Engineering Hydrology

Week-3

Lecture-3 Rainfall-Runoff Relationships

Sisay Demeku Derib (PhD, PE)
Sisay.demeku@aastu.edu.et
AASTU
February, 2025

Lecture contents of the last week

CHAPTER 1: Hydrology and its Measurement

1.1 Hydrologic balance and the water cycle

1.2. Meteorological data

1.3 Principle of data analysis

1.4 Hydrological data

1.5 Filling missing data

Home assignment:

Try to do on your exercise book and will see during tutorial time.

1. What possible control volumes can be considered for understanding water balance or water budget?

2. What important procedures can we follow to understand and analyze water balance for given potential control volume?

3. Two lake water balance workout questions

Lecture contents of the week

CHAPTER -2 Rainfall-runoff Relationships

2.1 Hydrological Models

2.2 Rational Method

2.3 Rainfall intensity and Time of Concentration

2.4 SCS Curve Number and Time-Area Methods

Lecture Learning Outcomes

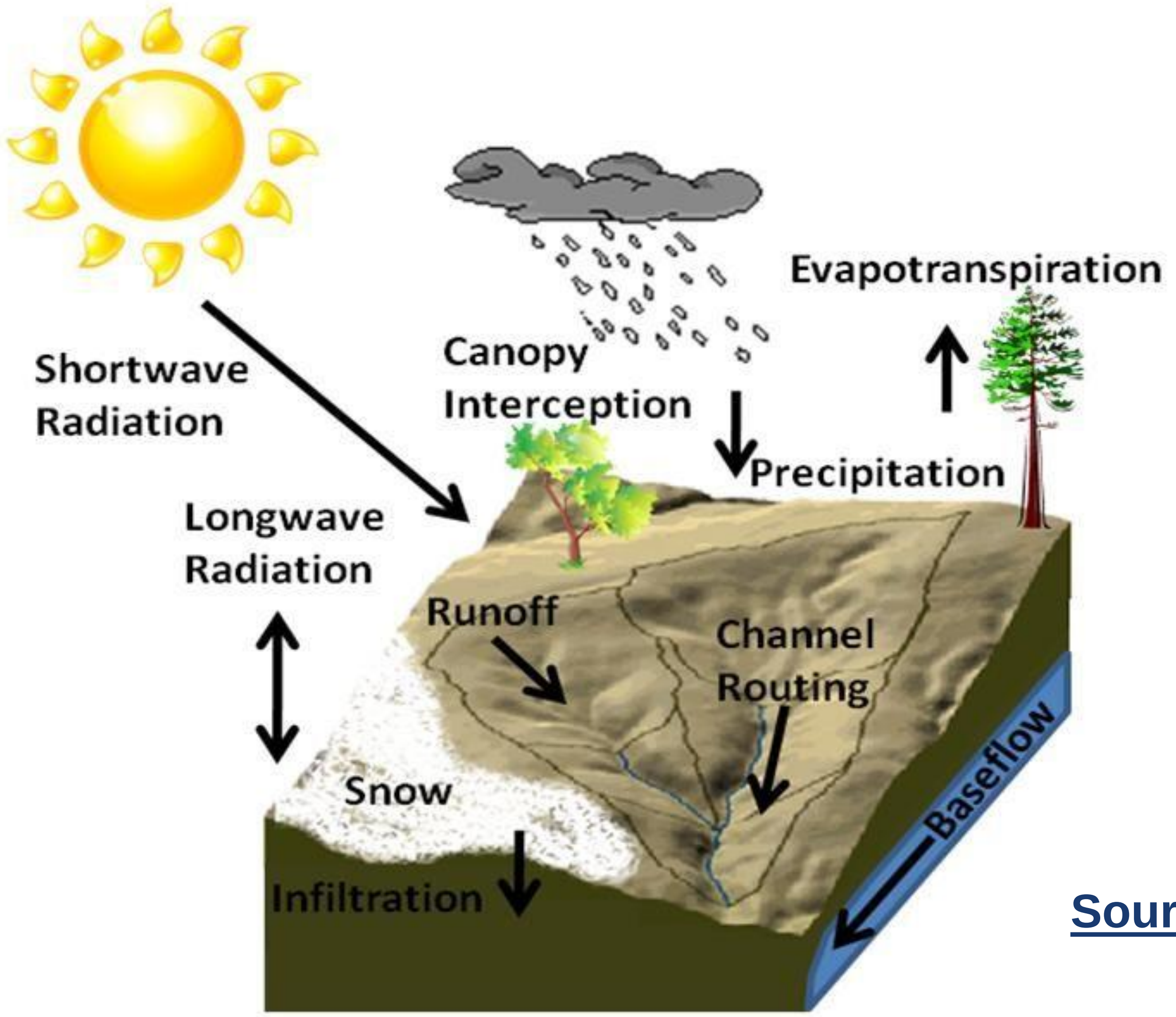
Course Learning Outcomes: After completion of this Lecture, you will be able to:

CLO-1: Apply measurement techniques of the components of the hydrologic cycle, water balance and filling of missed data;

CLO-2: Examine rainfall-runoff relationship and hydrograph;

- **Describe rainfall intensity with respect to time to runoff**
- **Examine hydrological modeling**
- **Apply rainfall-runoff models**

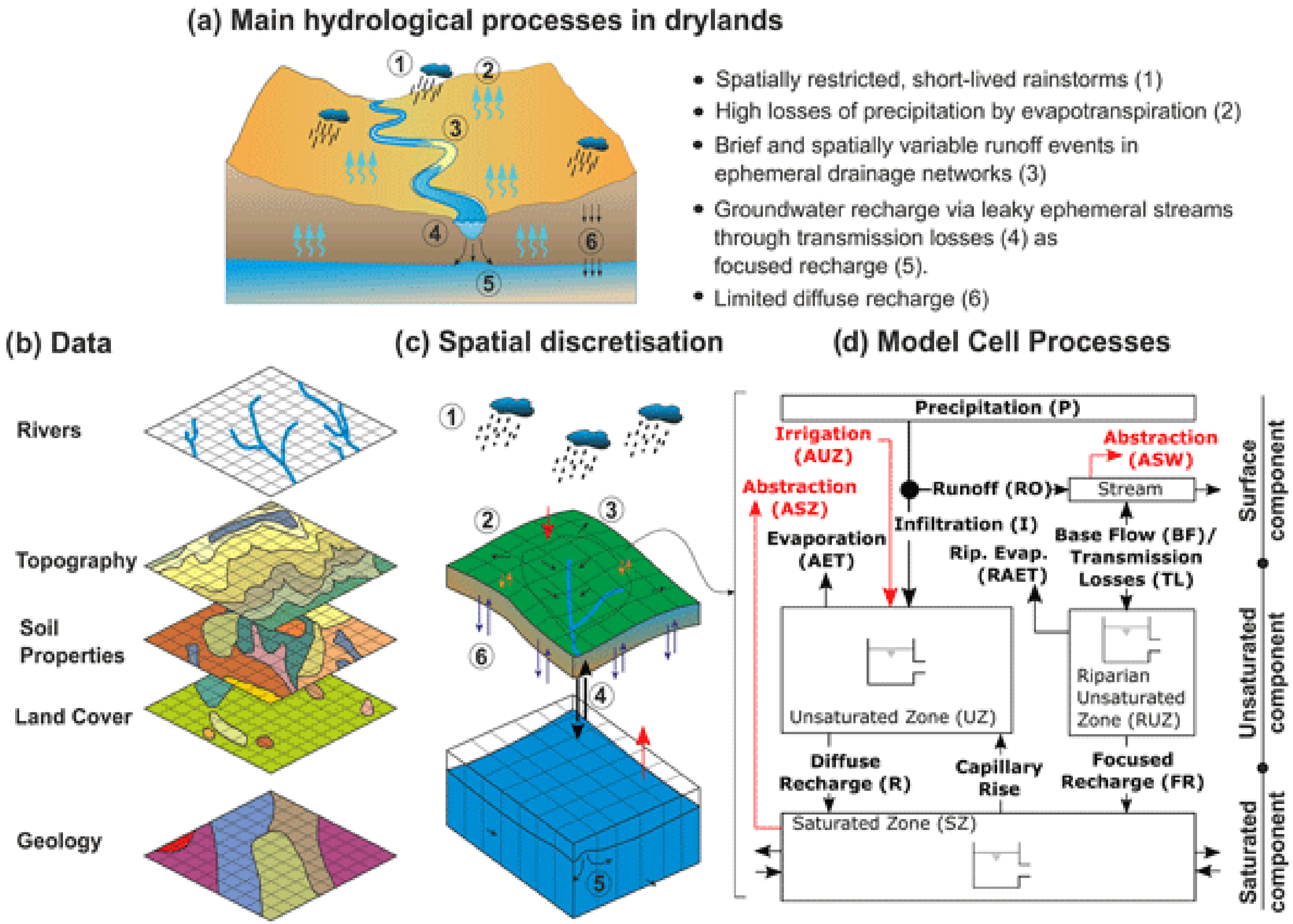
CLO-3: Examine the probability of occurrence;
CLO-4: Analyze the water movement in to, over, and through the soil surface;
CLO-5: Design capacity of reservoir;
CLO-6: Design runoff volume and time of distribution of the runoff hydrograph from urbanization effect.



Hydrological Modelling

Source: [1] hsB-SM

Hydrological Modelling



- Spatially restricted, short-lived rainstorms (1)
- High losses of precipitation by evapotranspiration (2)
- Brief and spatially variable runoff events in ephemeral drainage networks (3)
- Groundwater recharge via leaky ephemeral streams through transmission losses (4) as focused recharge (5).
- Limited diffuse recharge (6)

It is the **simplification** of a real-world system, e.g.,

- surface water,
- soil water,
- wetland,
- groundwater,
- estuary

- It helps in **understanding**, **predicting**, and **managing** water resources

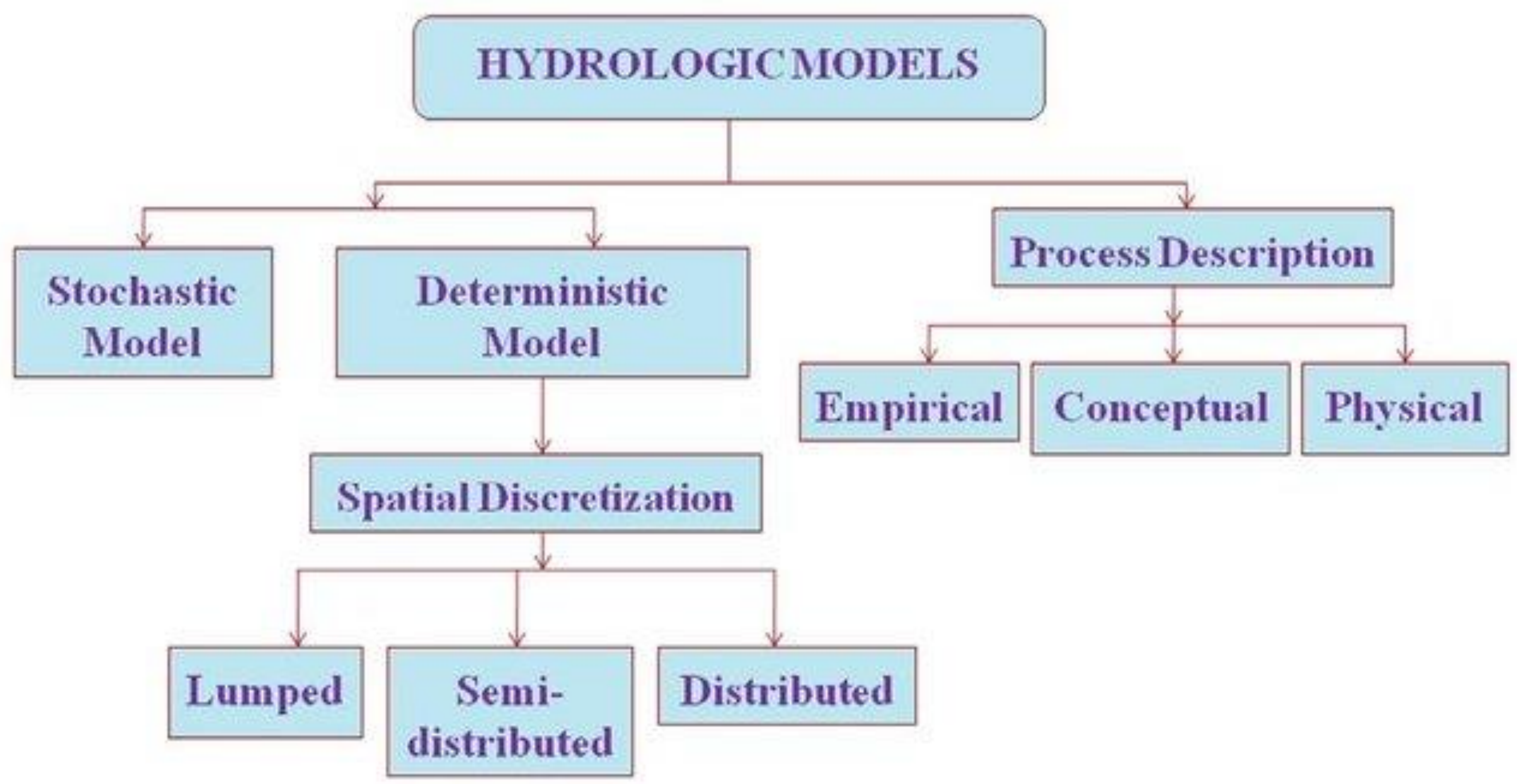
Source: [2] https://gmd.copernicus.org/articles/14/6893/2021/gmd-14-6893-2021-avatar-web.png

Hydrological Modelling

It is the s**implification** of a real-world system (e.g., surface water, soil water, wetland, groundwater, estuary) that aids in **understanding**, **predicting**, and **managing** water resources

- Important in assessing water availability, which is necessary to take decisions in water resources management.
- helps to understand very complex inter-relationship between various hydrological components such as:
  - Precipitation,
  - Evaporation,
  - Transpiration,
  - Infiltration, and
  - Runoff

Hydrological Modelling



Source: [3] (Dwarakish and Ganasri, 2015)

Hydrological Modelling

Hydrological models: Hydrologic models can be classified into:

(1) Deterministic models: Randomness is **not considered**; a given **input** always produces the same **output**.

(a) Deterministic lumped model:

- applied to a **single point** or considers a watershed as a **single unit**
- parameters represent spatially averaged characteristics in a system.
- is **simple** and computationally **efficient**.

(b) Deterministic semi-distributed model:

- It divides the whole catchment into **Hydrologic Response Units (HRUs), land use** and land **cover**, **soil** type, and **slope**.

(c) Deterministic distributed model:

- It considers the hydrological processes taking place **at each grid** and defines the model variables as functions of the space dimensions

(2) Stochastic models:

- The output of these models is at least partially **random** to make statistical predictions.

[1] Dwarakish and Ganasri, 2015

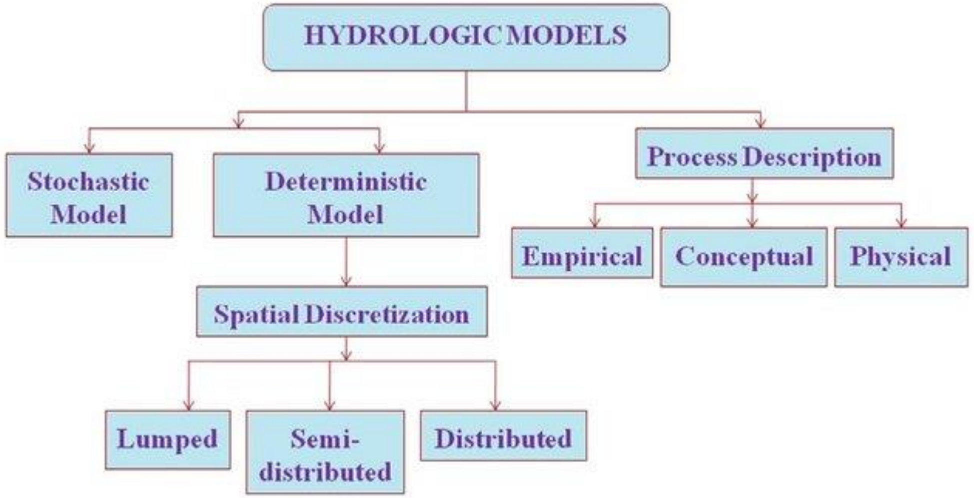
Hydrological Modelling

(3) Process based models:

(a) Empirical models:

- contain **no physical transformation** function to relate input to output;
- build a relationship between input and output based on hydro-meteorological **data**
  - E.g Artificial Neural Networks (ANNs), Fuzzy Logic, Genetic Algorithm (GA)

(b)Conceptual models: are simplifications of the complex processes of runoff generation in a catchment.



(c) Physical models: are able to explicitly represent the spatial variability of the important land surface characteristics such as:

- topographic elevation,
- Slope and aspect,
- vegetation, soil, climatic parameters

Hydrological Modelling

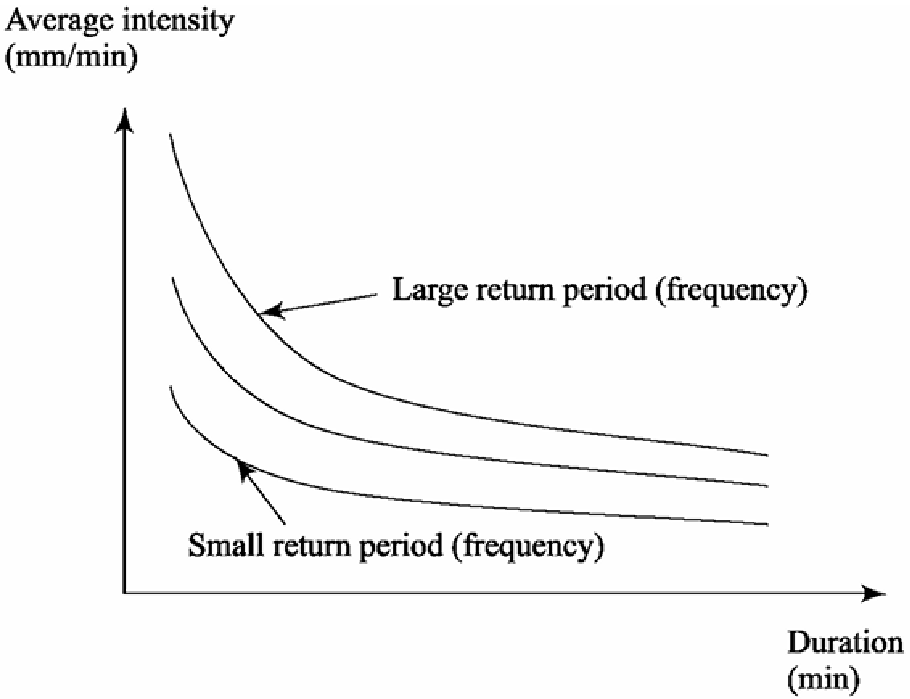
Rainfall characteristics:

- Rainfall **varies** in **amounts**, **timing** and **pattern**.

IDF: the rainfall data should be represented by three important variables (IDF):

1. **Intensity:** measure of the quantity of rain falling in a given time, expressed as in cm/hr, mm/hr, etc.
2. **Duration:** period of time, expressed as 10 min, 20 min, …   of a rain falling.
3. **Frequency:** the return period or frequency of a particular rainfall to appear again, expressed as 5, 50, 100 yrs return periods (frequencies).

IDF can be expressed graphically using three parameters: duration under the abscissa, intensity as the ordinate and frequency as different curves on the same coordinate plane.



Source: [4] (Ojha, C.S.P, 2008)

Hydrological Modelling

IDF: … An intensity-duration-frequency curve can be expressed also using a **mathematical equation**: $I = \frac{cT^a}{(D+b)^d}$

where; ***I*** - intensity (cm/hr)

T - return period (year)

D - duration (hr)

a , b ,c ,d **-** constants

- For a given rainfall amount and its duration measured, frequency can be estimated using:

$$N = T.m$$

where; ***N*** – No. of years

T - return period (year)

m - rank of a given rainfall intensity if the data is orderly rated.

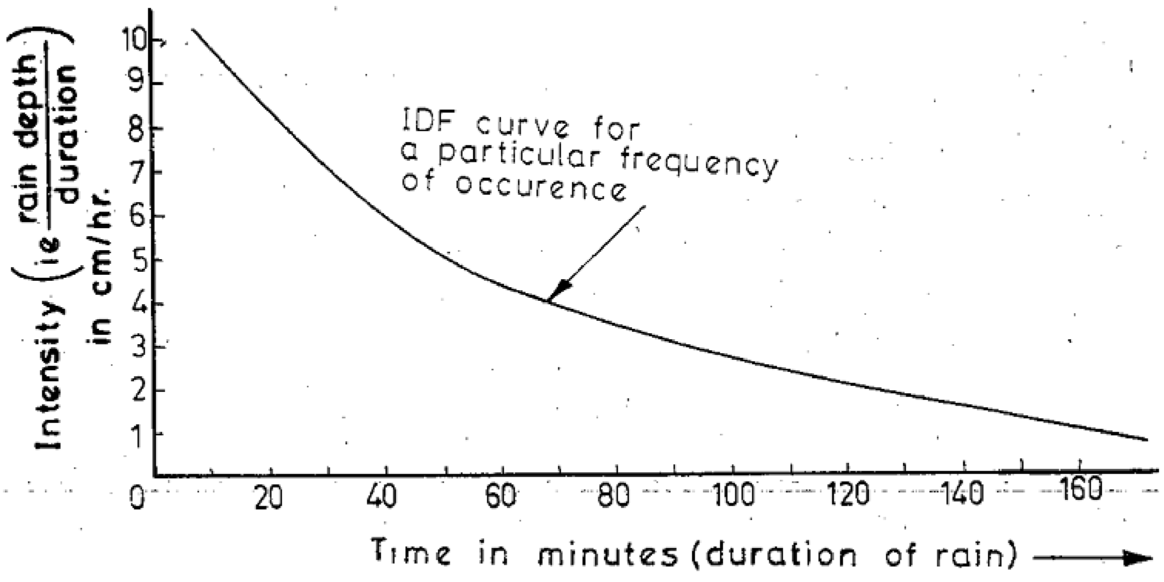


Fig . A typical IDF curve.

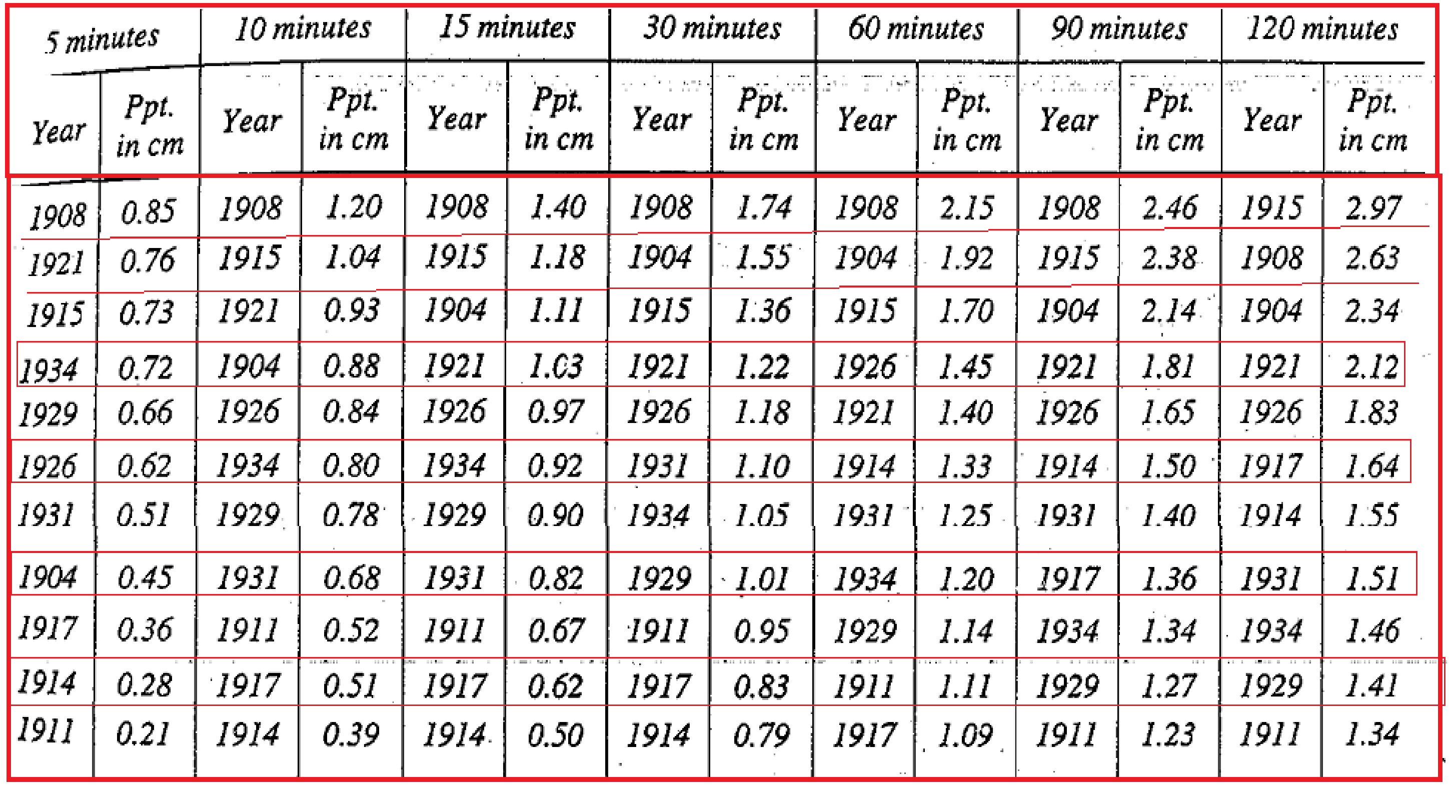
Source: [4] (Ojha, C.S.P, 2008)

Hydrological Modelling

IDF curve example - 1:

Rainfall data were given from a station for 31 years. Eleven worst storms of 7 durations have been stipulated in their decreasing order (See the table).

- Plot the IDF curves of the data for frequencies of:
    - 11 years
    - 1.4 years
    - 1 year



5 minutes		10 minutes		15 minutes		30 minutes		60 minutes		90 minutes		120 minutes	
Year	Ppt. in cm	Year	Ppt. in cm	Year	Ppt. in cm	Year	Ppt. in cm	Year	Ppt. in cm	Year	Ppt. in cm	Year	Ppt. in cm
1908	0.85	1908	1.20	1908	1.40	1908	1.74	1908	2.15	1908	2.46	1915	2.97
1921	0.76	1915	1.04	1915	1.18	1904	1.55	1904	1.92	1915	2.38	1908	2.63
1915	0.73	1921	0.93	1904	1.11	1915	1.36	1915	1.70	1904	2.14	1904	2.34
1934	0.72	1904	0.88	1921	1.03	1921	1.22	1926	1.45	1921	1.81	1921	2.12
1929	0.66	1926	0.84	1926	0.97	1926	1.18	1921	1.40	1926	1.65	1926	1.83
1926	0.62	1934	0.80	1934	0.92	1931	1.10	1914	1.33	1914	1.50	1917	1.64
1931	0.51	1929	0.78	1929	0.90	1934	1.05	1931	1.25	1931	1.40	1914	1.55
1904	0.45	1931	0.68	1931	0.82	1929	1.01	1934	1.20	1917	1.36	1931	1.51
1917	0.36	1911	0.52	1911	0.67	1911	0.95	1929	1.14	1934	1.34	1934	1.46
1914	0.28	1917	0.51	1917	0.62	1917	0.83	1911	1.11	1929	1.27	1929	1.41
1911	0.21	1914	0.39	1914	0.50	1914	0.79	1917	1.09	1911	1.23	1911	1.34

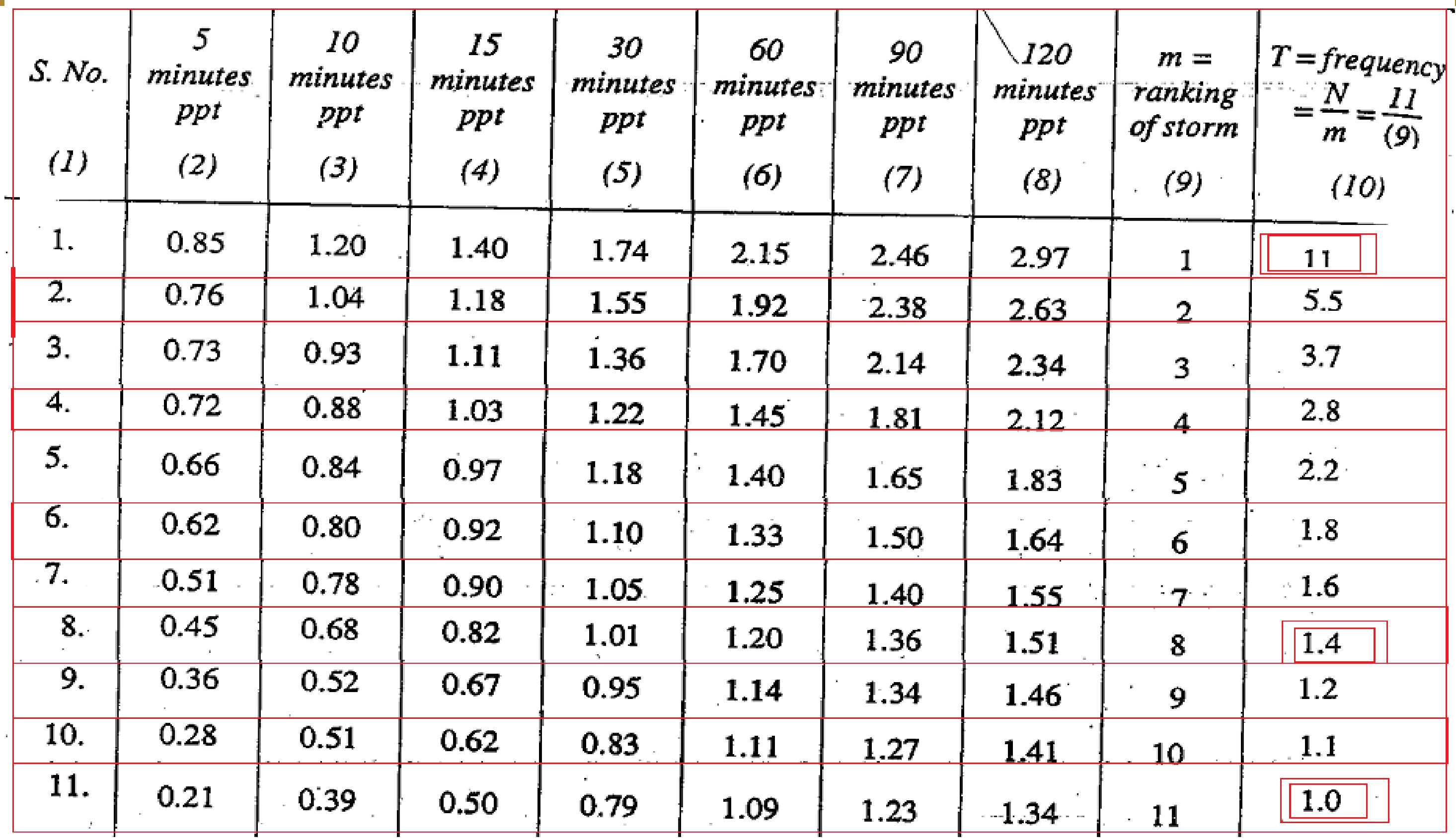
Given: 11 yrs ppt data (cms) from 31, N=11, 7 durations (min.)

Req.: 11 IDF curves for 3 frequencies

Hydrological Modelling

IDF curve example:

- Soln:
- Take the first 11 data with highest ppt in **decreasing order**.
- Assign **rank or m** value starting from 1 for highest ppt for each group of rainfall duration.
- Calculate frequency, T, for each ppt using, $\boldsymbol{T = \frac{N}{m}}$

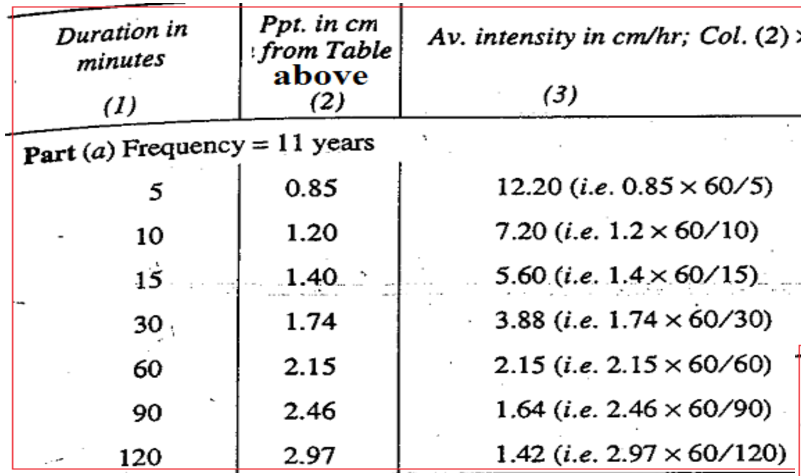


S. No. (1)	5 minutes ppt (2)	10 minutes ppt (3)	15 minutes ppt (4)	30 minutes ppt (5)	60 minutes ppt (6)	90 minutes ppt (7)	120 minutes ppt (8)	m = ranking of storm (9)	$T = \text{frequency} = \frac{N}{m} = \frac{11}{(9)}$ (10)
1.	0.85	1.20	1.40	1.74	2.15	2.46	2.97	1	11
2.	0.76	1.04	1.18	1.55	1.92	2.38	2.63	2	5.5
3.	0.73	0.93	1.11	1.36	1.70	2.14	2.34	3	3.7
4.	0.72	0.88	1.03	1.22	1.45	1.81	2.12	4	2.8
5.	0.66	0.84	0.97	1.18	1.40	1.65	1.83	5	2.2
6.	0.62	0.80	0.92	1.10	1.33	1.50	1.64	6	1.8
7.	0.51	0.78	0.90	1.05	1.25	1.40	1.55	7	1.6
8.	0.45	0.68	0.82	1.01	1.20	1.36	1.51	8	1.4
9.	0.36	0.52	0.67	0.95	1.14	1.34	1.46	9	1.2
10.	0.28	0.51	0.62	0.83	1.11	1.27	1.41	10	1.1
11.	0.21	0.39	0.50	0.79	1.09	1.23	1.34	11	1.0

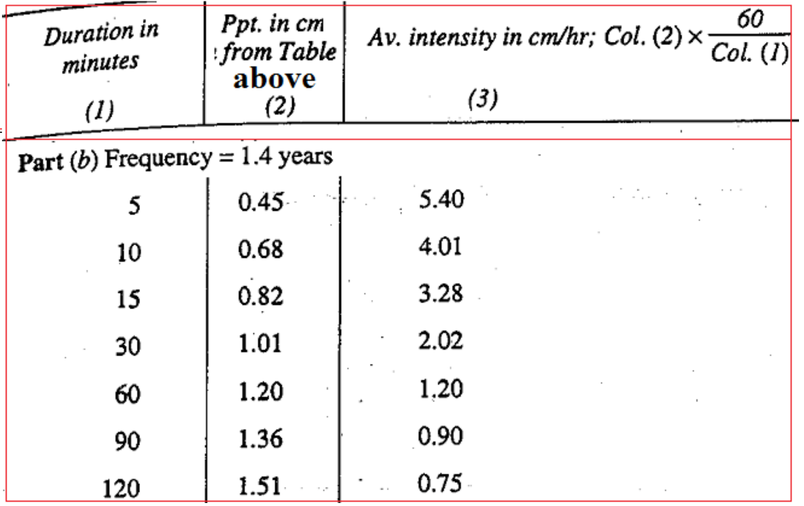
Hydrological Modelling

IDF curve example: Soln:

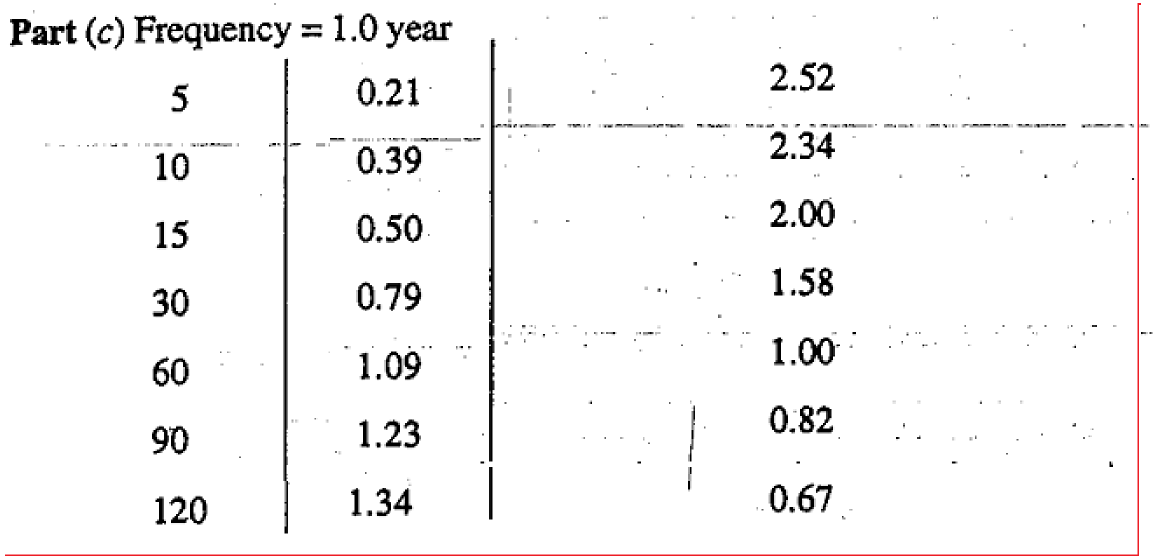
- Calculate intensity, I, for each duration and the three frequencies, T, using $I = \frac{ppt}{D}$



Duration in minutes *(1)*	*Ppt. in cm from Table* **above** *(2)*	*Av. intensity in cm/hr; Col. (2)* $\times \frac{60}{\text{Col. (1)}}$ *(3)*
Part (*a*) Frequency = 11 years		
5	0.85	12.20 (*i.e.* 0.85 × 60/5)
10	1.20	7.20 (*i.e.* 1.2 × 60/10)
15	1.40	5.60 (*i.e.* 1.4 × 60/15)
30	1.74	3.88 (*i.e.* 1.74 × 60/30)
60	2.15	2.15 (*i.e.* 2.15 × 60/60)
90	2.46	1.64 (*i.e.* 2.46 × 60/90)
120	2.97	1.42 (*i.e.* 2.97 × 60/120)



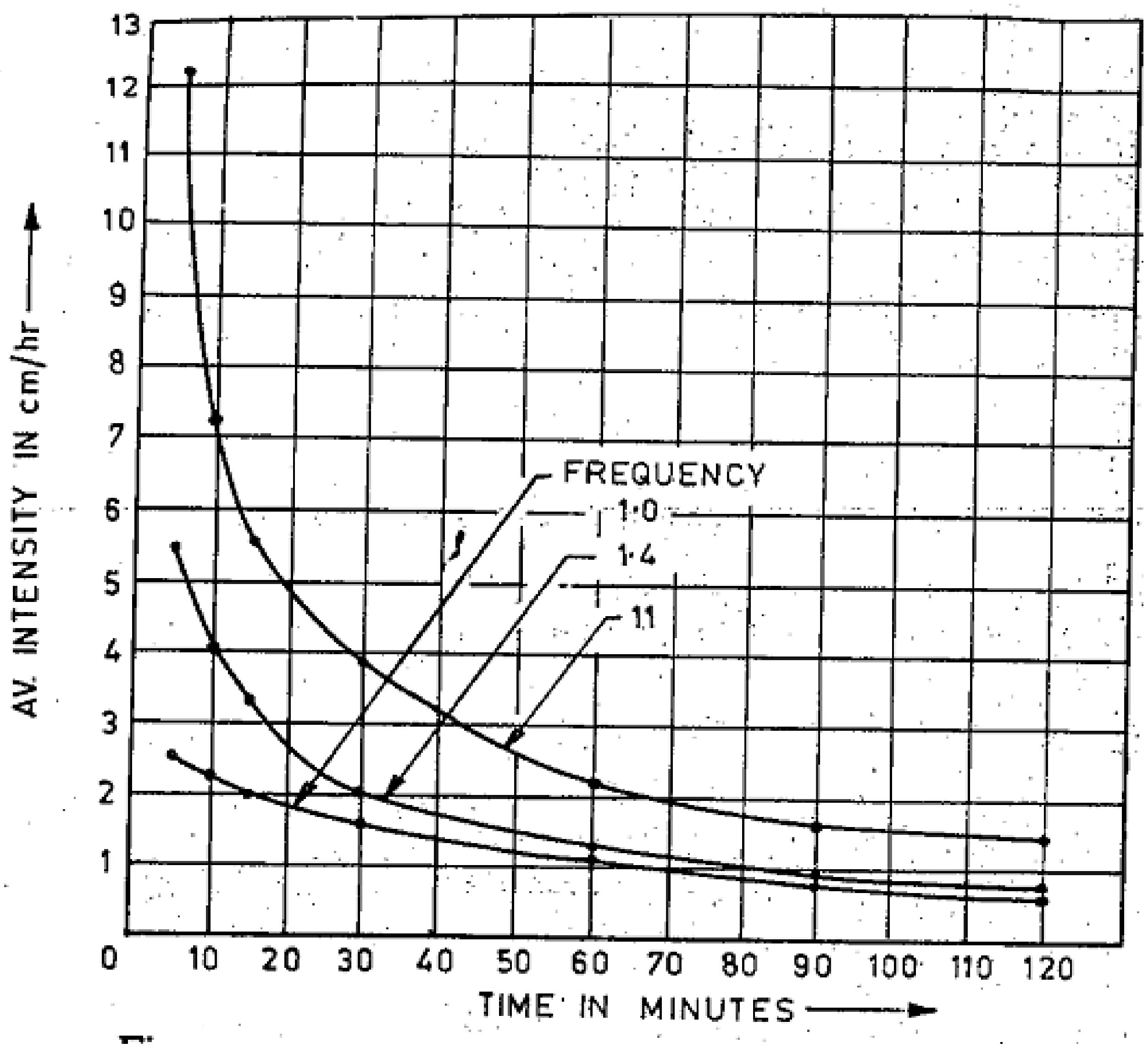
Duration in minutes *(1)*	*Ppt. in cm from Table* **above** *(2)*	*Av. intensity in cm/hr; Col. (2)* $\times \frac{60}{\text{Col. (1)}}$ *(3)*
Part (*b*) Frequency = 1.4 years		
5	0.45	5.40
10	0.68	4.01
15	0.82	3.28
30	1.01	2.02
60	1.20	1.20
90	1.36	0.90
120	1.51	0.75



Part (*c*) Frequency = 1.0 year

5	0.21	2.52
10	0.39	2.34
15	0.50	2.00
30	0.79	1.58
60	1.09	1.00
90	1.23	0.82
120	1.34	0.67

Hydrological Modelling



IDF curve example:

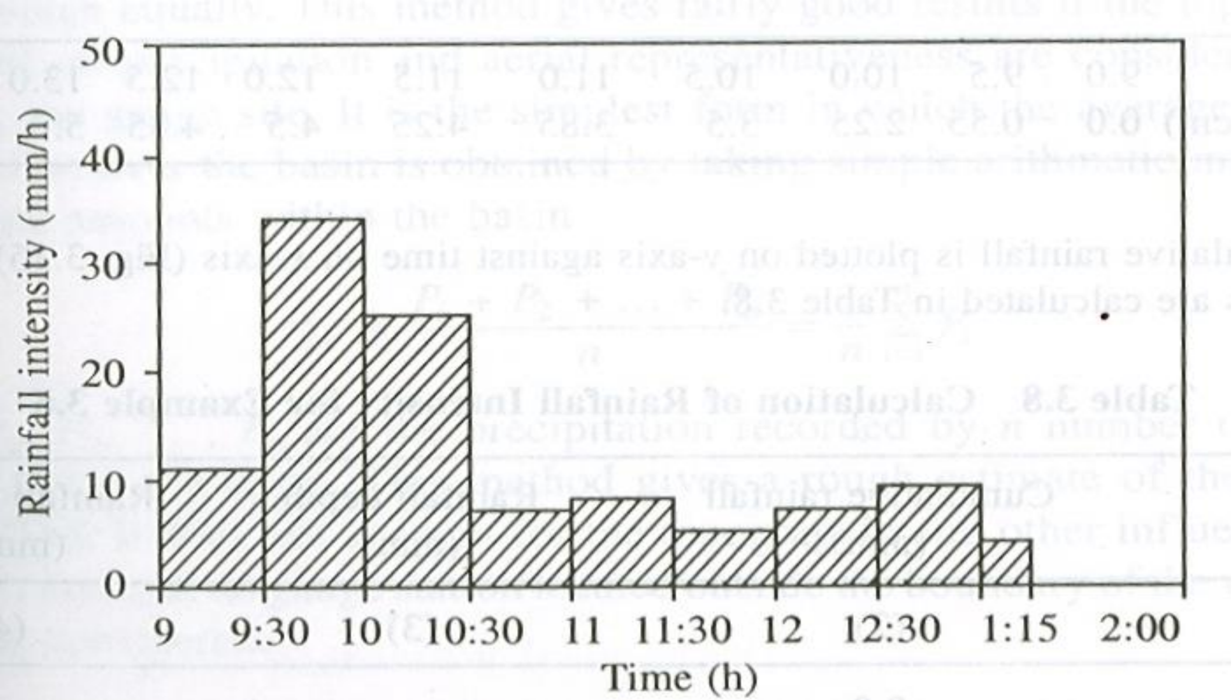
Soln:

- Draw the three intensity versus duration curves on the same coordinate plane, called IDF curves.

Hydrological Modelling

Rainfall Hyetograph:

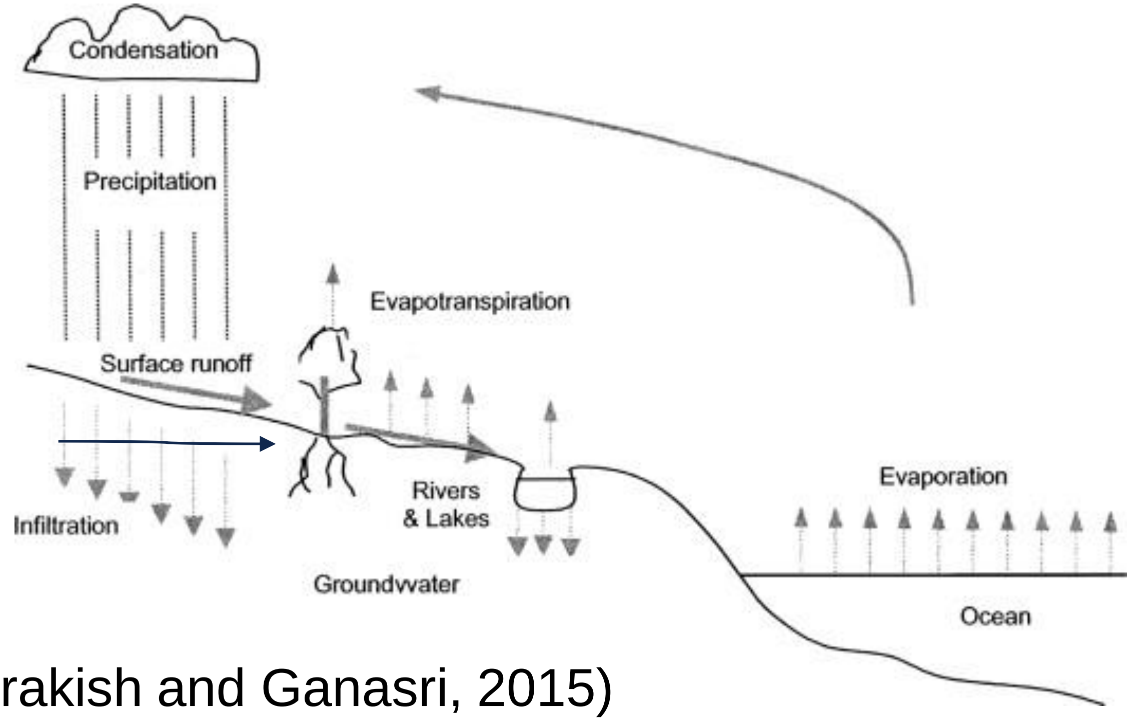
- Is the plot of rainfall **intensity** with time.
- It’s usually expressed in **bar graph**.
- It’s very useful for flood studies and calculation of **rainfall loss** indices.
- The **area** under the hyetograph represents the **total rainfall** within the total period.



Hydrological Modelling

Hydrologic losses:

- The rainfall that does not contribute to <u>**direct runoff**</u> is termed as a hydrological loss.
- Direct runoff has two parts: **surface** and **subsurface** flows.
- They can be divided by various processes and can be divided as:
  - i) Interception
  - ii) Transpiration
  - iii) Evaporation
  - iv) Depression storage
  - v) Infiltration



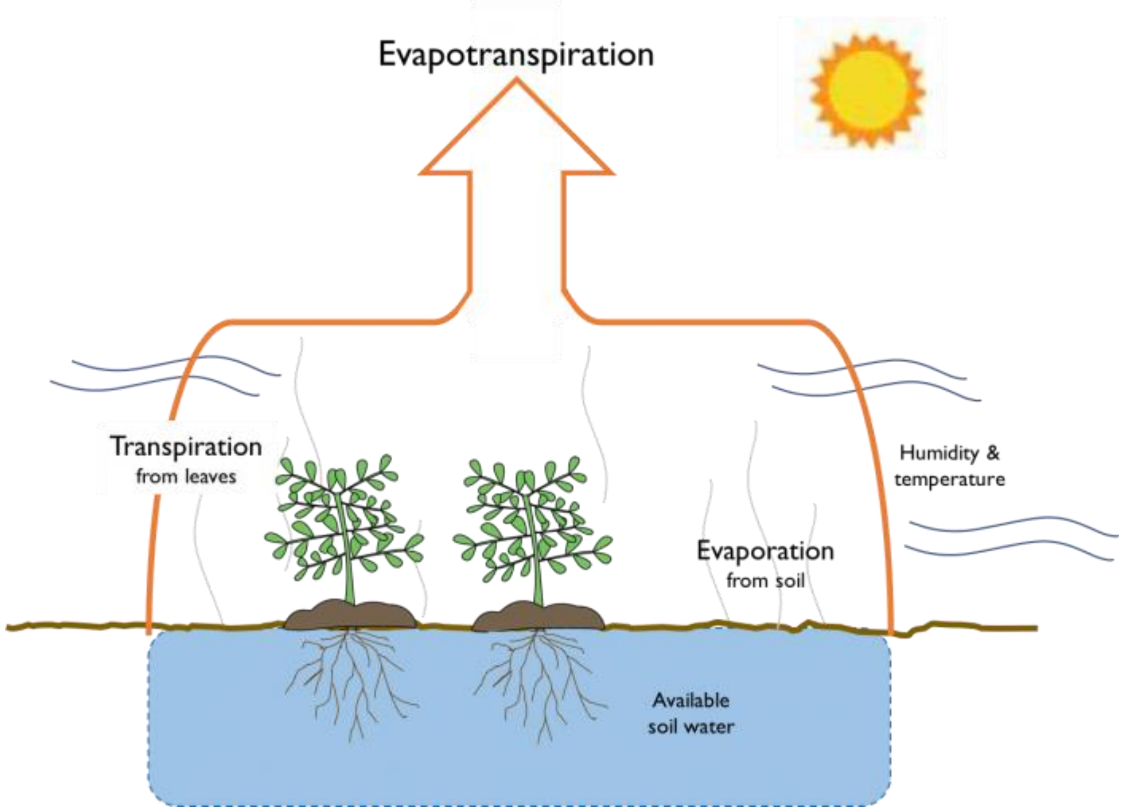
Source: [3] (Dwarakish and Ganasri, 2015)

$$Rainfall - Losses = Runoff$$

Hydrological Modelling

Evapotranspiration (ET):

- The combination of evaporation and transpiration.
- Methods of estimating evapotranspiration:
  1. Thornthwaite method (1948),
  2. Blaney- Criddle (1950),
  3. Evaporation index method
  4. Hargrave method (1985)
  5. Penman method (1948)



https://serc.carleton.edu/

Hydrological Modelling

Evapotranspiration (ET): 1) Thornthwaite method (1948)

- This method uses the following parameter to estimate potential evapotranspiration (PET):
  - the mean daily **temperature**,
  - latitude of the place
  - the month of the year

$$PET_{Thorn} = \begin{cases} 0, & \text{if } T < 0 \\ 16 \cdot \frac{N}{360} \cdot \left(\frac{10 \cdot T}{I}\right)^{a}, & \text{if } 0 \leqslant T \leqslant 26 \\ \frac{N}{360} \cdot \left(-415.85 + 30.5332.24 \cdot T - 0.43 \cdot T^{2}\right), & \text{if } T > 26 \end{cases}$$

where;

PET is potential evapotranspiration [**mm/day**],

N is the duration of sunlight in hours, varying with season and latitude

T is average daily air temperature [°C], and

I is a heat index calculated as follows:

$$I = \sum_{Jan}^{Dec} \left(\frac{max[0, T_m]}{5}\right)^{1.514}$$

a is a constant calculated as:

The exponent, ***a***, can be calculated as:

$$a = (6.75 \cdot 10^{-7} \cdot I^{3}) - (7.71 \cdot 10^{-5} \cdot I^{2}) + (0.01792 \cdot I) + (0.49239)$$

Hydrological Modelling

Evapotranspiration (ET): 1) Thornthwaite method (1948)

- It can be estimated **at monthly** levels as:

$$\mathrm{PET} = 1.62C\left(\frac{10T_m}{I}\right)^a$$

where;

PET is potential evapotranspiration [**mm/month**],

C is reduction factor(coefficient)

T_m is mean monthly temperature, [°C], and

I is a heat index calculated as follows:

a is a constant calculated as:

$$I = \sum_{m=1}^{12}\left(\frac{T_m}{5}\right)^{1.51}$$

The exponent a can be calculated as:

$$a = (6.75 \cdot 10^{-7} \cdot I^3) - (7.71 \cdot 10^{-5} \cdot I^2) + (0.01792 \cdot I) + (0.49239)$$

Hydrological Modelling

Evapotranspiration (ET): 2) Blaney-Criddle method (1950)

- requires the following information on for predicting reference crop evapotranspiration:
  - the average daily percentage of total daily hours and
  - mean daily air temperature.
- It can be estimated at monthly levels as:

$$ET_0 = a + b\left[p\left(0.46T + 8.13\right)\right]$$

where;

ET$_0$ is reference crop evapotranspiration (mm/d);

a and b are calibrated constants;

p is the average daily percentage of total annual daytime hours; and

T is the average daily air temperature (°C).

a is a constant calculated as: $a = 0.0043RH_{min} - (n/N) - 1.41$

RHmin is the lowest daily relative humidity (%); and

n/N is the average ratio of actual to possible sunshine hours.

The **b, p** and **N** values can be received from tables when specifying latitudes and months

Hydrological Modelling

Evapotranspiration (ET): 3) Evaporation index method (pan evaporation)

- The relationship between the evapotranspiration (***E_t***) and pan evaporation (***E_p***) is usually expressed.

$$E_t = KE_p$$

where;

K is a coefficient (i.e. E_t/E_p) and is found to vary according to the stage of growth of the crop.

Hydrological Modelling

Evapotranspiration (ET): 4) Hargrave method (1985)

- is one of two **temperature-based** evapotranspiration methods included in HEC-HMS and other rainfall-runoff models.
- is based on an empirical relationship **solar radiation** and **air temperature** data.
- It can be estimated at monthly levels as:

$$ET_o = K * RS * (T + 17.8)$$

where;

ET$_0$	is reference crop evapotranspiration (mm/d);
K	is a coefficient;
RS	is solar radiation, and
T	is the average daily air temperature (°C).

Hydrological Modelling

Evapotranspiration (ET): 5) Penman-Monteith (1985)

- determines the evapotranspiration from the **hypothetical grass** reference surface and
- It requires meteorological data and the corresponding definition of the reference surface.
  - Evapotranspiration from an area is governed by the amount of **energy that is available** to transform water from liquid to gas.
  - The amount of water that can **theoretically** evaporate (water is not a **limiting factor**, e.g., water can evaporate from a free water surface) is called **potential evaporation**.
    - when water is a limiting factor, e.g., when soil surface is only **partially saturated**, is called **actual evaporation**.
    - Similar conclusions an be deriver from observation for **potential and actual evapotranspirations**.
- Two major factors govern the amount of water that can evaporate from a surface: **wind** and **temperature**.

Hydrological Modelling

Evapotranspiration (ET): 5) Penman-Monteith (1985)

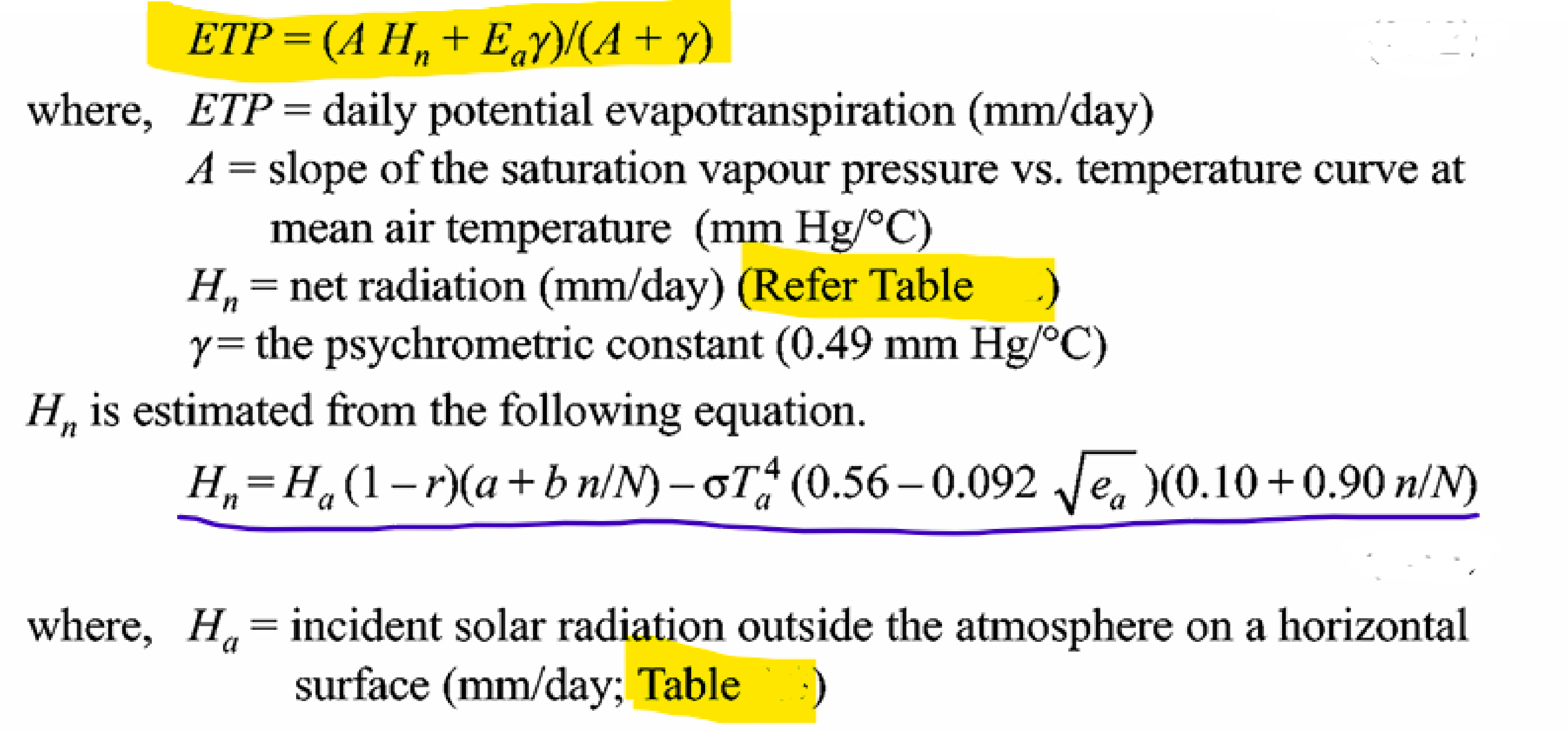
- **Saturated vapor pressure**: is a specific amount of vapor in the atmosphere at a ***specific temperature*** that the atmosphere can hold at its ***maximum*** limit.
- The **evaporation rate** (***E***) will then be proportional to the difference in **actual** vapor pressure ($\boldsymbol{e_a}$) and saturated vapor pressure ($\boldsymbol{e_s}$),
  - $E = c(e_s - e_a)$ where c is a constant …… called Dalton evaporation law
- The presence of **wind transports** the evaporated water away and replaces it by dry air.
- If $(e_s - e_a) > 0$, ***condensation*** will take place.
- This method that apply a combination of **energy balance** and **wind transfer** to calculate potential evapotranspiration is called **Penman method**.

Hydrological Modelling

Evapotranspiration (ET): 5) Penman-Monteith (1985)

- The Penman equation is reads: General form

$$E = \frac{\Delta}{(\Delta+\gamma)} E_r + \frac{\gamma}{(\Delta+\gamma)} E_a \quad [LT^{-1}]$$



$$ETP = (A\,H_n + E_a\gamma)/(A + \gamma)$$

where, ETP = daily potential evapotranspiration (mm/day)

A = slope of the saturation vapour pressure vs. temperature curve at mean air temperature (mm Hg/°C)

H_n = net radiation (mm/day) (Refer Table)

γ = the psychrometric constant (0.49 mm Hg/°C)

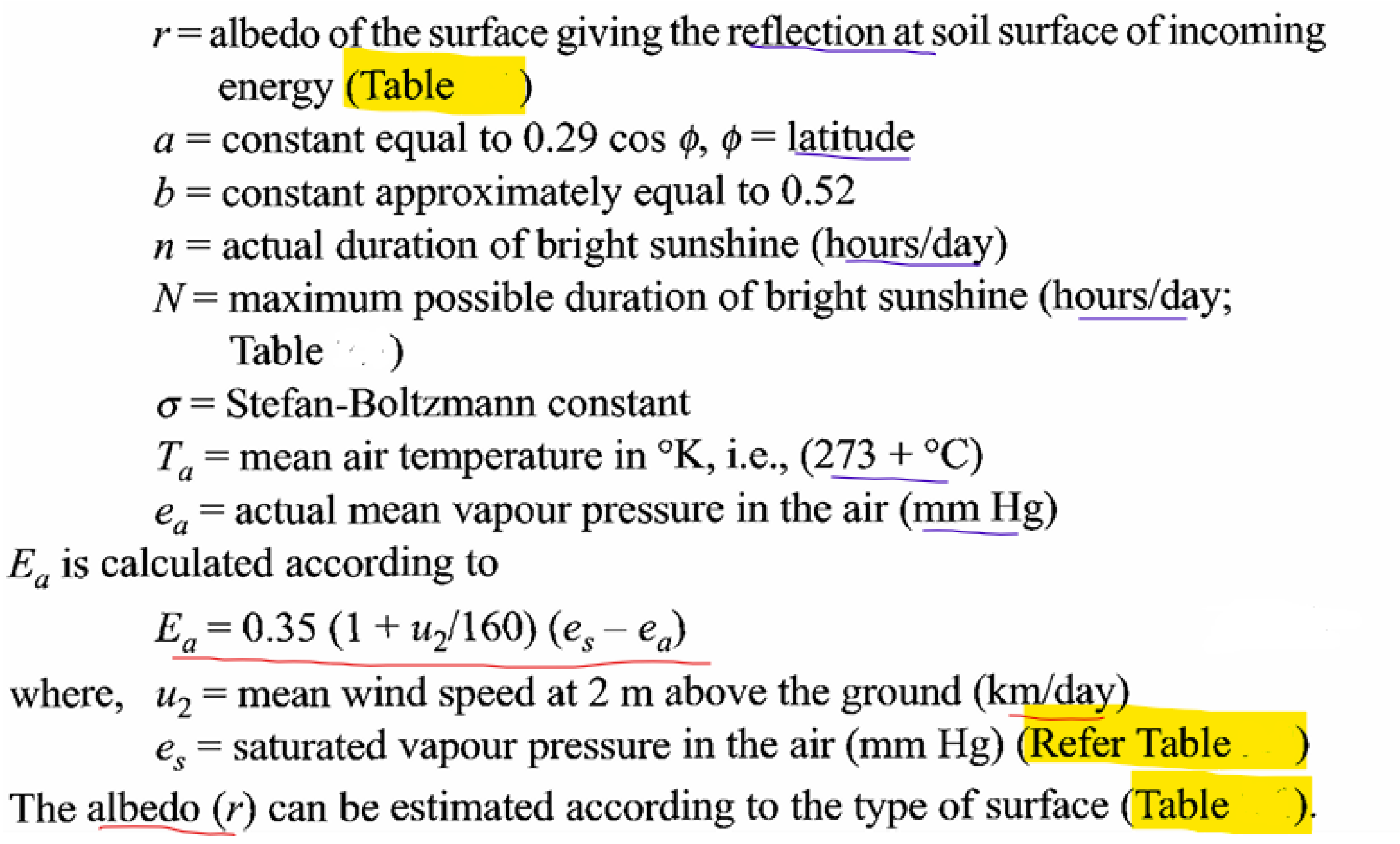
H_n is estimated from the following equation.

$$\underline{H_n = H_a(1-r)(a + b\,n/N) - \sigma T_a^4 (0.56 - 0.092\sqrt{e_a})(0.10 + 0.90\,n/N)}$$

where, H_a = incident solar radiation outside the atmosphere on a horizontal surface (mm/day; Table)

Evapotranspiration (ET): 5) Penman-Monteith (1985)

- The Penman equation is reads: $ETP = (A\,H_n + E_a\gamma)/(A + \gamma)$



r = albedo of the surface giving the reflection at soil surface of incoming energy (Table)
a = constant equal to 0.29 cos ϕ, ϕ = latitude
b = constant approximately equal to 0.52
n = actual duration of bright sunshine (hours/day)
N = maximum possible duration of bright sunshine (hours/day; Table)
σ = Stefan-Boltzmann constant
T_a = mean air temperature in °K, i.e., (273 + °C)
e_a = actual mean vapour pressure in the air (mm Hg)

E_a is calculated according to

$$E_a = 0.35\,(1 + u_2/160)\,(e_s - e_a)$$

where, u_2 = mean wind speed at 2 m above the ground (km/day)
e_s = saturated vapour pressure in the air (mm Hg) (Refer Table)

The albedo (r) can be estimated according to the type of surface (Table).

Hydrological Modelling

Example-2

- Assuming a growing season of 4 months, December - March for wheat,
  - determine the **consumptive use (ET_a)** of wheat in the month of January if the pan evaporation for the month is 9.5cm. Take the consumptive use coefficient of the crop as 0.52.
- Given: E_p=9.5 cm, K_p=0.52
- Solution: $ET_a = KE_p$
  - ET_a = 0.52 x 9.5 cm = **4.94 cm**. for January.
- The daily consumptive use for the month of January = 4.94/31 = 0.16cm/day …….. #Ans.

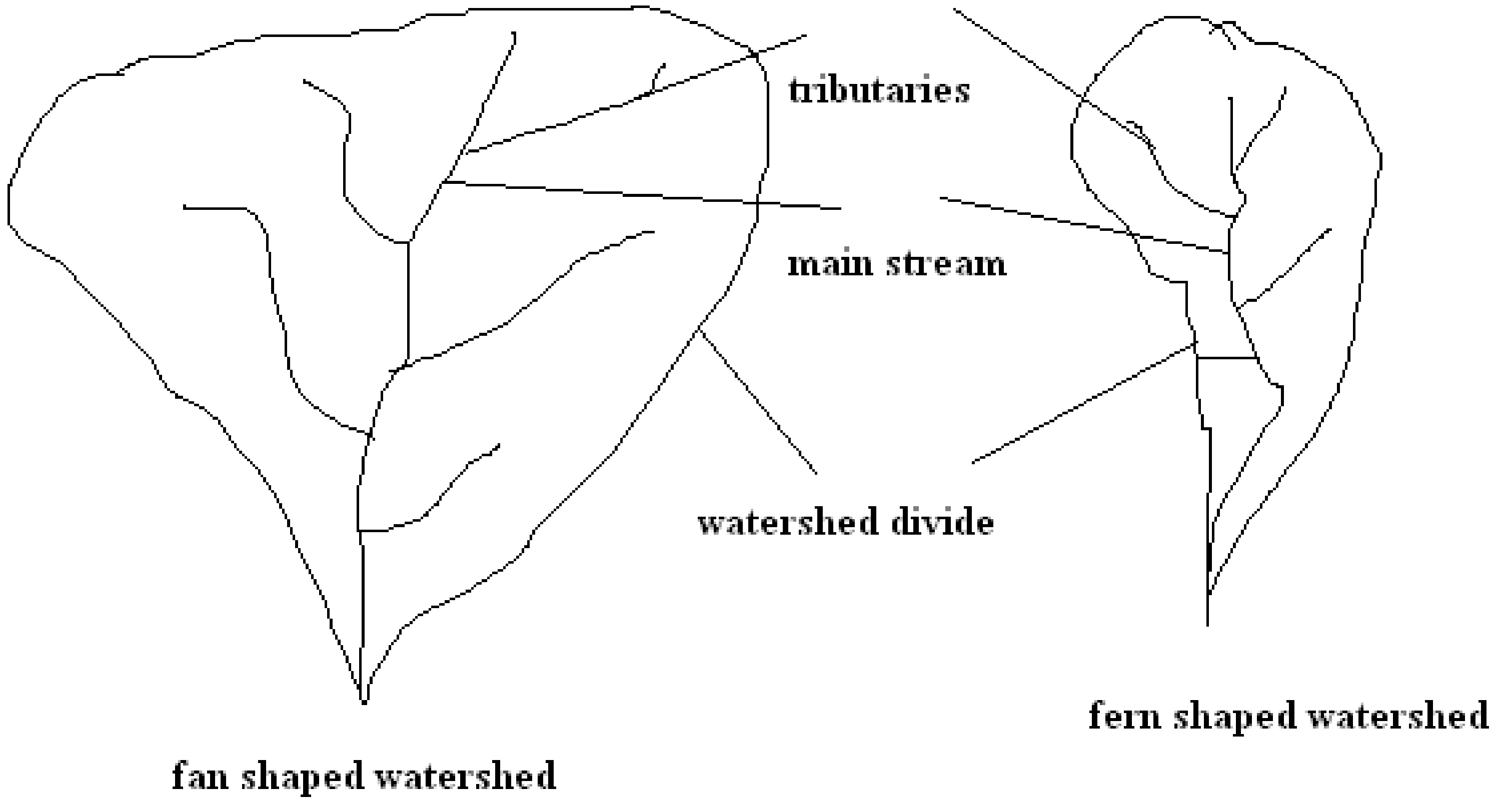
Rainfall-runoff relationships

- **Runoff** is defined as the portion of precipitation that makes its way towards rivers, or seas, or oceans, etc as surface and sub surface flow.
- The runoff generally consists of:
  - Surface runoff
  - Sub-surface (ground) runoff
  - Direct precipitation over the streams
- Factors Affecting Runoff
  - Characteristics of precipitation
  - Characteristics of drainage basin

Characteristics of Precipitation

- ➢Type of precipitation
- ➢Rain Intensity
- ➢Duration of rainfall
- ➢Rainfall Distribution
- ➢Soil Moisture deficiency
- ➢Direction of the prevailing storm
- ➢Other climatic Factors: such as wind, temperature, humidity

Rainfall-runoff relationships

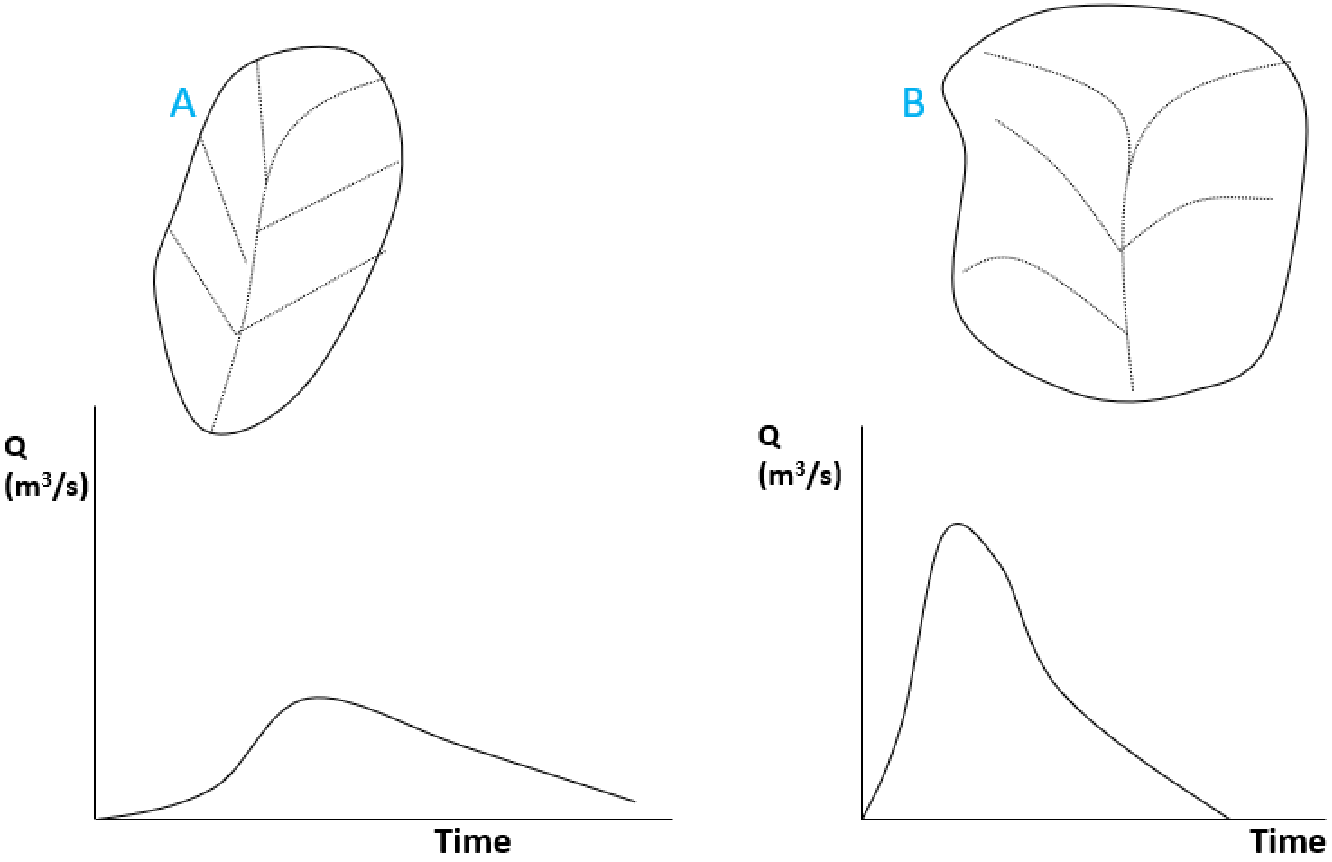


Characteristics of drainage basin

A)Shape and size of the basin

- There are **two types** of catchment in general.
  1. Fan shaped catchment
  2. Fern leaf shaped catchment

Rainfall-runoff relationships



Effect of catchment shape on runoff

Characteristics of drainage basin

A) Shape and size of the basin

- There are **two types** of catchment.
  1. Fan shaped catchment
  2. Fern leaf shaped catchment

Rainfall-runoff relationships

Characteristics of drainage basin

A) Elevation of the watershed

$$z = \frac{a_1 z_1 + a_2 z_2 + \dots + a_n z_n}{A} = \frac{\sum az}{A}$$

- where
  - A = area of the basin
  - z_i = values of **mean elevation** between 2 successive contours
  - a_i = areas between 2 successive contours

C)Other factors ;

- The arrangement of the stream channels formed,
- The type of the soil,
- The type of the vegetation cover, etc

Rainfall-runoff relationships

Important terms in runoff

- **Time of concentration (TOC), T_c** - the time required by the water to reach the outlet from the most remote part of the drainage basin called the **critical point**.

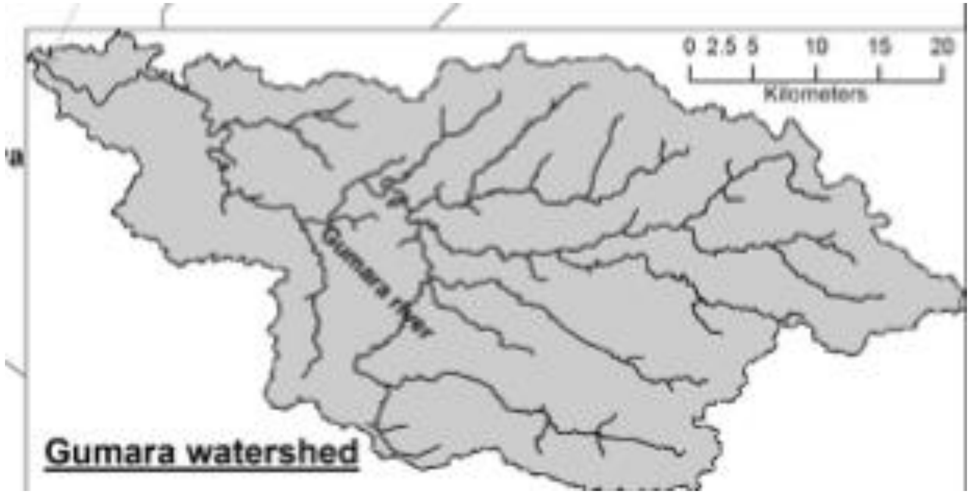
$$Tc = 0.019\ L0.77\ S - 0.385$$

….. called **kirpich equation**.

where; L is length of the longest stream.

S is slope of the catchment.

- **Time of overland flow (TOF) T_L** – is the time that needs the excess rainfall to find its way over land to the river stream and appears as surface runoff.
- **Hydrograph** - is a plot of **discharge** (direct runoff + baseflow) versus **time** at any section of river.



Source: [5] Derib, S.D. 2005

Rainfall-runoff relationships

- One of the popular methods is to make use of the available **rainfall-runoff data** to develop a relationship.
  - These relationships are used for homogeneous regions where flood-producing patterns are similar.
  - Stream flow records are short or rarely available.
- The relationships fall into **two categories**.

1. to compute **total runoff** using **total rainfall** in a given time.
2. to compute only **peak value** of runoff

Rainfall-runoff relationships

- We will see some commonly used **relationships** here:
  1. Rational Method (Peak discharge)
  2. US SCS Curve Number (Soil Conservation Services) method (for peak and total runoff)
  3. Rainfall-Runoff correlation
  4. Infiltration indices method
  5. Hydrograph analysis.
  6. Rainfall intensity and Time of Concentration
  7. Time-Area Methods (Total runoff in relation to total rainfall)
  8. Hydrological modeling

Rational Method

Rational Method is developed in mid-nineteenth century, originally developed for **urban catchments**.

- The rational approach considers the following **assumptions**:

  1. The peak rate of runoff is a function of the average rainfall rate during the **time of concentration**,
  2. Rainfall intensity is constant during the rainfall, or **uniformly spread** over an area.
  3. Rainfall occurs with a uniform intensity for the duration (**Temporal uniformity**)
  4. The rainfall intensity is uniformly distributed through the catchment (**spatial uniformity**).

Rational Method

Rational Method Mathematically expressed as:

$$Q_p = \sum_{i=1}^{n} C_i I_i A_i$$

$$\boldsymbol{Q_p = \frac{CIA}{3.6}} = 0.278\ C\ I\ A$$

OR, A = area is in **km²**

where,

- Q_p = peak flow [m^3/s]
- C = runoff coefficient
- I = intensity of rainfall, mm/hr
- A = drainage area, ha.
- The **C** values are dependent on the **topography**, **vegetation cover** and **soil characteristics** of the region.

Rational Method

- When the watershed has different features regarding **land use** and **soil** types:
  - then, the weighted value of runoff coefficient is determined.
- The value of weighted runoff coefficient (C) is given by:

$$C = \frac{C_1 a_1 + C_2 a_2 + C_3 a_3 + C_4 a_4 + C_5 a_5}{a_1 + a_2 + a_3 + a_4 + a_5}$$

$$C = \frac{\sum_{i=1}^{n} C_i a_i}{A}$$

- In which, A is the total area of watershed.

Rational Method

Values of C as a function of:

- land use,
- topography and
- soil type for use in rational Method

- NB: The value of C for completed paved area is 1.00.

Land use and topography	Soil Types		
	Sandy loam	Clay and siltloam	Tight clay
Cultivated land			
i) Flat	0.30	0.50	0.60
ii) Rolling	0.4	0.60	0.70
iii) Hilling	0.52	0.70	0.82
Pasture land			
i) Flat	0.10	0.30	0.40
ii) Rollin	0.16	0.36	0.55
iii) Hilling	0.22	0.42	0.60
Forest land			
i) Flat	0.10	0.30	0.40
ii) Hilling	0.30	0.50	0.60
Populated land			
i) Flat	0.40	0.55	0.65
ii) Rolling	0.50	0.65	0.80

Rational Method

Example 3:

Compute the value of weighted runoff coefficient of watershed from the following data regarding watershed characteristics.

- Cultivated land + flat topography + sandy soil …. **100ha**
- Pasture land + rolling topography + sandy soil….. **30 ha**
- Populated land + flat topography + sandy loam soil ….. **80 ha**

Land use and topography	Soil Types		
	Sandy loam	Clay and siltloam	Tight clay
Cultivated land			
i) Flat	0.30	0.50	0.60
ii) Rolling	0.4	0.60	0.70
iii) Hilling	0.52	0.70	0.82
Pasture land			
i) Flat	0.10	0.30	0.40
ii) Rollin	0.16	0.36	0.55
iii) Hilling	0.22	0.42	0.60
Forest land			
i) Flat	0.10	0.30	0.40
ii) Hilling	0.30	0.50	0.60
Populated land			
i) Flat	0.40	0.55	0.65
ii) Rolling	0.50	0.65	0.80

Rational Method

Example 3:

Compute the value of weighted runoff coefficient of watershed from the following data regarding watershed characteristics.

- Cultivated land + flat topography + sandy soil …. 100ha
- Pasture land + rolling topography + sandy soil….. 30 ha
- Populated land + flat topography + sandy loam soil ….. 80 ha

Given:

Land use/ topography	Area (ha)	C
1. Cultivated land + flat topography + sandy soil	100	0.30
2. Pasture land + rolling topography + sandy soil	30	0.16
3. Populated land + flat topography + sandy loam soil	80	0.40

Required: Weighted C

Soln:

$$C = \frac{C1A1 + C2A2 + C3A3}{A1 + A2 + A3}$$

$$\boldsymbol{C = \frac{100 * 0.3 + 30 * 0.16 + 80 * 0.4}{100 + 30 + 80}}$$

C=0.318 ....#

Rational Method

Example 4: An engineer is required to design a drainage system for an airport with an area of 2.5 km². The rainfall intensity in that region is given by:

$$I = \frac{35}{(t+10)^{0.38}}$$

where, I is intensity in cm/h and t is duration (time of concentration) in minutes.

If the concentration time for the area is estimated as 50 minutes,

what is **discharge** that must be used to design the system?

Given: Concentration time t_c = 50 min, A= 2.5 km^{2,} Intensity of rainfall,$I = \frac{35}{(t+10)^{0.38}} = \frac{35}{60^{0.38}} = \frac{35}{4.74} = \mathbf{7.384 cm/h}$ **…..#**

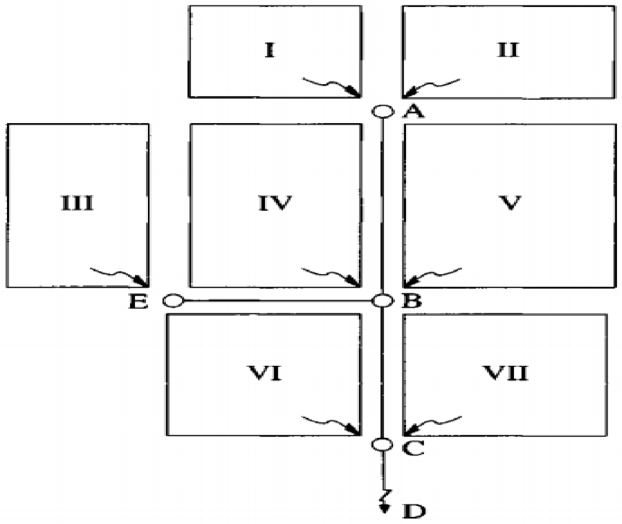
Since the airport is fully paved, it may be considered impervious and the runoff coefficient C may be taken as **unity.**

Required: Discharge Q_p = ? in $\boldsymbol{m^3/s}$

Solution: $Q_p = 2.778CAI = 2.778 \times 1 \times 2.5 \times 7.384 = \mathbf{51.25 m^3/s}$ **……#**

Rational Method

Exercise 1: A hypothetical drainage basin comprising seven sub catchmer is shown in the table and figure.



An inlet time of 10 minutes.

The rainfall intensity (in mm/hr) is given by:

$i = \frac{120T^{0.175}}{T_d+27}$, where

T is return period (5-year), and

T_d is rainfall duration in minutes (10 minutes).

The ground elevation difference between the end of each storm sewer and their length are also given on the second table. Assume Manning's n is 0.015.

Determine:

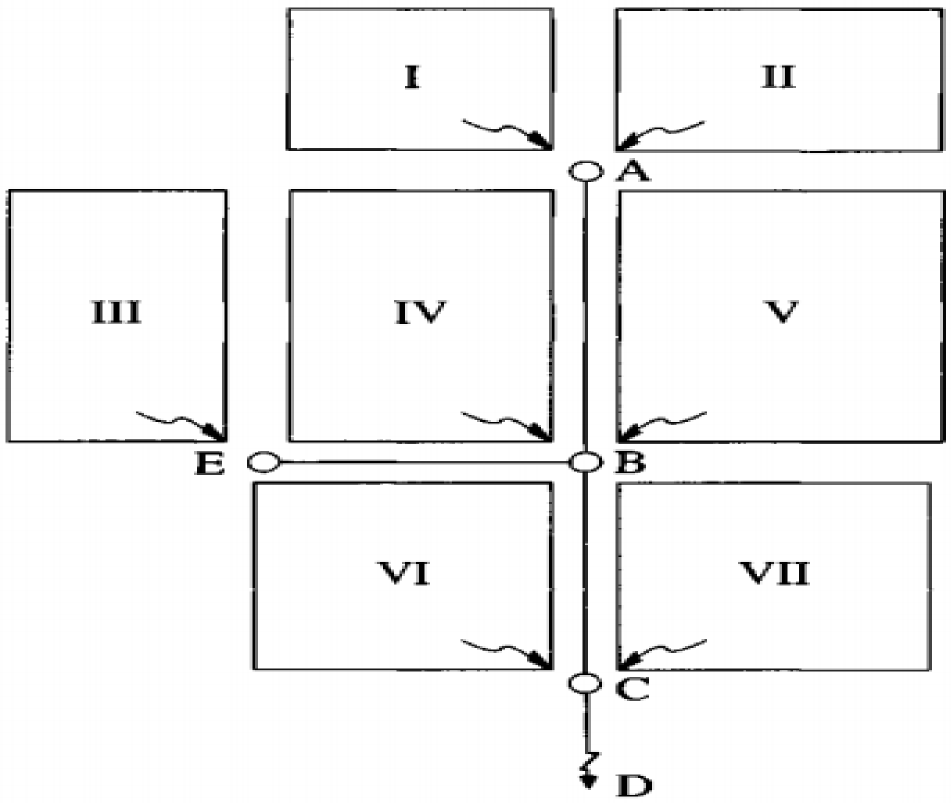
1) the **flow time** in each pipe.

2) the required **capacity** of each storm sewer.

Rational Method

Exercise **1:**

No.	Catc.	Area (m^2)	C
1	I	20,000	0.4
2	II	10,000	0.5
3	III	30,000	0.6
4	IV	5,000	0.6
5	V	7,000	0.5
6	VI	1,000	0.4
7	VII	2,000	0.3



No.	sewer	L (m)	End E (m)
1	AB	500	1210
2	EB	400	1208
3	BC	200	1206
4	CD	300	1200

References

[1] hsB-SM, https://czo-archive.criticalzone.org/images/made/images/national/photos-and-images/Jemez-Catalina/models/model_fig5_729_642_80auto.jpg

[2] https://gmd.copernicus.org/articles/14/6893/2021/gmd-14-6893-2021-avatar-web.png

[3]G.S. Dwarakish, G. B. and G. B. Puttaswamigowda 2015. Impact of land use change on hydrological systems: A review of current modeling approaches, Cogent Geoscience 1(1):1115691. DOI: 10.1080/23312041.2015.1115691

[4] Ojha, C.S.P., R. Berndtsson, and P. Bhunya, 2008. Engineering Hydrology, Oxford University Press ISBN: 978-0-19-569461-1

[5] Derib, S.D. 2015. Balancing water availability and water demand in the Blue Nile: A case study of Gumara watershed in Ethiopia. Ecology and Development Series. Bd 95. ISBN 978-3-940124-48-7

Thank you very much for your active attendance!!