Lecture (1)

(Weather and Hydrology)

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Introduction:

Hydrology is the study of the movement, distribution, and quality of water throughout the Earth, including the hydrologic cycle, water resources and environmental watershed sustainability. A practitioner of hydrology is a hydrologist, working within the fields of either earth or environmental science, physical geography, geology or civil and environmental engineering. Domains of hydrology include hydrometeorology, surface hydrology, hydrogeology, drainage basin management and water quality, where water plays the central role. Oceanography and meteorology are not included because water is only one of many important aspects.
The hydrologist studies the fundamental transport processes to be able to describe the quantity and quality of water as it moves through the cycle (evaporation, precipitation, streamflow, infiltration, ground water flow, and other components). The engineering hydrologist, or water resources engineer, is involved in the planning, analysis, design, construction and operation of projects for the control, utilization, and management of water resources. Water resources problems are also the concern of meteorologists, oceanographers, geologists, chemists, physicists, biologists, economists, political scientists, specialists in applied mathematics and computer science, and engineers in several fields.

Problems in Hydrology:

- Extreme weather and rainfall variation
- Streamflow and major flood devastation
- River routing and hydraulic conditions
- Overall water supply - local and global scales
- Flow and hydraulics in pipes, streams and channels
- Flood control and drought measures
- Watershed management for urban development

The Hydrological data is normally required:

- Weather records (temperature, humidity, wind speed),
- Precipitation data,
- Stream-flow records,
- Evaporation and transpiration data,
- Infiltration characteristics of the area,
- Groundwater characteristics,
- Physical and geological characteristics.

Application of Hydrology Engineering:

- Planning and operation of Hydraulic Structures for control and use of Water.
- Forecasting the flood discharge over a spillway, and other hydraulic structures
- designing the urban storm sewer system,
- forecasting the reservoir capacity to comfort adequate quantity of water for multipurpose uses,
- finding the effect of flood discharge or stream on the reservoirs, canals, and other control works, and selecting the practical boundaries for the flood plain.

The Hydrologic Cycle:

The hydrological cycle represents water circulation and transformation in the three parts of the earth system: atmosphere, hydrosphere, and lithosphere. The atmosphere is a gaseous envelope above the earth surface. The hydrosphere is the water body on earth surface, and the lithosphere is a solid rock under the hydrosphere. Since the water is renewable substance/material the hydrological cycle has no beginning or end. The water evaporates from the land and the oceans and as a water vapor becomes a part of the atmosphere. The water vapor rises due to orographic lifting, frontal lifting, and convective air heating. It cools, condenses, and finally precipitates to the earth (land and oceans). The precipitated water (rain,snow) may be intercepted or transpired by plants, may run over the ground surface and in the streams, or may infiltrate into the ground. Thus, the hydrological cycle may be described as a simple link between different arcs, but represents also very complicated processes of evapotranspiration, precipitation, infiltration, percolation, and runoff, Figure(1) ., The water quantities in hydrological cycle may be evaluated by the simple water balance equation, which is known also as hydrological equation:

$$I - O = \Delta S \qquad (1.1)$$

where I is the inflow over a given period (total precipitation over the area, total inflow runoff, total groundwater inflow), O is outflow (evaporation, transpiration, total surface outflow, groundwater outflow, water use), and ΔS is the change in storage.

Hydrologic Budget Equation for Urban Drainage:

For urban drainage system,ET(evapotranspiration) is often neglected,

P-I-R-D= 0 ………………(1.2)

Where:

P= precipitation

I = infiltration

R = direct runoff

D= combination of interception and depression storage

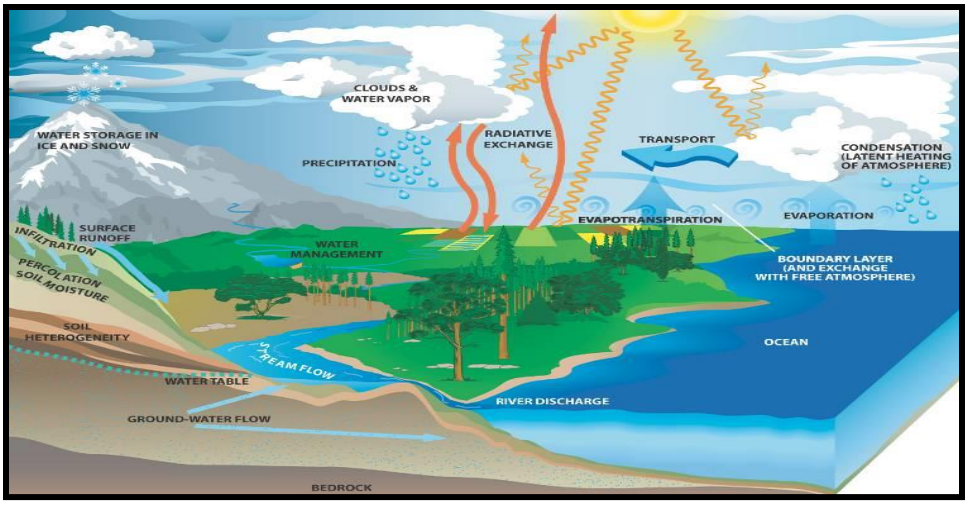


Fig. (1) The Hydrologic Cycle

Example (1): In *a given year, a 10,000 Km^2 watershed received 30 cm of precipitation. The annual rate of flow measured in the river draining the area is 60 m^3/sec. Estimate the Evapotranspiration. Assume negligible change of storage and net groundwater flow*.

Solution:

Combining E and T, then ET = P – R

Volume due to runoff = 60 m^3/s x 86400 sec/day x 365 day/yr = 1.89216 x 10^9 m^3

= 1.89216 x 10^9 m^3 x (100 cm/m)^3 = 1.89216 x 10^{15} cm^3

Equivalent depth = volume of water / area of watershed

= 1.89216 x 10^{15} / [(10,000) (100,000 cm/km)^2] = 18.92 cm

Amount of Evapotranspiration ET = P – R = 30 – 18.92 = 11.08 cm /yr

Example (2): The drainage area of a river in a city is 11,839 km^2. If the mean annual runoff is determined to be 144.4 m^3/s and the average annual rainfall is 1.08 m, estimate the ET losses for the area. Assume negligible changes in groundwater flow and storage.

Solution:

ET = P – R,

R = [144.4 m3/s x 86400 s/day x 365 day/yr] / [11,839 km2 x 106 m2/km2] = 0.38 m

ET = P – R = 1.08 – 0.38 = 0.7 m

Example (3): A small catchment of area 150 ha received a rainfall of 105 mm in 90 minutes due to a storm. At the outlet of the catchment, the stream draining the catchment was dry before the storm and experienced a runoff lasting for 10 hours with an average discharge value of 2.0 m^3/sec. the stream was again dry after the runoff event.

1. What is the amount of water which was not available to runoff due to combined effect of infiltration, evaporation and transpiration.
2. What is the ratio of runoff to precipitation?

Solution :

Losses = 157,000 - 72,000 = 85,500 m^3 = Water not available to runoff.

The water budget equation for the catchment in a time Δt is :

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

Rainfall occurred in 90 minutes and the rest (8.5 hours) the precipitation was zero.

$\Delta S = 0$

1. G + E + T = water not available to runoff = Losses = L

Hence : P - R = L

P = Precipitation = 150x100x100x10.5/100 = 157,500 m^3

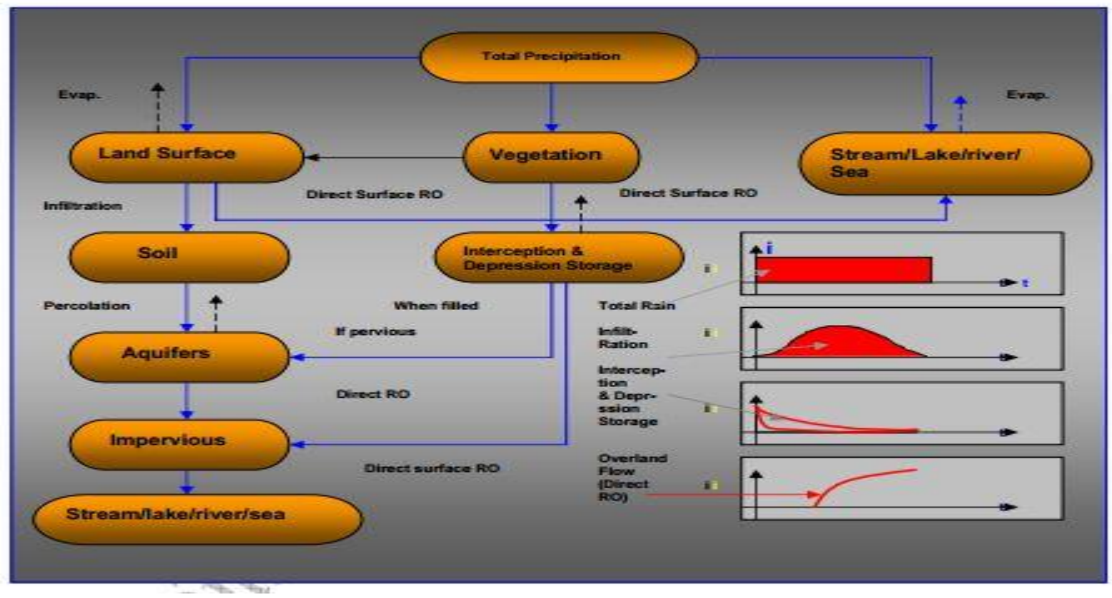
R = Runoff volume = 2.0x10x60x60= 72,000 m^3

2. Runoff/rainfall = 72,000/157,500 = 0.457

Precipitation:

The mass of water or ice that falls to earth is called *precipitation*. Rain and snow are of greatest importance to hydrology and engineering, especially their amount and distribution. The precipitation is related to the condensation of water vapor in the atmosphere. The rain is a liquid precipitation and can be classified as drizzle, light rain, moderate rain, and heavy rain. Drizzle is a fine sprinkle of very small and rather uniform water drops with diameter less than 0.5 mm and its falling intensity is <0.1 cm/h. Heavy rain intensity is >0.8 cm/h. Freezing rain is called glaze and it appears when rain falls into a cold air and freezes when it strikes the ground. Other forms of precipitation that are significant in meteorology include snow, hail, sleet, mist and fog. Snow is precipitation of solid water, mainly in the shape of branched hexagonal crystals, or stars. Hail consists of concentric layers of ice that build up to large diameters due to buffeting and continued suspension by turbulence in the moisture and freezing atmosphere. Sleet is melting snow or a mixture of snow and rain. Mist and fog are airborne droplets that remain suspended in the air because they are so small. Since the precipitation is caused by water vapor condensation in the clouds, one should know more about clouds. The basic groups of clouds are cirrus, cumulus, and stratus. Some the other types of clouds are altocumulus, altostratus, nimbus, cumulonimbus, and nimbostratus.

Distribution of Precipitation:

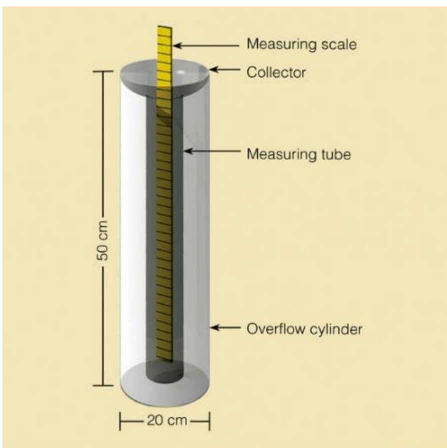


Measurement of Precipitation:

Precipitation is expressed in terms of the depth to which rainfall water would stand on an area if all the rain were collected on it. The precipitation is collected and measured in a rain *gage*.

Non-recording Gauges

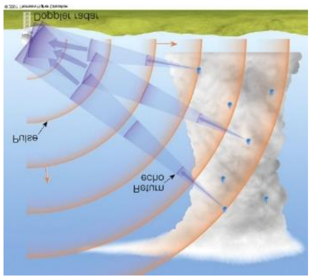
A rain gauge is a weather tool used to collect rain. Using measurements on the side of the rain gauge, you can see how many inches (or mm) it rained.



Recording Gauges

- *Tipping—Bucket Type*
- *Weighing—Bucket Type*
  Float — Syphon Type

Radar and Precipitation



- **rader**
- **Doppler radar**

Weather Systems for Precipitation:

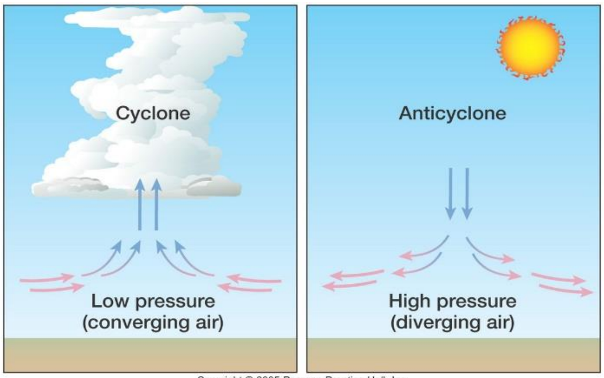
1. Cyclonic Precipitation

Lifting of moist air converging into a large low pressure area with circular wind motion.

Two types of cyclones are recognized:

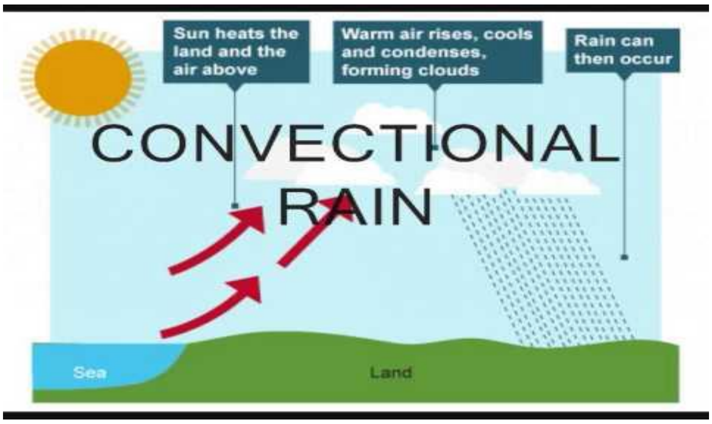
a-tropical cyclones , and

b- extra tropical cyclones.



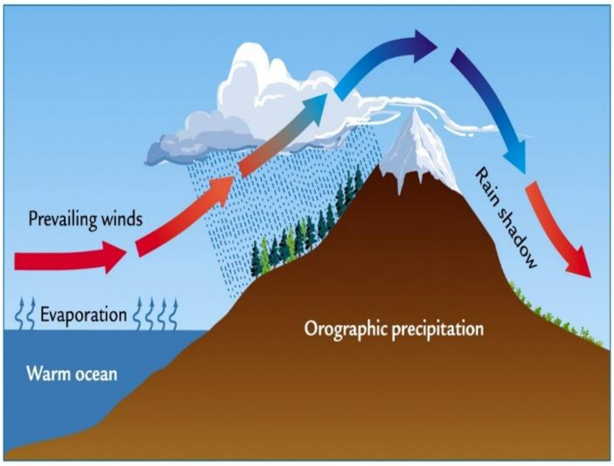
2- Convective Precipitation

In this type of precipitation, a packet of air which is warmer than surrounding air due to localized heating rises because of its lesser density. Air from cooler surroundings flows to take up its place thus setting up a convective cell. The warm air continues to rise, undergoes cooling and results in precipitation.



3- Orographic Precipitation

The moist air masses may get lifted-up to higher altitudes due to the presence of mountain barriers and consequently undergo cooling, condensation and precipitation. *Such* a precipitation is known as *Orographic precipitation*



Methods of Estimating Areal Precipitation in the Ground:

The records of rainfall gauges are expected to represent a large area. Low accuracy is expected if one-gauge record data is used. The amount of precipitation can be estimated more accurately if more than one gauge is in or near the area of interest. The average precipitation over a region may be estimated by different methods: arithmetic average method, *Thiessen* polygon method, and isohyetal method.

1. Arithmetic Mean:

The simplest means of calculating the average precipitation. It is accomplished by summing up all precipitation values and the sum is divided by the total number of gauges. The method is satisfactory for flat areas having relatively large number of gauges, Individual variations must not be far from mean rainfall .The arithmetic method is not accurate for large area where rainfall distribution is variable

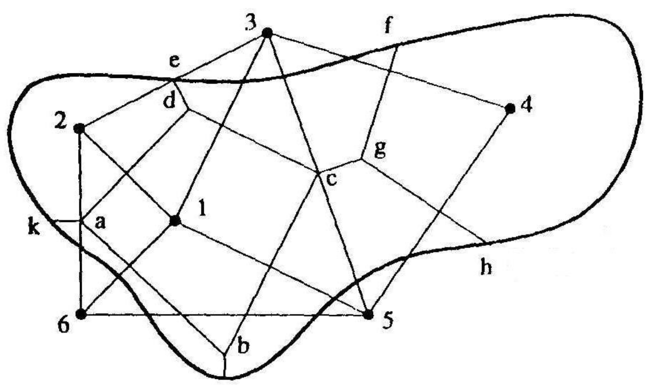
$$\overline{P} = \frac{P_1 + P_2 + \ldots + P_i + \ldots P_n}{N}$$

$$= \frac{1}{N}\sum_{I=1}^{N} P_i$$

2. Theisson Polygon:

The method provides weighing factor for each gauge by enabling data from adjacent areas to be incorporated in the mean. The method is accomplished by constructing perpendicular bisectors through straight lines joining adjacent gauges, leaving each gauge in the center of each polygon. The average precipitation is computed by multiplying the precipitation of each station by its assigned area and totaling. The average precipitation is then obtained by dividing the total by the area of the watershed.

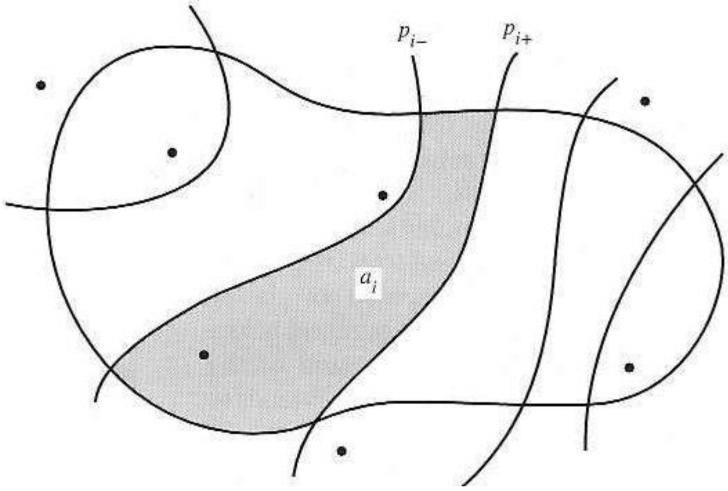
$$\overline{P} = \frac{\sum_{i=1}^{M} P_i A_i}{A} = \sum_{i=1}^{M} P_i \frac{A_i}{A}$$



3. Isohyetal Method:

This method provides the most accurate estimate of average precipitation. The method is accomplished by drawing the isohyets of equal precipitation. The isohyets by the average precipitation between the two and totaling. The average is obtained by dividing the total by the area of the watershed average precipitation is computed by multiplying the area between each

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



FREQUENCY OF POINT RAINFALL:

(a) The probability of an event of exceedence probability (*P)* occurring 2 times in n successive years is;

$$P_{2,n}=\frac{n!}{(n-2)!2!}P^2q^{n-2}$$

(b) The probability of the event not occurring at all in , successive years is;

$$P_{0,n}=q^n=(1-P)^n$$

(c) The probability of the event occurring at least once in n successive years;

$$P_1=1-q^n=1-(1-P)^n$$

EXAMPLE 2.7 *Analysis of data on maximum one-day rainfall depth at Madras indicated that a depth of 280 mm had a return period of 50 years. Determine the probability of a one-day rainfall depth equal to or greater than 280 mm at Madras occurring (a) once in 20 successive years, (b) two times in 15 successive years, and (c) at least once in 20 successive years.*

SOLUTION: Here $P = \frac{1}{50} = 0.02$

By using Eq. (2.12):

(a) $n = 20, r = 1$

$$P_{1,20} = \frac{20!}{19!1!} \times 0.02 \times (0.98)^{19} = 20 \times 0.02 \times 0.68123 = 0.272$$

(b) $n = 15, r = 2$

$$P_{2,15} = \frac{15!}{13!2!} \times (0.02)^2 \times (0.98)^{13} = 15 \times \frac{14}{2} \times 0.0004 \times 0.769 = 0.323$$

(c) By Eq. (2.13)

$$P_1 = 1 - (1 - 0.02)^{20} = 0.332$$

Computing IDF curves:

1. Computation from rainfall records
2. Wenzel method
3. Chen method

Computation from rainfall records:

1. Choose duration Δt and determine maximum rainfall depths for this duration in each year.
2. Rank the precipitation amounts from high to low
3. Compute the return period.

$$p(x > x_m) = \frac{m}{n+1} \quad \Rightarrow \quad T = \frac{n+1}{m}$$

4.Repeat for the next duration.

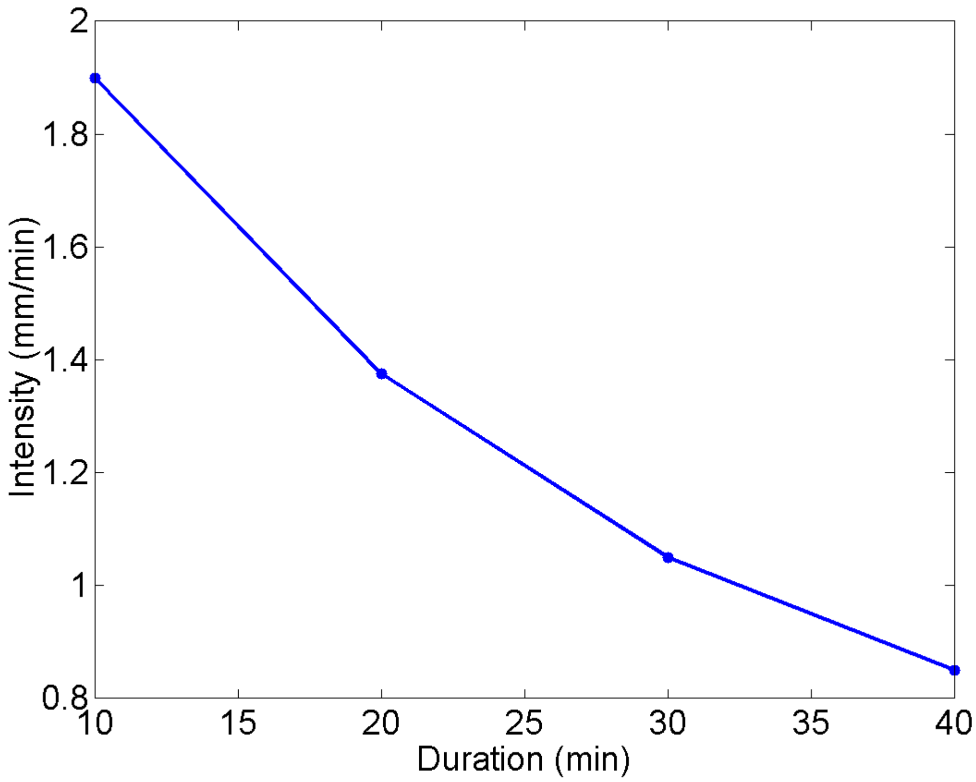
5.Interpolate to the desired return period

6.Compute intensity = depth/duration.

Example: Given 39 year record, top two depths (mm) are listed. Calculate intensity vs. duration for 30-year storm.

Solution:

Rank	T(year)	10	20	30	40
1	40	20	30	34	36
	30	19	27.5	31.5	34
2	20	18	25	29	32



References:

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- V. T. Chow, and others (1988), Applied Hydrology.
- P. Jaya Rami Reddy (2013), A Textbook of Hydrology