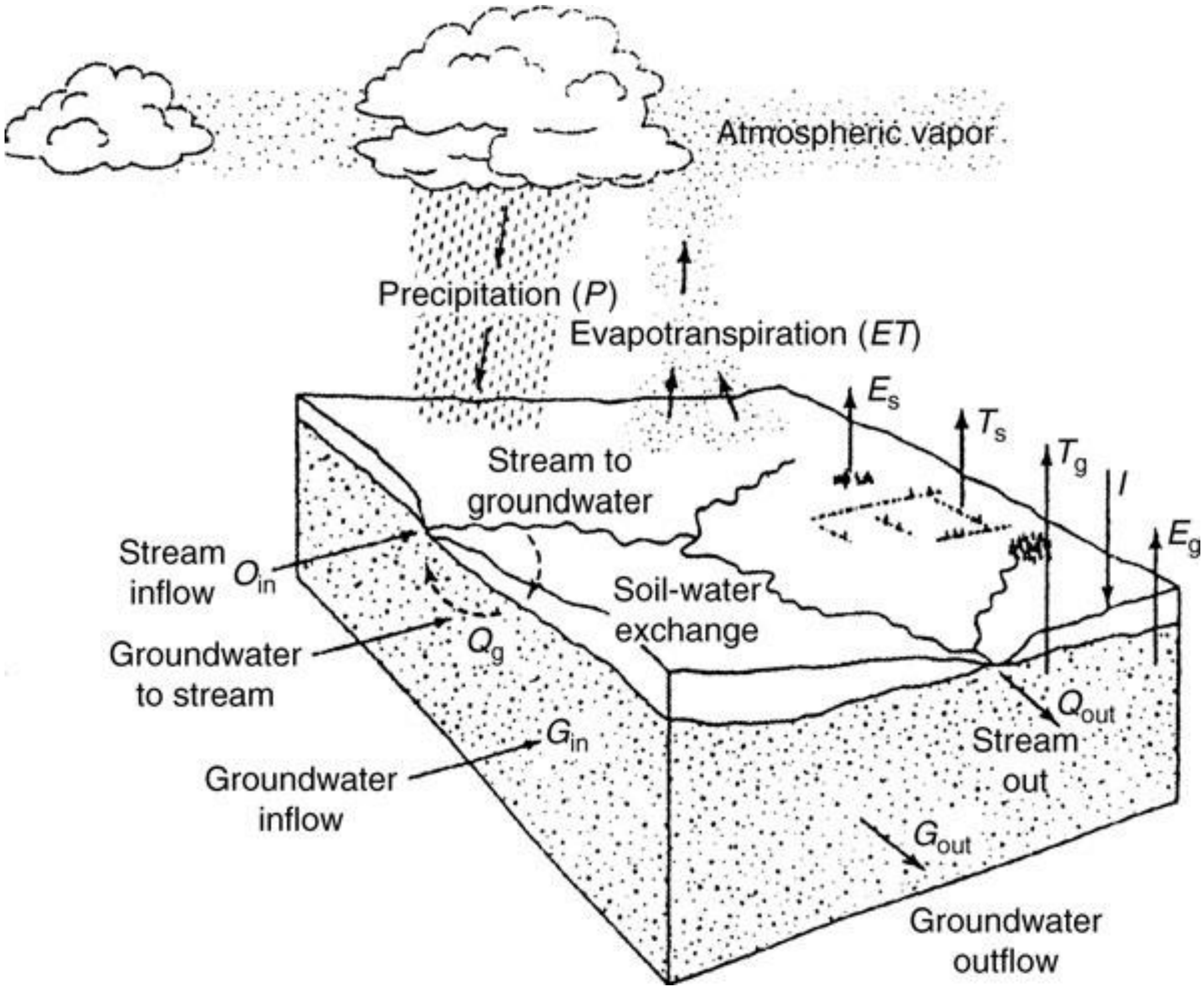
- Hydrologic systems convert precipitation into runoff and groundwater flow.
- Basic water balance: $P = Q + E + \Delta S$.
- Inputs: Precipitation;

Outputs: Evapotranspiration and Runoff;

Storage: Soil and Groundwater.

- Used for watershed, reservoir, and climate modeling.

Hydrologic Budget



Water Balance

- Using net mass exchanges, the above system hydrologic budget can be expressed as:

$$P - Q - G - E - T = \Delta S$$

Evaporation Fundamentals

- Evaporation: liquid to vapor; controlled by solar radiation, temperature, and humidity.
- Energy Balance Method: $E = (R_n - G) / (\lambda \rho_w)$.
- Aerodynamic Method: depends on vapor pressure gradient and wind speed.
- Penman Method: combines energy and aerodynamic factors for accuracy.

Evaporation

- **Evaporation:**
- Evaporation occurs when water is converted into water vapor at the evaporating surface, the contact between water body and overlapping air. At the evaporative surface, there is a continuous exchange of liquid water molecule into water vapor & vice versa.

Factors affecting Evaporation:

Temperature:

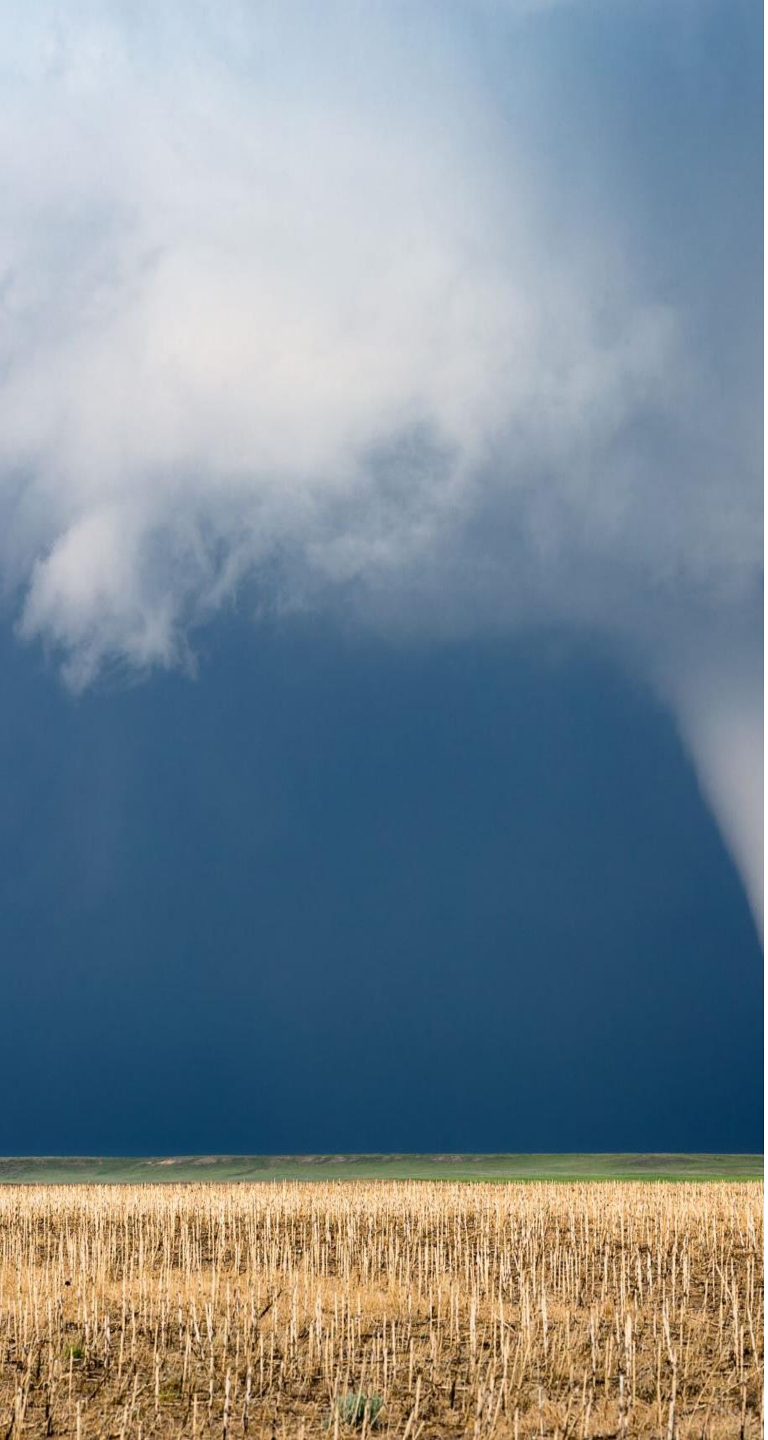
As the temperature of air is increased, its capacity to hold moisture also increases. Any increase in air temperature raises the temperature of water at the evaporation source which means that more energy is available to the water molecules for escaping from liquid to a gaseous state. Hence evaporation is directly proportional to the temperature of evaporating surface. Warmer the evaporating surface, higher the rate of evaporation.

Relative humidity:

The rate of evaporation is closely related with the relative humidity of air. Since the moisture holding capacity of air at a given temperature is limited, drier air evaporates more water than moist air. In other words, higher the vapour pressure, lower the rate of evaporation. It is a common experience that evaporation is greater in summer and at mid-day than in winter and at night.

Wind-speed:

Evaporation depends on the wind speed as well. When the winds are light, a thin layer of air just above the surface gets nearly saturated; under the circumstances the difference between the vapour pressure between ground and air is very small. This results in very low evaporation. On the other hand, when the wind velocity is high, turbulence is set up in the air. Moisture evaporated from the ground is mixed upward and the vapour-pressure difference between the atmosphere and the surface remains large. Thus, the rate of evaporation is accelerated. Wherever there is a combination of high temperature, very low relative humidity and strong wind, the rate of evaporation is exceptionally high. This leads to dehydration of soil to a depth of several inches.



Area of the evaporating surface:

The rate of evaporation is determined by the area of the exposed surface of water. Larger areas of evaporating surface increase the rate of evaporation.

Air-pressure:

Evaporation is also affected by the atmospheric pressure exerted on the evaporating surface. Lower pressure on open surface of the liquid results in the higher rate of evaporation.

Composition of water:

Evaporation is inversely proportional to the salinity of water. Rate of evaporation is always greater over fresh water than over salt water. Under similar conditions, the ocean water evaporates about 5 per cent more slowly than the fresh water.

- **Rate of Evaporation:**
- The rate of evaporation is defined as the amount of water evaporated from a unit surface area per unit of time. It can be expressed as the mass or volume of liquid water evaporated per area in unit of time, usually as the equivalent depth of liquid water evaporated per unit of time from the whole area. The unit of time is normally a day. The amount of evaporation should be read in mm. Depending on the type of instrument, the usual measuring accuracy is 0.1 to 0.01 mm.

Methods of measurement of evaporation:

Direct methods

1. Water Budget Technique

2. Lysimeter

- Weighing Type
- Non-weighing Type

Indirect methods

1. Aerodynamic method or Mass Transfer Method
2. Energy Budget Method
3. Penman Equation
4. Blaney & Criddle Method
5. Jensen Haise method
6. Hargreaves method or Pan Evaporation Method

Hargreaves method or Pan Evaporation Method

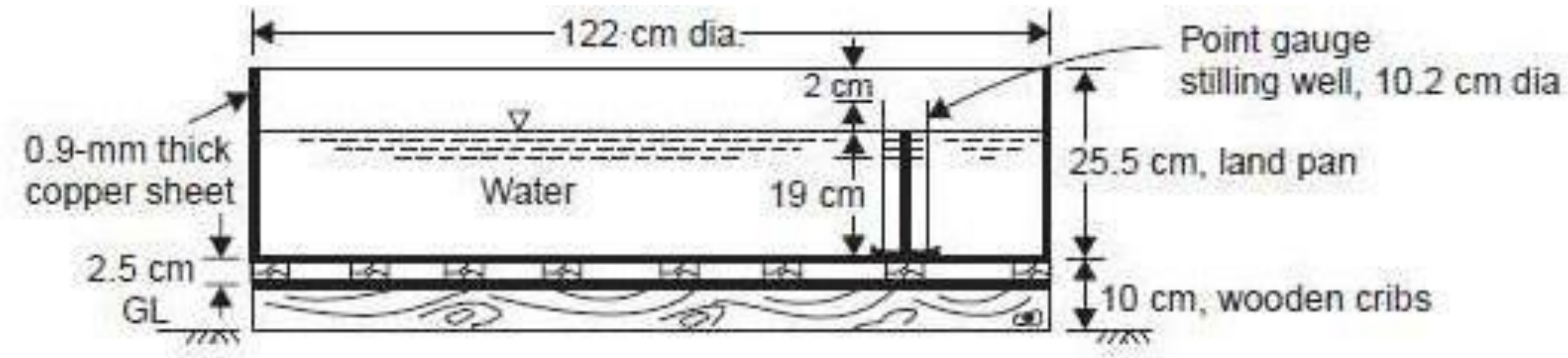
An evaporation pan is usually used to estimate evaporation from an open water body (e.g. lake or reservoir). The pan evaporation is computed based on the difference in the observed water levels adjusted for any precipitation observed between observations. The actual evaporation from a real open water body is smaller than that measured from a pan. Therefore, a correction coefficient is applied to the measured pan evaporation:

EL = K.EP

Where,

- EL = evaporation from an open water body
- K = pan coefficient (0.6-0.8, with an average value of 0.7) EP = pan evaporation

Pan Method



122 cm dia.
Point gauge
stilling well, 10.2 cm dia
2 cm
0.9-mm thick
copper sheet
Water
19 cm
25.5 cm, land pan
2.5 cm
GL
10 cm, wooden cribs

Evapotranspiration (ET)

- Evapotranspiration = evaporation + transpiration through vegetation.
- Estimated using Penman-Monteith, Blaney-Criddle, and FAO-56 methods.
- ET represents the largest water loss term in arid regions like Jordan.
- Measured using lysimeters and remote sensing techniques.

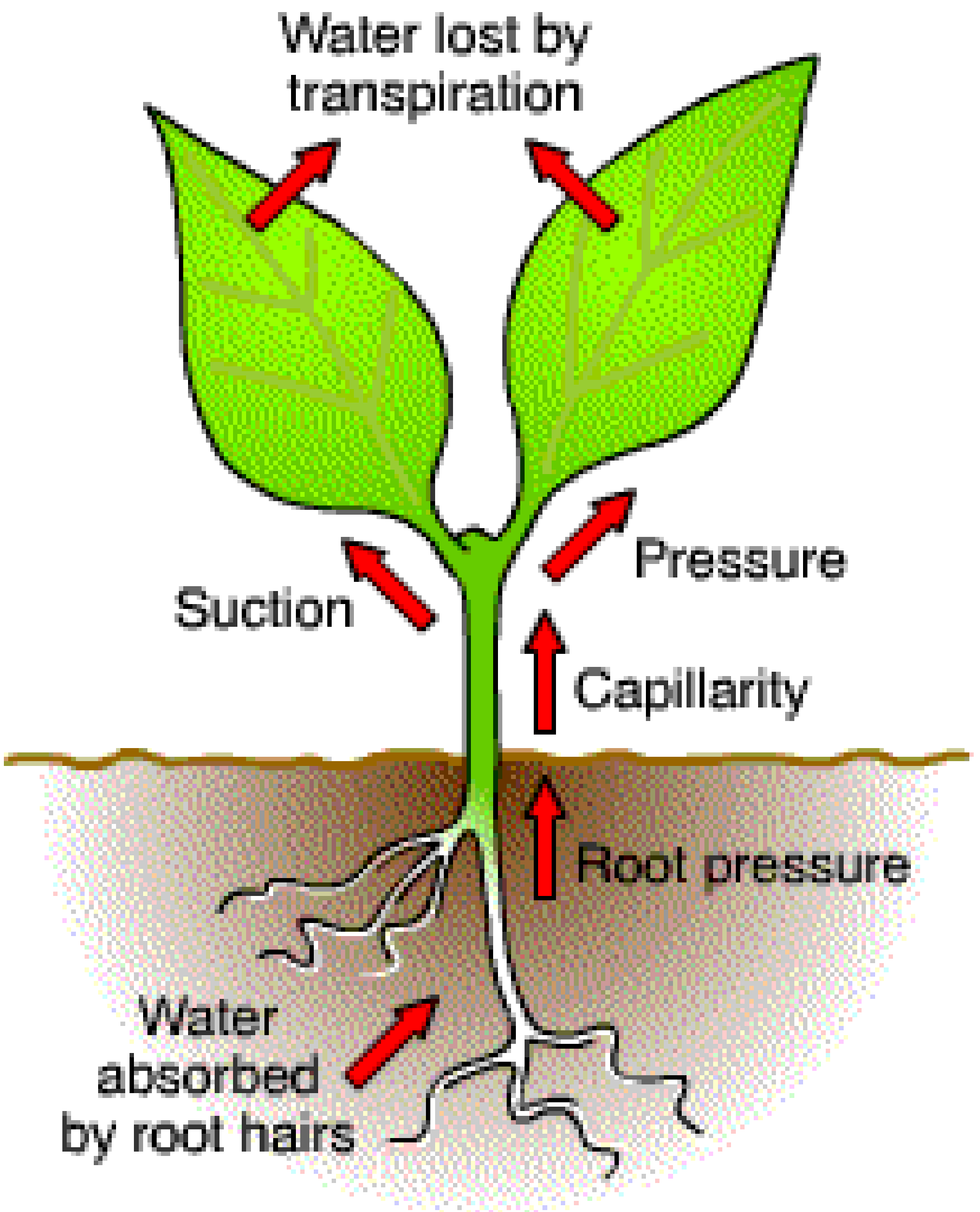
Evapotranspiration

Transpiration:

Transpiration is the process by which the water vapour escapes from the living plant leaves and enters the atmosphere.

Various methods are devised by botanists for the measurement of transpiration and one of the widely used methods is by phytometer

Transpiration



Evapotranspiration

- Evapotranspiration is the combined processes by which water is transferred to the atmosphere from open water surfaces and vegetation. It consists of evaporation, which is the amount of water vaporized into the atmosphere from open water surfaces and land areas, and transpiration, which is the amount of water absorbed by plants and crops and eventually discharged into the atmosphere through the plant's stomata.

Potential evapotranspiration is the evapotranspiration from the short green vegetation when the roots are supplied with unlimited water covering the soil. It is usually expressed as a depth (cm, mm) over the area. It is usually higher in the summer, on sunny days.

Actual evapotranspiration is the actual amount of evaporation that occurs when water is limited.

Factors affecting evapotranspiration

- Climatological factors like percentage sunshine hours, wind speed, mean monthly temperature and humidity.

- Crop factors like the type of crop and the percentage growing season.

- The moisture level in the soil.

Estimation of evapotranspiration

The following are some of the methods of estimating evapotranspiration:

- Lysimeter
- PM Method
- Hargreaves Method
- Blaney & Criddle Method

Thank you