CE 501: Surface Water Hydrology

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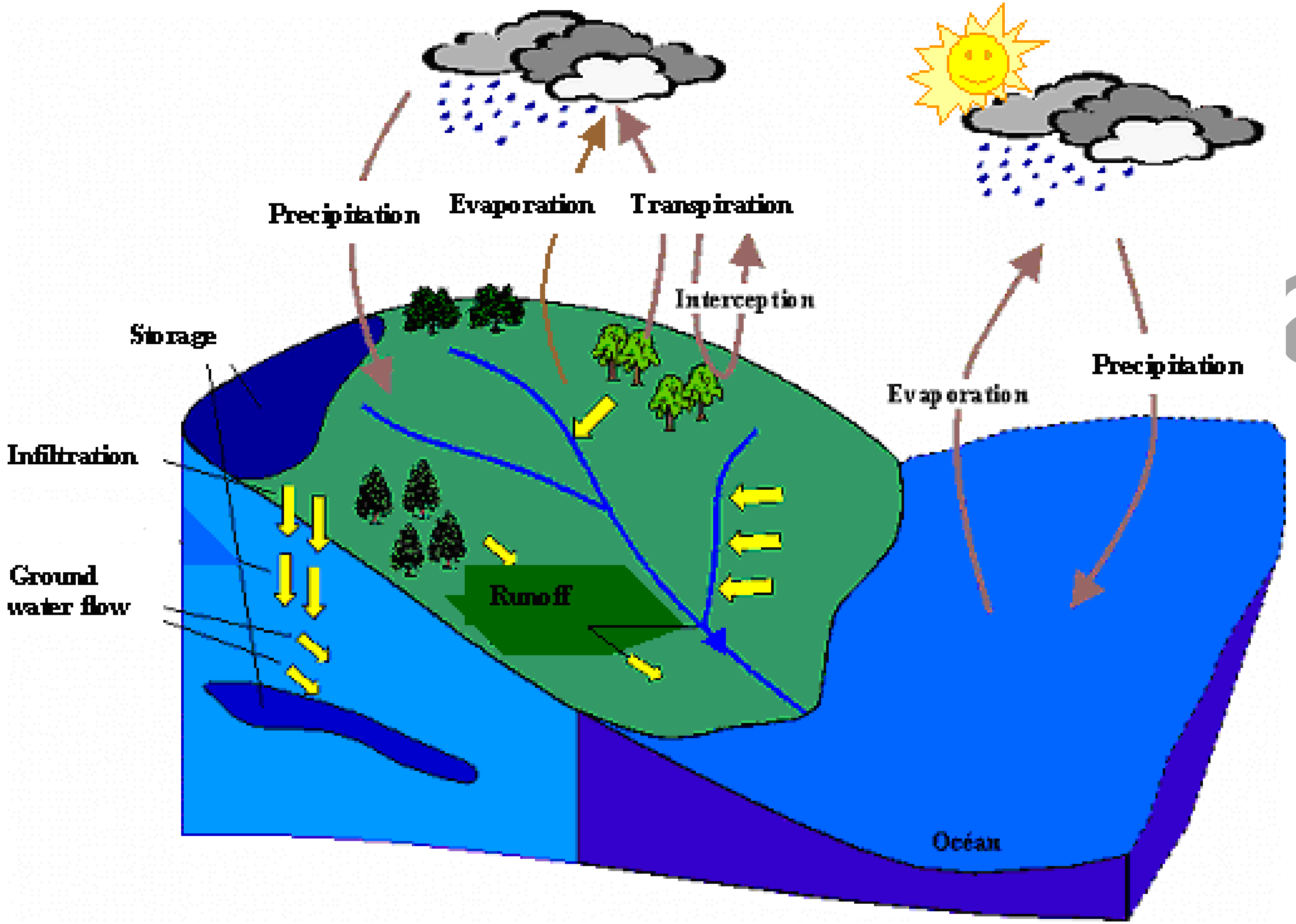
Introduction

Hydrologic Cycle



- ✓ Evaporation from ocean
- ✓ Evaporation from water bodies
- ✓ Evaporation from land
- ✓ Transpiration
- ✓ Raindrop evaporation
- ✓ Rainfall
- ✓ Interception
- ✓ Surface runoff
- ✓ Infiltration
- ✓ Groundwater
- ✓ Deep percolation

- ✓ Each path of the hydrologic cycle involves in
  - ✓ Transportation of water
  - ✓ Temporary storage
  - ✓ Change in state

- ✓ Rainfall: Change in state and transportation
- ✓ Groundwater: Change in storage and transportation

Residence Time

Residence time:

Average travel time for water to pass through a subsystem of the hydrologic cycle

$$T_r = \frac{S}{Q}$$

(Storage/flow rate)

Residence time of global atmospheric moisture

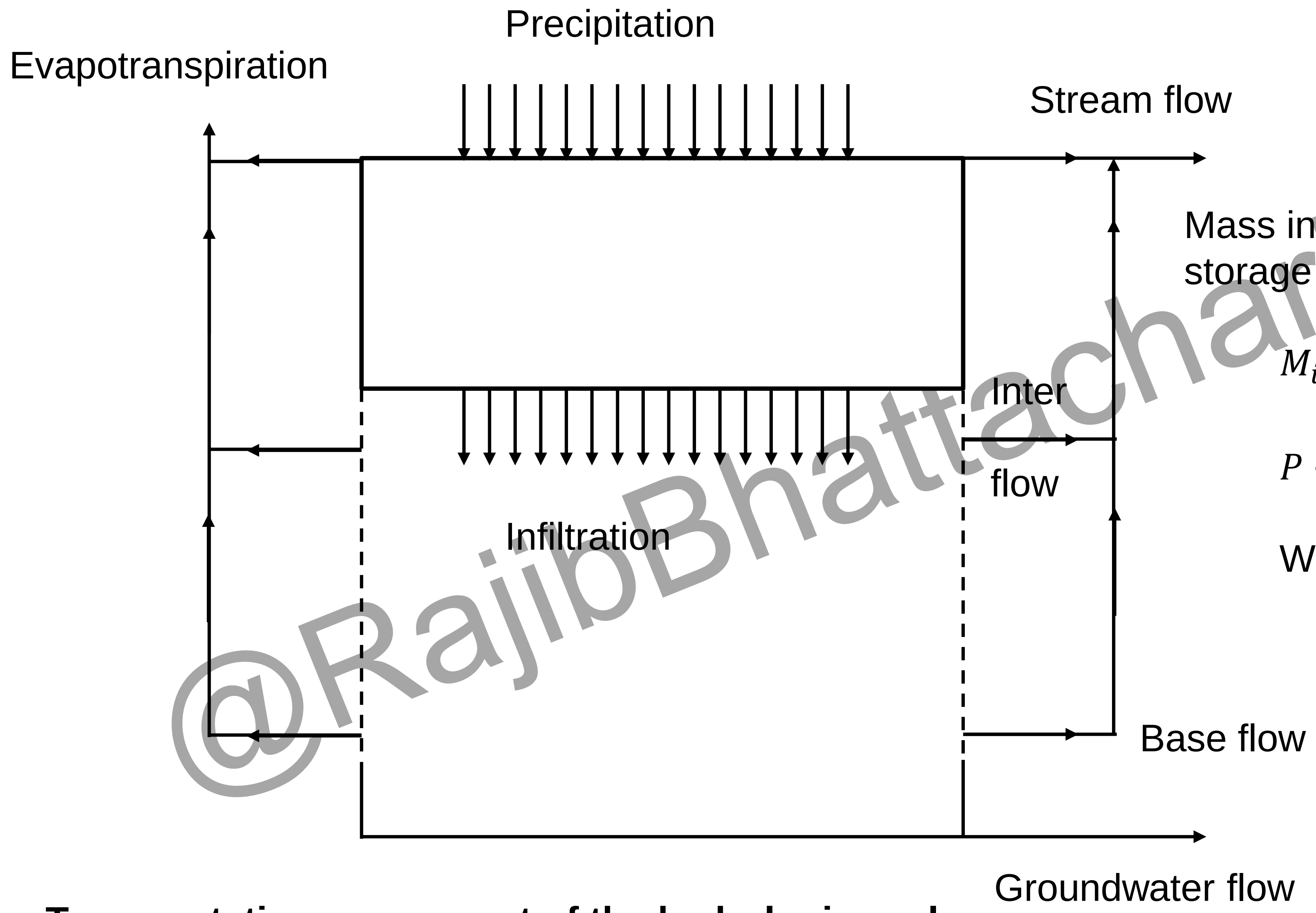
Volume (storage) of atmospheric water: 12,900 km^3

Flow rate of moisture from the atmosphere as precipitation = 577,000 km^3/yr

T_r= 12,900/577,000 = 0.022 yr = **8.2 days**

One reason why weather cannot be forecast accurately more than a few days ahead

Hydrologic Cycle



Transportation component of the hydrologic cycle

Water budget equation

Mass inflow – Mass outflow = Change in mass storage

$$M_i - M_o = \Delta S$$

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

Where

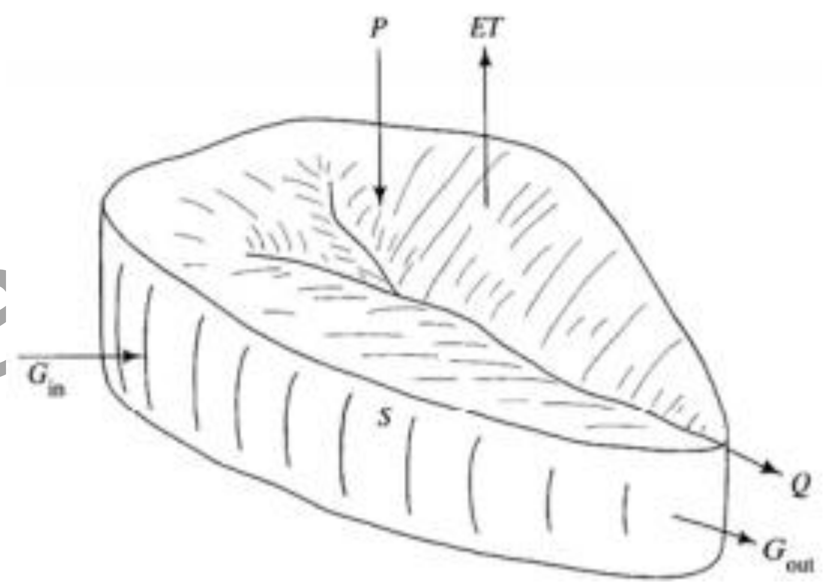
P is the precipitation
R is the surface runoff
G is the net groundwater flow out of the catchment
E is the evaporation
T is the transpiration
ΔS is the change in storage

Water balance equation

Drainage basin

Inflow – Outflow = Change in storage

$$\{P + G_{in}\} - \{Q + G_{out} + ET\} = \Delta S$$



Unit/Dimension

- ✓ Depth (L) over area (L^2)
- ✓ Volume (L^3)
- ✓ Rate of water movement (L^2T^{-1})
- ✓ E.g. mm/h, cm/day, m^3/sec, etc

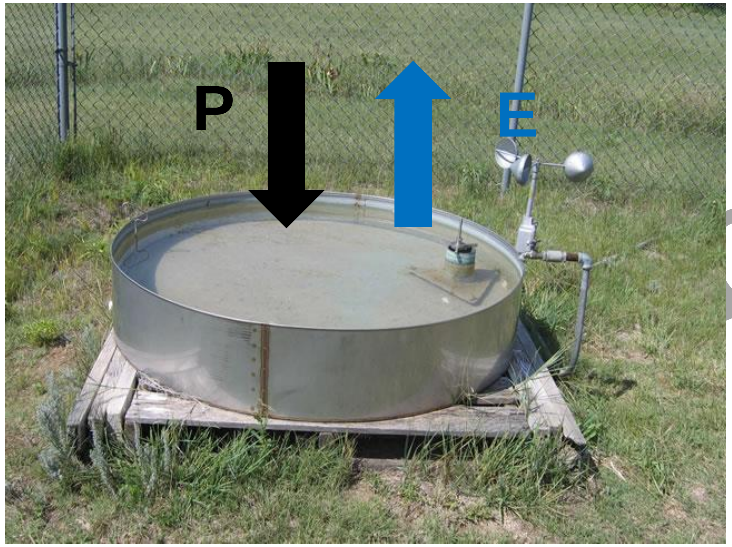
P is the precipitation
ET is the evapo-transpiration
Q is the Stream outflow
G_{in} is the groundwater inflow
G_{out} is the groundwater inflow
S is the storage

Water balance equation

Applications of the Water Balance Equation

- ✓ accounting of major inputs, outputs & delayed components over specific spatial & temporal scale
- ✓ annual water budget from monthly climate averages
    - ✓ determine times of moisture use, deficit, recharge, surplus, water supply/recharge planning
    - ✓ assessing human impacts

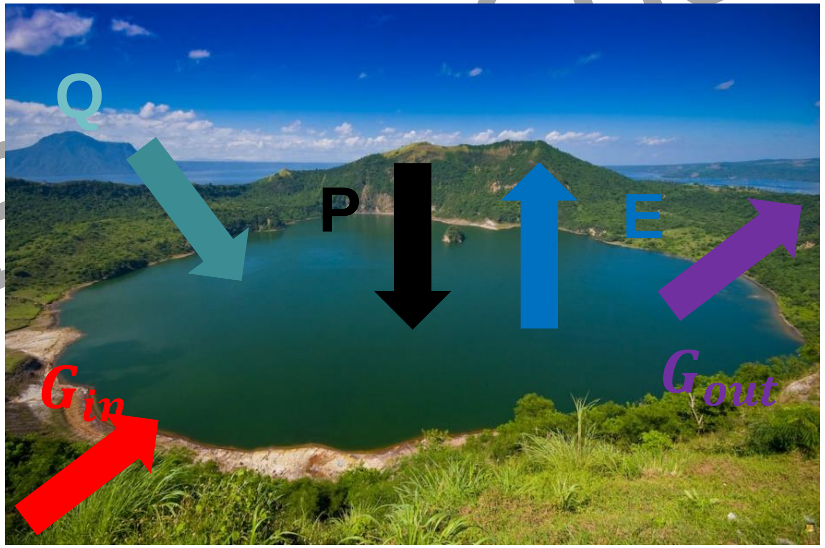
Example: Evaporation pan



Water balance component

$P - E = \Delta S$ (mm)

Water Balance of a Lake



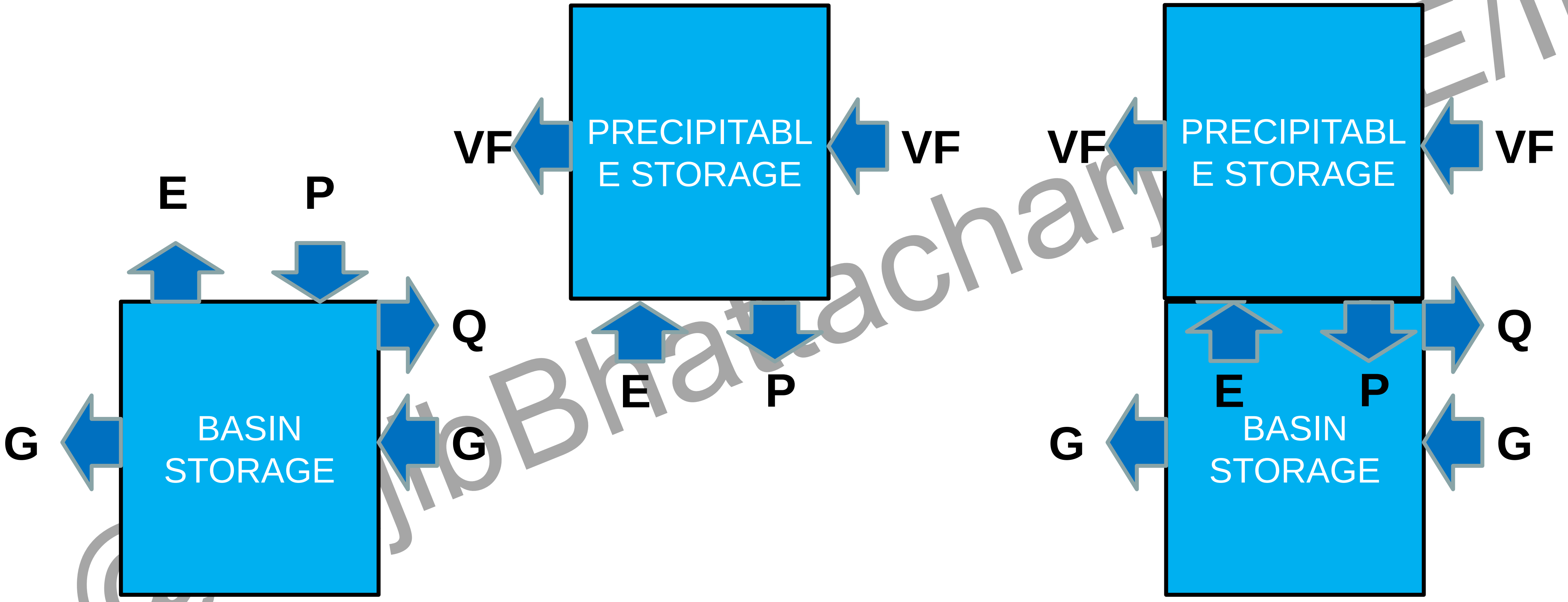
Water balance component

$Q + P + G_{in} - E - G_{out} = \Delta S$

P is the precipitation
E is the evaporation
Q is the inflow
G_{in} is the groundwater inflow
G_{out} is the groundwater inflow
S is the storage

Water balance equation

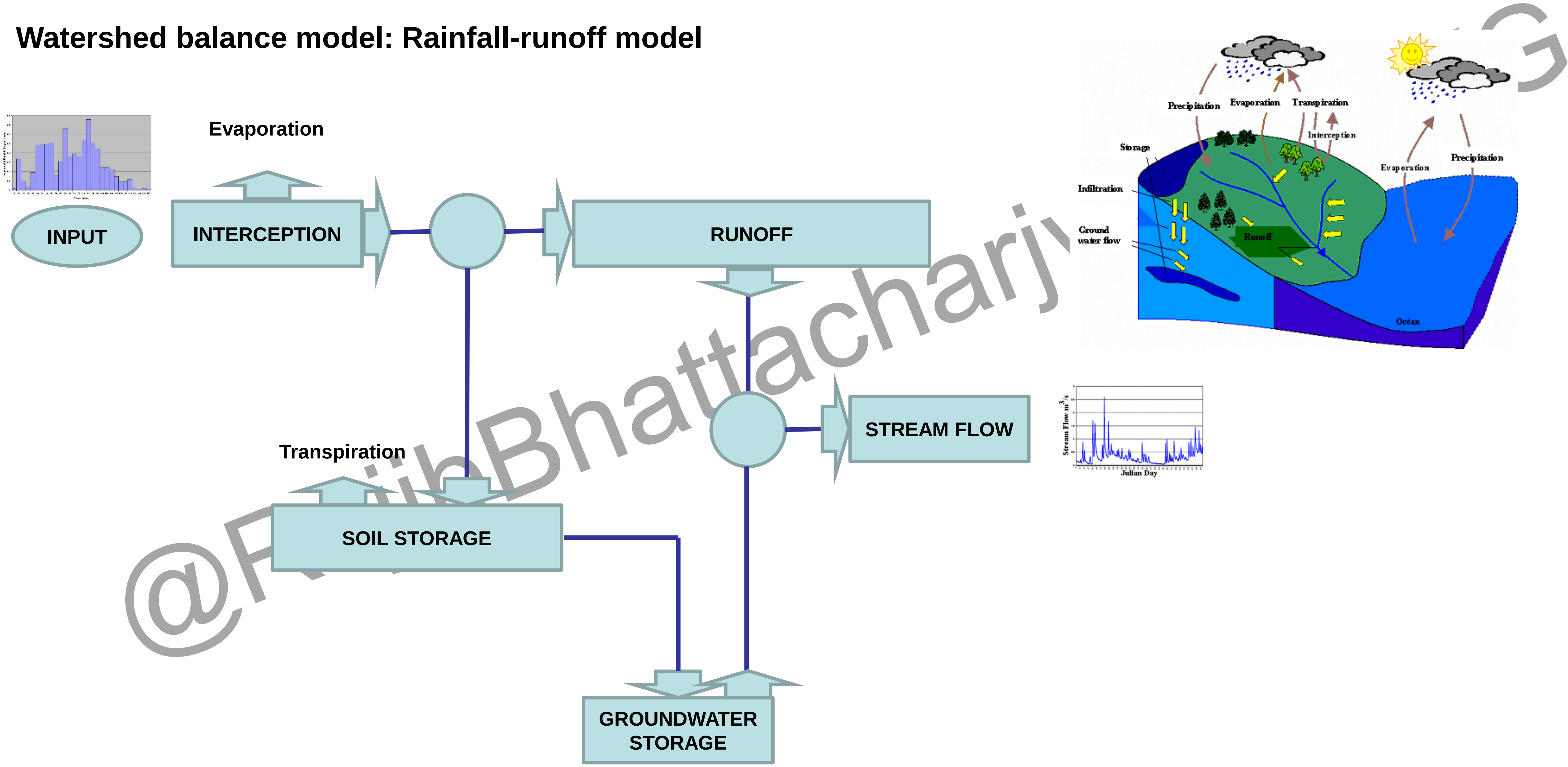
Global water balance model



(a) Terrestrial **(a) Atmospheric** **(a) Combined**

Water balance equation

Watershed balance model: Rainfall-runoff model



Precipitation

- All forms of water that reach the earth from the atmosphere is called precipitation.
- Forms are rainfall, snowfall, frost, hail, dew.
- Rainfall is the predominant form of precipitation.

Rainfall

Snowfall

Frost

Hail

Dew

Precipitation

Types of precipitation: **Rain, snow, hail, drizzle, glaze, sleet**

Rain: Precipitation in the form of water drops of size between 0.5 - 6mm

Light rain – (intensity up to 2.5 mm/hr)
Moderate – (intensity between 2.5 mm/hr to 7.5 mm/hr)
Heavy rain – (above 7.5 mm/hr)

Snow: Snow is formed from ice crystal masses

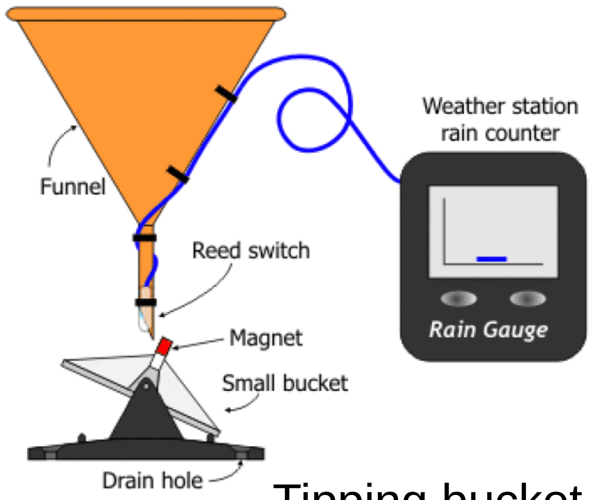
Hail: precipitation in the form of small balls or lumps usually consisting of concentric layers of clear ice and compact snow. Hail varies from 0.5 to 5 cm in diameter and can damage crops and small buildings

Drizzle: A fine sprinkle of numerous water droplets of size less than 0.5 mm and intensity less than 1mm/h is known as drizzle.

Sleet: It is frozen raindrop of transparent grains which form when rain falls through air at sub-freezing temperature.

Measurement of Rainfall

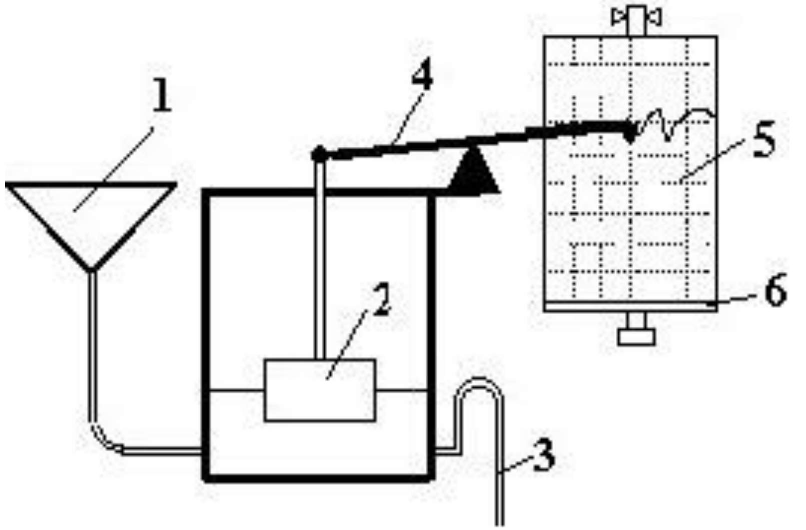
- Rainfall and other forms of precipitation are measured in terms of depth, the values being expressed in millimeter.
- One millimeter of precipitation represents the quantity of water needed to cover the land with a 1mm layer of water, taking into account that nothing is lost through drainage, evaporation or absorption.
- Instrument used to collect and measure the precipitation is called rain gauge.



Tipping bucket

Standard

Float-and-Lever rain gauge



Recording type rain gauge

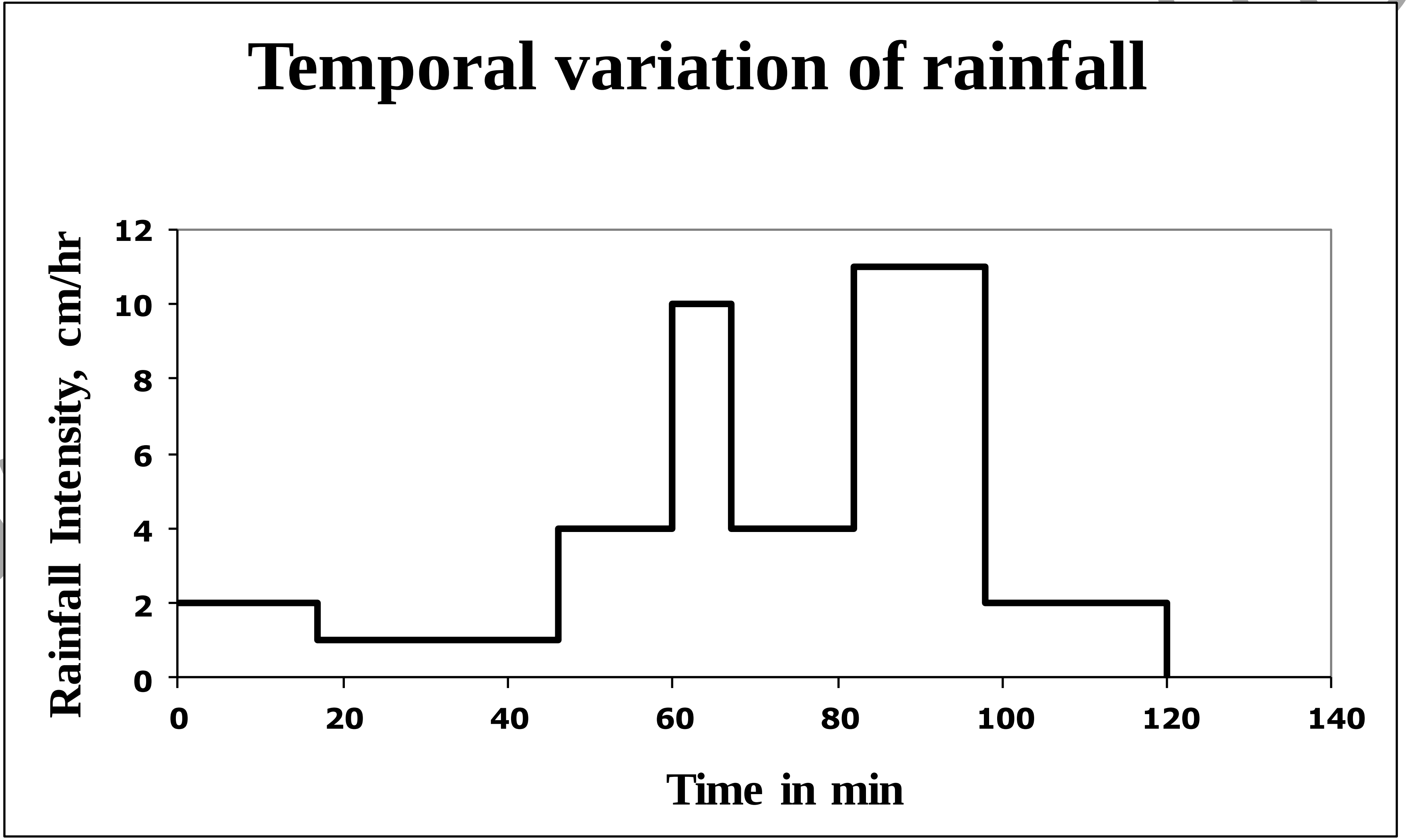
Radar measurement of rainfall

- The meteorological radar is the powerful instrument for measuring the area extent, location and movement of rainstorm.
- The amount of rainfall over a large area can be determined through the radar with a good degree of accuracy.
- The radar emits a regular succession of pulse of electromagnetic radiation in a narrow beam so that when the raindrops intercept a radar beam, its intensity can easily be known.

Precipitation

Rainfall varies greatly both in time and space

The temporal variation may be defined as hourly, daily, monthly, seasonal variations and annual variation (long-term variation of precipitation)



Rain gauge Network

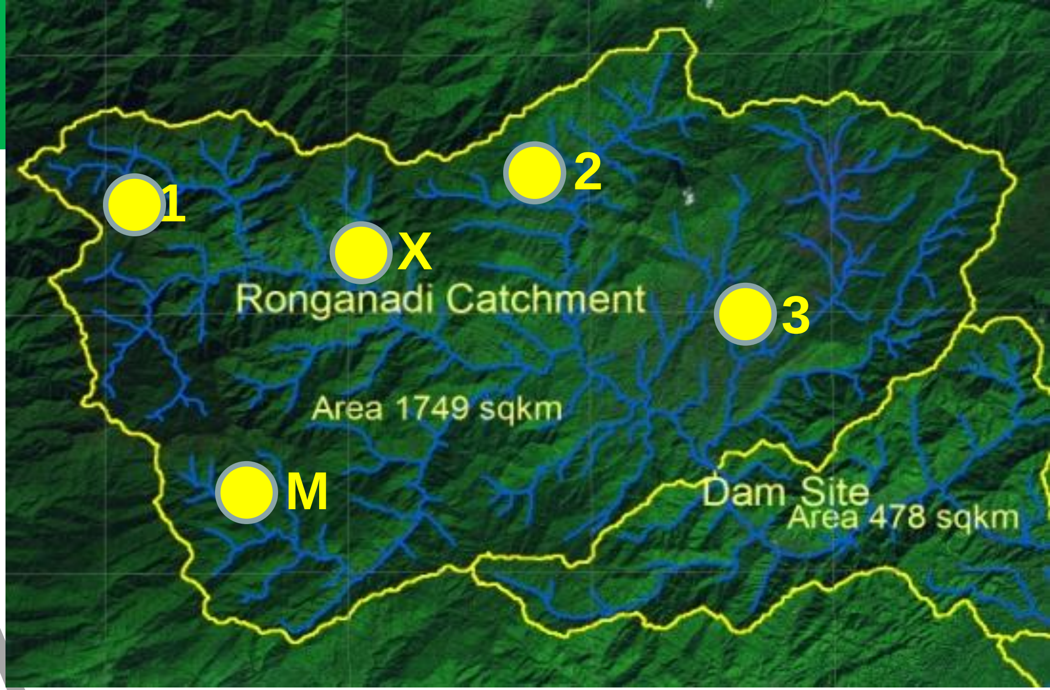
- Since the catching area of the rain gauge is very small as compared to the areal extent of the storm, to get representative picture of a storm over a catchment, the number of rain gauges should be as large as possible, i.e. the catchment area per gauge should be small.

- There are several factors to be considered to restrict the number of gauge:
  - Like economic considerations to a large extent
  - Topographic & accessibility to some extent.

Rain gauge Network

- World Meteorological Organization (WMO) recommendation:
  - In flat regions of temperate, Mediterranean and tropical zones
    - Ideal → 1 station for 600 – 900 km^2
    - Acceptable →1 station for 900 – 3000 km^2
  - In mountainous regions of temperate , Mediterranean and tropical zones
    - Ideal → 1 station for 100 – 250 km^2
    - Acceptable → 1 station for 250 – 1000 km^2
  - In arid and polar zone
    - 1 station for 1500 – 10,000 km^2
- 10 % of the rain gauges should be self recording to know the intensity of the rainfall

Preparation of Data



- Before using rainfall data, it is necessary to check the data for continuity and consistency
  - Missing data
  - Record errors

Estimation of Missing Data

✓ Given annual precipitation values $P_1, P_2, P_3, \ldots P_m$ at neighboring M stations of station X.

✓ The normal annual precipitation given by $N_1, N_2, N_3, \ldots, N_m, N_x \ldots$ (including station X)

✓ To find the missing precipitation, P_x , of station X

$$P_x = \frac{N_x}{M}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \ldots + \frac{P_m}{N_m}\right]$$

Normal rainfall: Average value of rainfall at a particular date, month or year over a specified 30-year period.

Test for consistency record

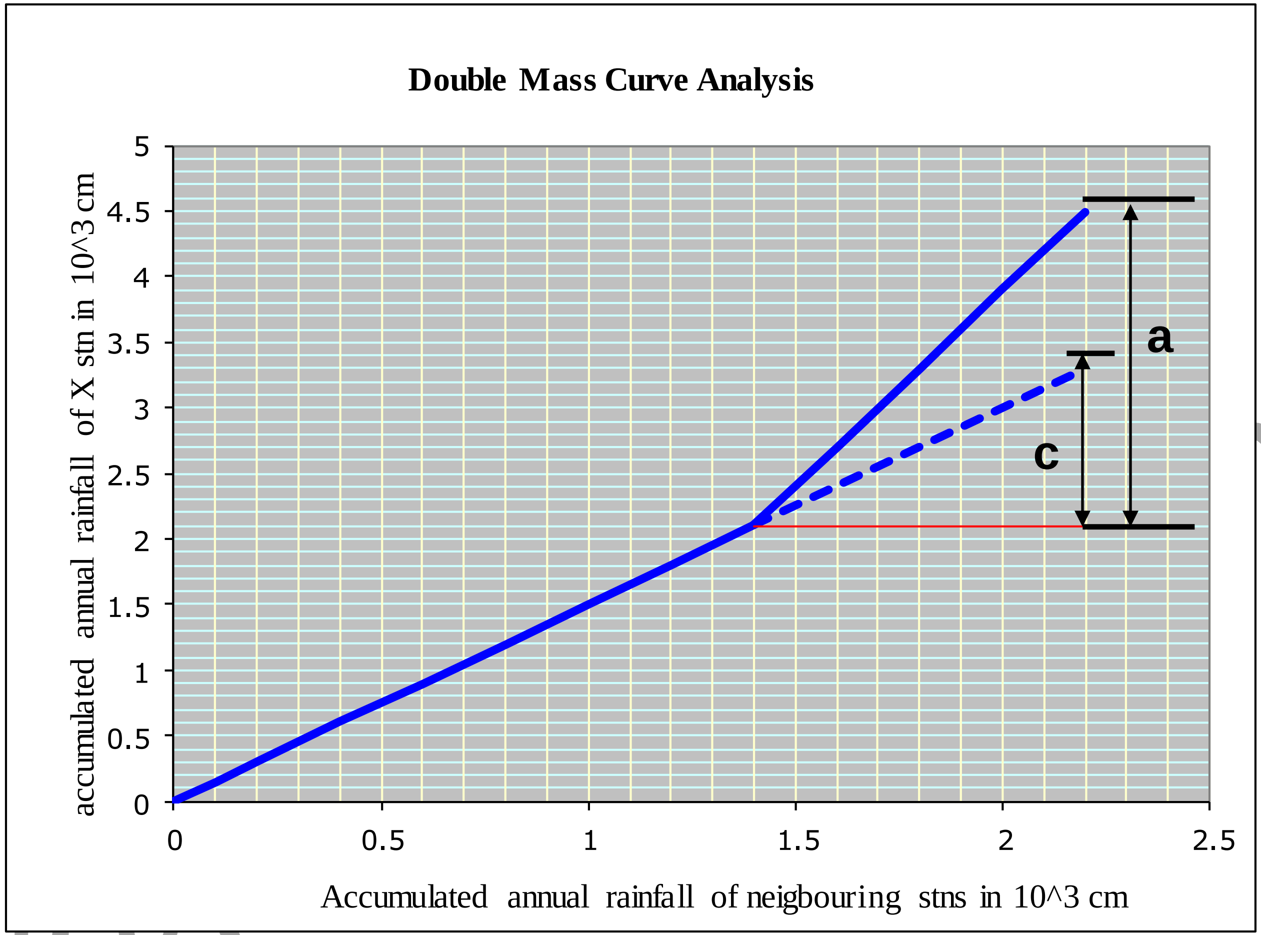
Causes of inconsistency in records

- ✓ Shifting of rain gauge to a new location
- ✓ Change in the ecosystem due to calamities
- ✓ Occurrence of observational error from a certain date

Double mass curve techniques

- ✓ Select a group of 5 to 10 base stations in the neighborhood of the problem station X
- ✓ Arrange the data of X station rainfall and the average of the neighboring stations in reverse chronological order (from recent to old record)
- ✓ Accumulate the precipitation of station X $(\sum P_x)$ and the average values of the group base stations $\left(\sum P_{avg}\right)$ starting from the latest record.
- ✓ Plot the $(\sum P_x)$ against $\left(\sum P_{avg}\right)$ as shown on the next figure
- ✓ A decided break in the slope of the resulting plot is observed that indicates a change in precipitation regime of station X, *i.e.* inconsistency.
- ✓ Therefore, it should be corrected by the factor shown on the next slide

Test for consistency record



$$\frac{M_c}{M_a} = \frac{c}{a}$$

$$P_{cx} = P_x \frac{M_c}{M_a}$$

P_{cx} – corrected precipitation at any time period t_1 at station X

P_x – Original recorded precipitation at time period t_1 at station X

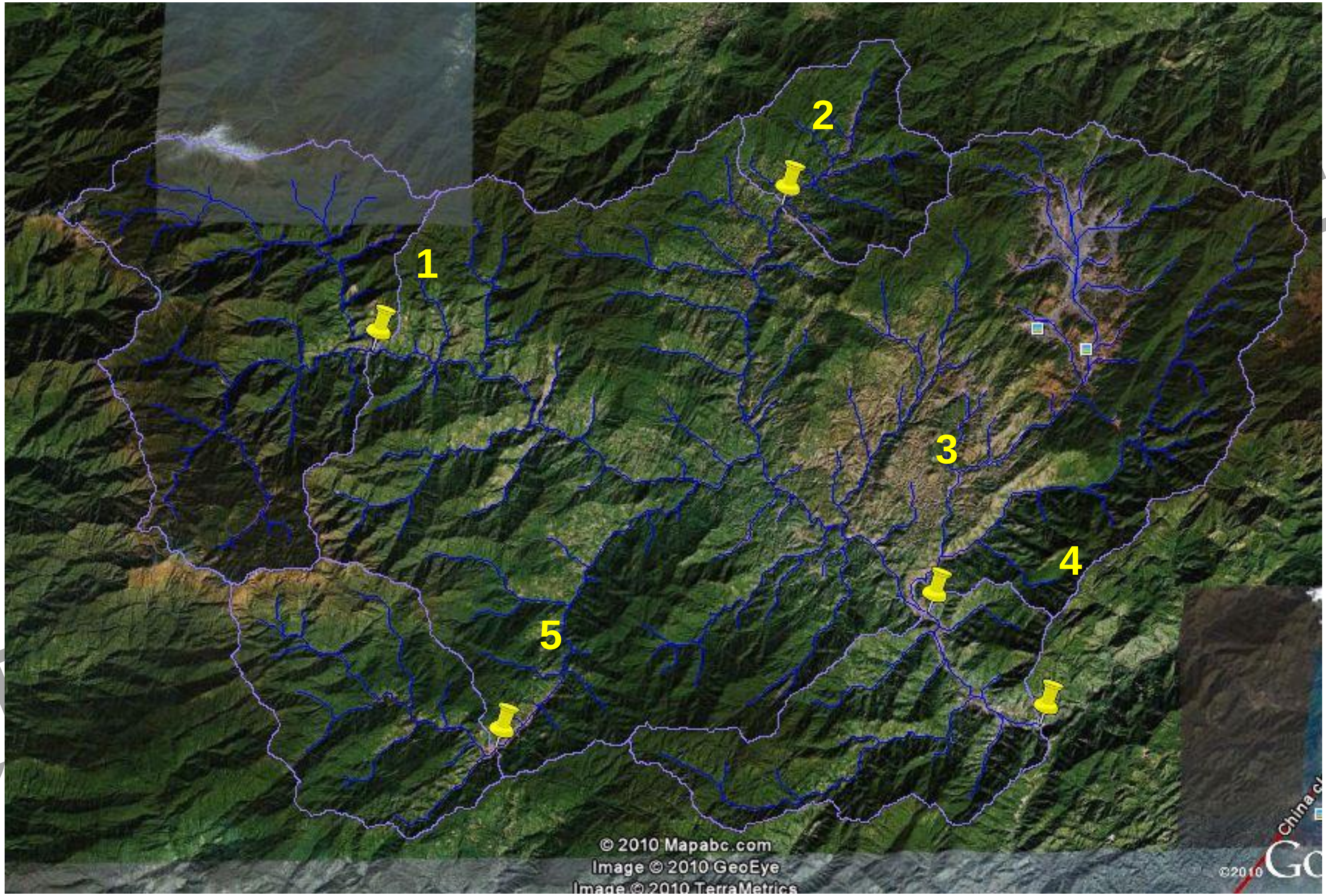
M_c – corrected slope of the double mass curve

M_a – original slope of the mass curve

Mean Precipitation over an area

- ✓ Rainfall recorded on a gauge represents only the point sampling of the areal distribution of a storm
- ✓ The important rainfall for hydrological analysis is a rainfall over an area, such as over the catchment
- ✓ To convert the point rainfall values at various stations into average value over a catchment, the following methods are used:
  - ✓ arithmetic mean
  - ✓ the method of Thiessen polygons
  - ✓ the isohyets method

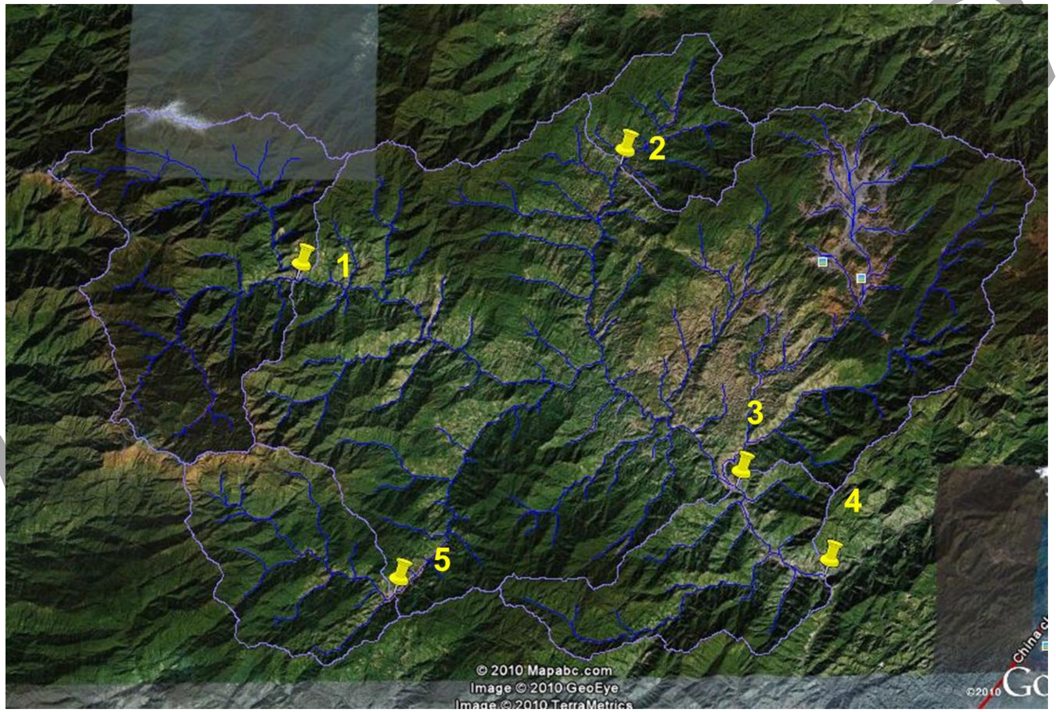
Mean Precipitation over an area



Ranganadi Watershed, Arunachal Pradesh

Arithmetic Mean Method

- When the area is physically and climatically homogenous, the average rainfall $(\bar{P})$ for a basin can be obtained as the arithmetic mean of the P_i values recorded at various stations.
- Applicable rarely for practical purpose

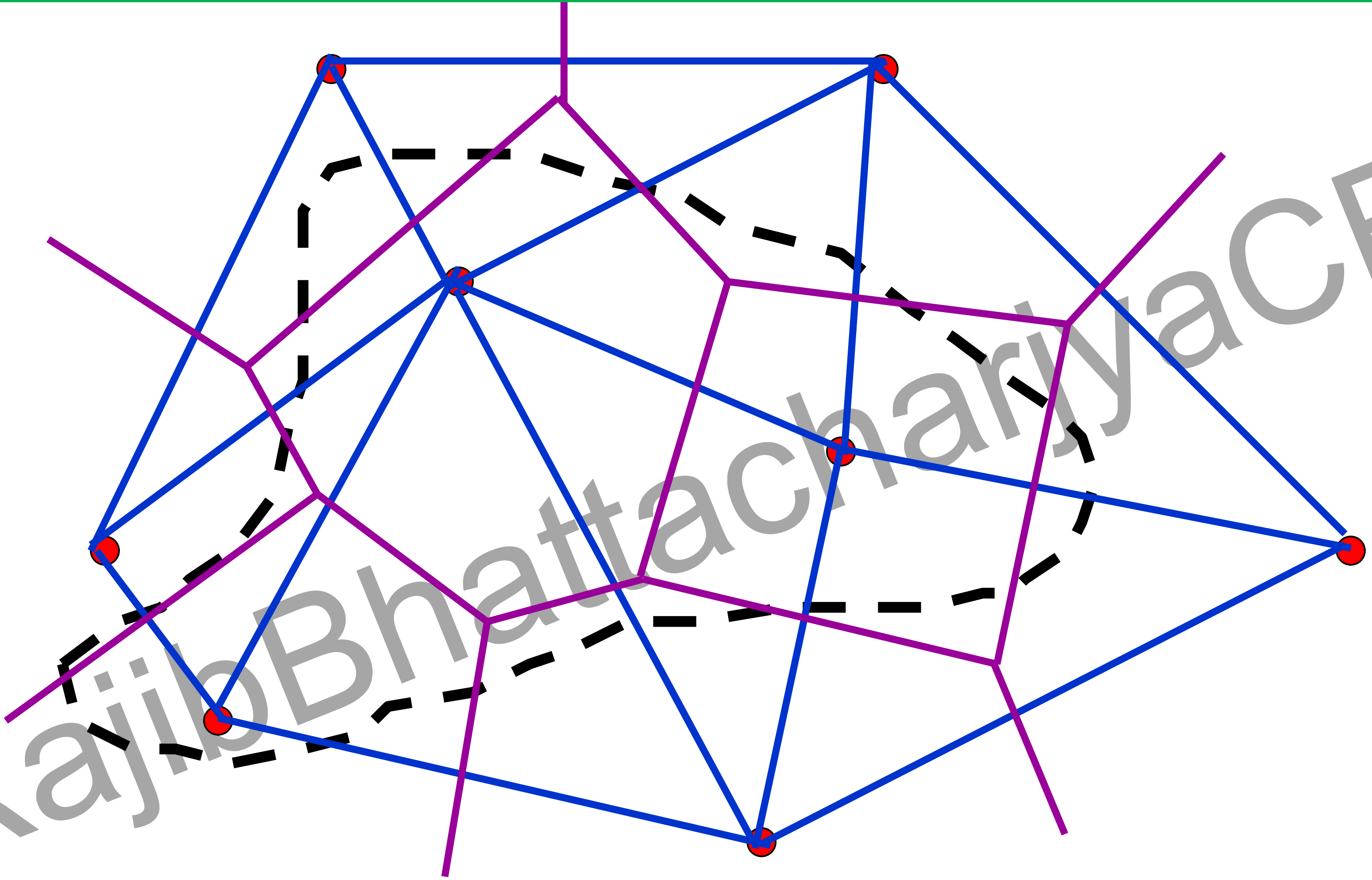


$$\bar{P} = \frac{P_1 + P_2 + \ldots\ldots + P_i + \ldots\ldots P_n}{N} = \frac{1}{N}\sum_{i=1}^{N} P_i$$

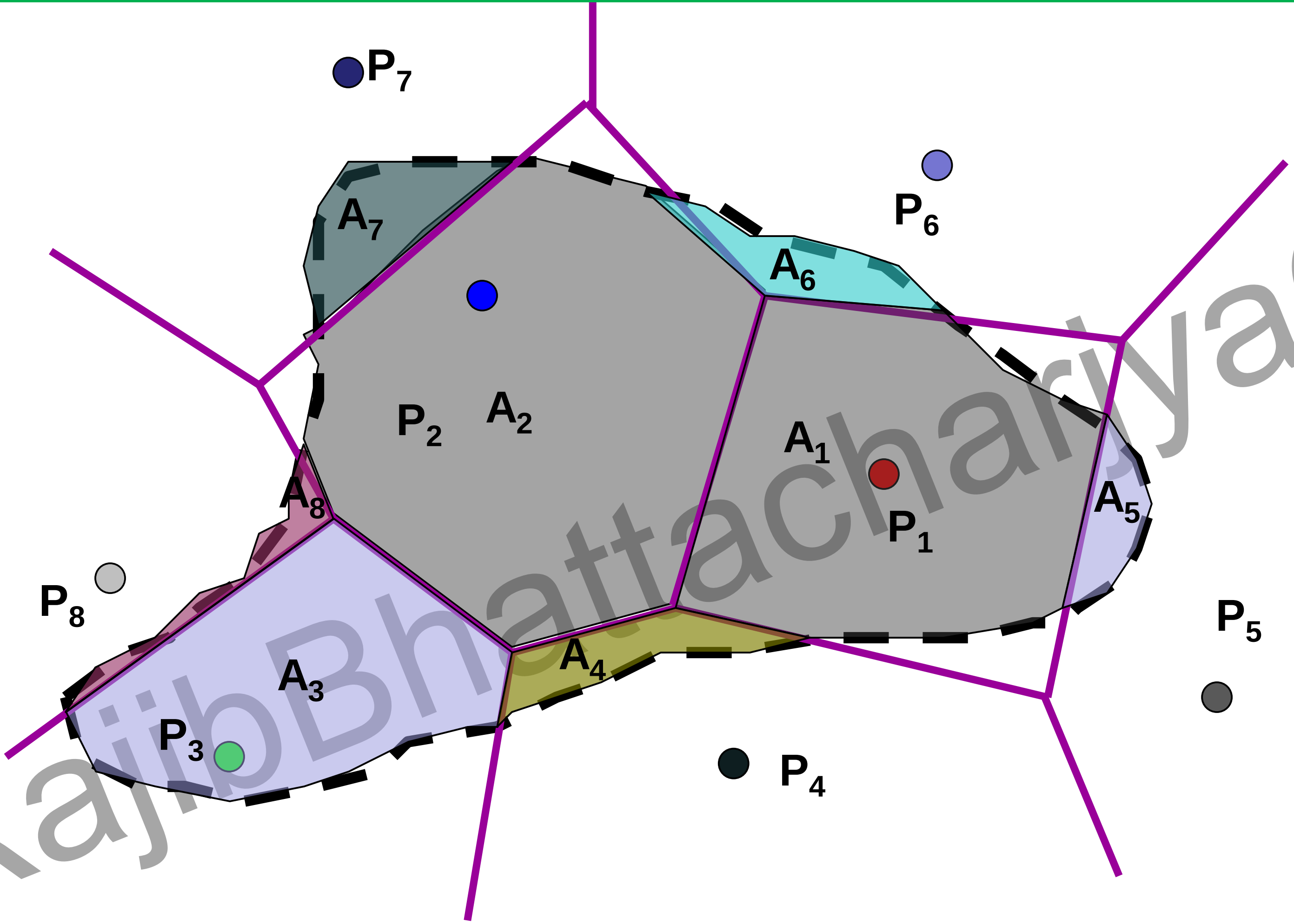
Method of Thiessen polygons

- The method of Thiessen polygons consists of attributing to each station an influence zone in which it is considered that the rainfall is equivalent to that of the station.
- The influence zones are represented by convex polygons.
- These polygons are obtained using the mediators of the segments which link each station to the closest neighboring stations

Method of Thiessen polygons



Method of Thiessen polygons



Method of Thiessen polygons

$$\overline{P} = \frac{P_1 A_1 + P_2 A_2 + \ldots\ldots + P_m A_m}{\left(A_1 + A_2 + \ldots\ldots + A_m\right)}$$

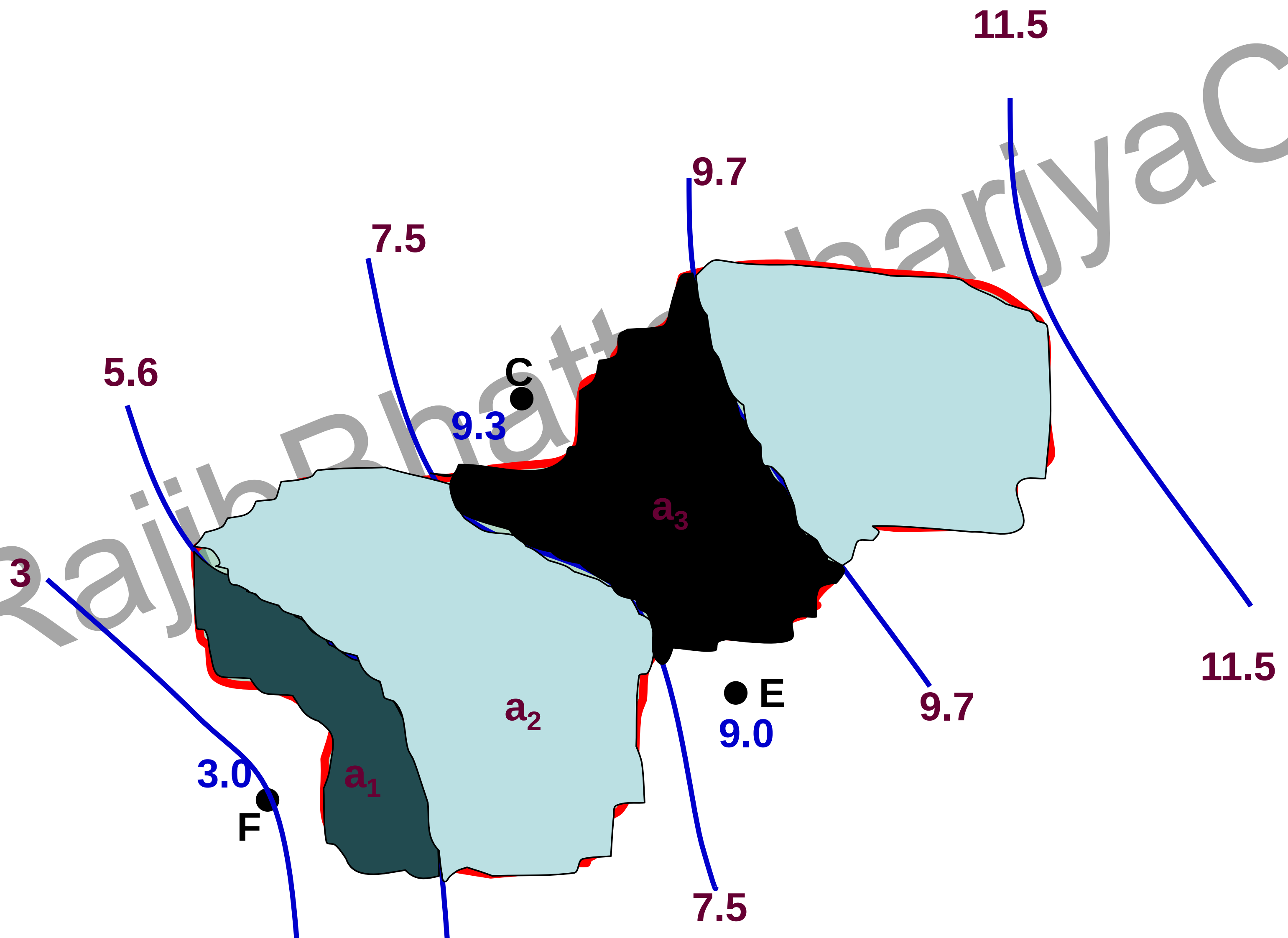
Generally for M station

$$\overline{P} = \frac{\sum_{i=1}^{M} P_i A_i}{A_{total}} = \sum_{i=1}^{M} P_i \frac{A_i}{A}$$

The ratio $\frac{A_i}{A}$ is called the weightage factor of station i

Isohyetal Method

An isohyet is a line joining points of equal rainfall magnitude.



Isohyetal Method

- $P_1, P_2, P_3, \ldots, P_n$ – the values of the isohytes
- $a_1, a_2, a_3, \ldots, a_4$ – are the inter isohytes area respectively
- A – the total catchment area

The mean precipitation ($\overline{P}$) over the catchment

$$\overline{P} = \frac{a_1\left(\frac{P_1+P_2}{2}\right)+a_2\left(\frac{P_2+P_3}{2}\right)+\ldots+a_{n-1}\left(\frac{P_{n-1}+P_n}{2}\right)}{A}$$