HYDROLOGY

UNIT-1

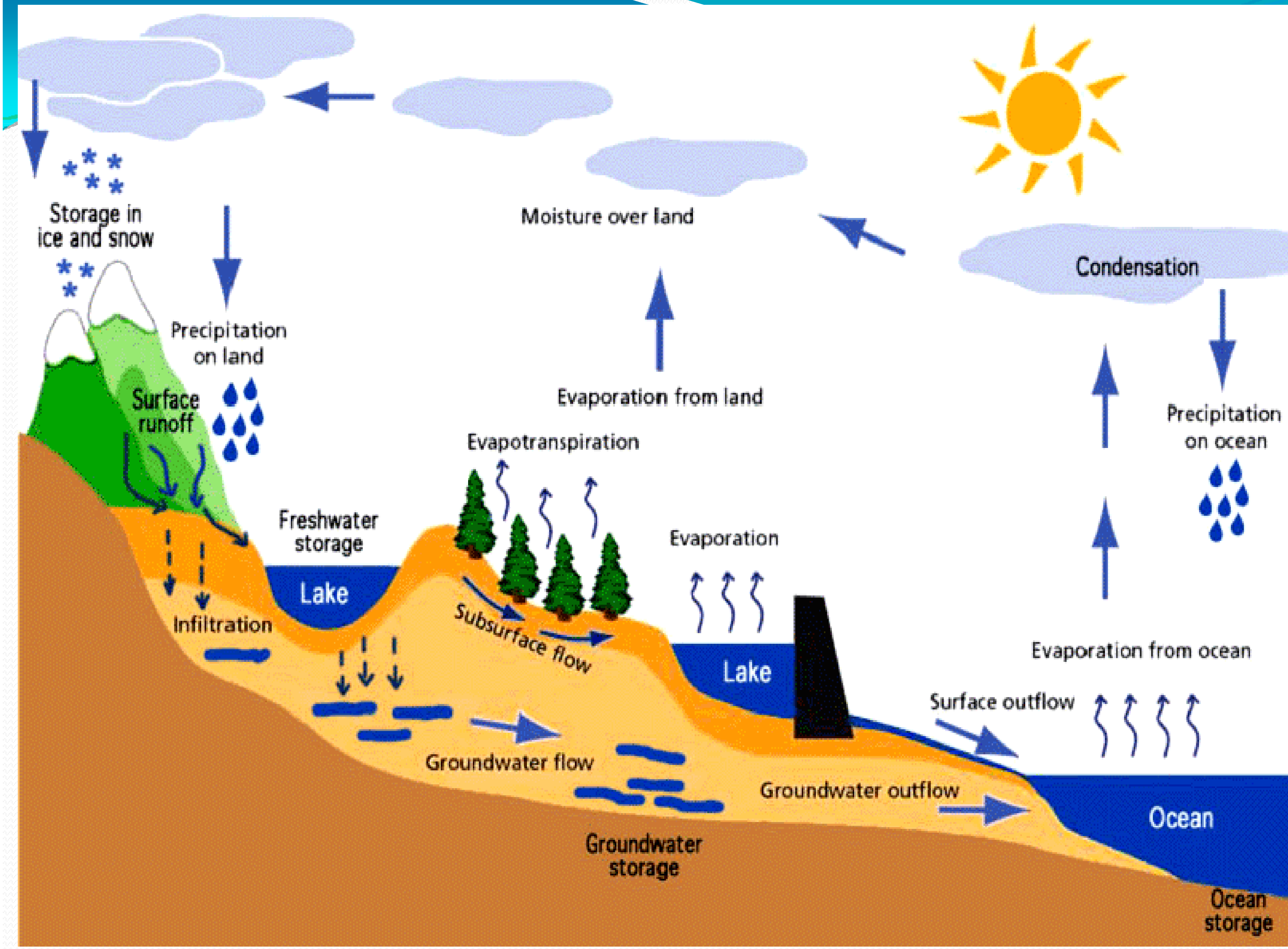
INTRODUCTION

Hydor + logos (Both are Greek words)

“Hydor” means water and **“logos”** means study.

Hydrology is a branch of Earth science which deals with the occurrence, circulation and distribution of water of the earth and earth’s atmosphere. It is basically an applied science.

Hydrological Cycle: It is also known as water cycle. The hydrologic cycle is a continuous process in which water is evaporated from water surfaces and the oceans, moves inland as moist air masses, and produces precipitation, if the correct vertical lifting conditions exist.



Storage in ice and snow
Precipitation on land
Surface runoff
Moisture over land
Evaporation from land
Condensation
Precipitation on ocean
Evapotranspiration
Freshwater storage
Lake
Infiltration
Subsurface flow
Evaporation
Lake
Evaporation from ocean
Surface outflow
Groundwater flow
Groundwater outflow
Ocean
Groundwater storage
Ocean storage

DRAINAGE BASIN

•Also known as catchment area or drainage area.

•It is the area of land draining into a stream or a water course at a given location.

• In USA, it is known as watershed.

•The drainage basin acts as a funnel by collecting all the water within the area covered by the basin and channeling it to a single point. Each drainage basin is separated topographically from adjacent basins by a geographical barrier such as a ridge, hill or mountain.

•Drainage basins are open systems. Inputs to these systems include precipitation, snow melt, and sediment. Drainage basins lose water and sediment through evaporation, deposition, and stream flow

INFLUENCE OF HUMAN ACTIVITIES AND LAND USE CHANGES ON HYDROLOGIC CYCLE

Watersheds are subjected to many types of changes, major or minor, for various reasons. Some of these are natural changes and some are due to human activities. Watershed changes affect virtually all elements of the hydrologic cycle. The quality of water is significantly deteriorating at many places due to industrial and agricultural activities. There has been a growing need to quantify the impact of major human-induced changes on the hydrologic cycle in order to anticipate and minimize the potential environmental detriment and to satisfy water resources requirements of the society. Even if the water of adequate quantity were present at a place, its use may be limited because of poor quality.

UNIT-2

PRECIPITATION

WHAT IS PRECIPITATION?

The term precipitation denotes all forms of water that reach the Earth from the atmosphere.

For precipitation to form:

i) The atmosphere must have moisture
ii) There must be sufficient nuclei present to aid condensation
iii) Weather conditions must be good for condensation of water vapors to take place.
iv) The products of condensation must reach the earth.

FORMS OF PRECIPIATTION

•**Rain:** Water drops that have a diameter of at least 0.5 mm. It can be classified based on intensity as:

Light rain	up to 2.5 mm/h
Moderate rain	2.5 mm/h to 7.5 mm/h
Heavy rain	> 7.5 mm/h

•**Snow:** Precipitation in the form of ice crystals which usually combine to form flakes, with an average density of 0.1 g/cm^3.

•**Drizzle:** Rain-droplets of size less than 0.5 mm and rain intensity of less than 1mm/h is known as drizzle.

•**Glaze:** When rain or drizzle touches ground at 0^oC, glaze or freezing rain is formed.

•**Sleet:** It is frozen raindrops of transparent grains which form when rain falls through air at subfreezing temperature.

•**Hail:** It is a showery precipitation in the form of irregular pellets or lumps of ice of size more than 8 mm.

MEASUREMENT OF PRECIPITATION

- It is expressed in terms of the depth to which rainfall water would stand on an area if all the rain were collected on it.
- 1cm of rainfall over a catchment area of 1 km^2 represents a volume of water= 10^4 m^3.
- It is collected and measured in a Rain gauge/ pluvimeter/ ombrometer/ hyetometer.
- Types of rain gauges:

1) **Non-Recording**
   - ✓Symon's gauge
2) **Recording**
   - ✓Tipping-bucket type
   - ✓Weighing-bucket type
   - ✓Natural-syphon type

RAIN GAUGE NETWORK

Rainfall data is the most important and fundamental data required for all hydrological investigations.

Catch area of a rain gauge is very small compared to the aerial extent of a storm. Hence to get a representative picture of a storm over the entire drainage basin, the number of rain gauges should be as large as possible (drainage area/rain gauge should be small).

The rain gauge network should consist of adequate number of rain gauges evenly distributed all over the drainage basin.

However the number of rain gauges is many a time restricted by economic considerations as well as topography, accessibility etc.

Desired density would also depend on the purpose.

Aim: Establish a rain gauge network with an optimum density of rain gauges from which a reasonably accurate information about storms can be obtained

PRESENTATION OF RAINFALL DATA

1) Mass Curve of Rainfall

- It is a plot of accumulated precipitation against time, plotted in chronological order.
- Records of float type, weighing bucket type etc rain gauges are of this form.
- It gives information on duration and magnitude of a storm. Intensity at various time intervals in a storm = slope of the curve.
- It can be prepared for non-recording rain gauges also if the approximate start and end of a storm are known.

2) Hyetograph

- It is a plot of rainfall intensity against time interval.
- Time interval depends on the purpose (urban drainage problems – small durations, flood flow computations from large catchments~ 6h).
- It can be derived from the mass curve of rainfall.
- It is represented as a bar chart.
- It is useful in developing design storms to predict extreme floods.
- Area under a hyetograph = total precipitation received in that time period.

MEAN PRECIPITATION OVER AN AREA

Raingauge – does point sampling of the areal distribution of a storm
Hydrological Analysis – requires information on rainfall over an area, say, over a catchment
Methods used to convert point rainfall values at different raingauge stations into an average value over a catchment include

- Arithmetical Mean Method
- Thiessen Polygon Method
- Isohyetal Method

UNIT-3

EVAPORATION AND TRANSPIRATION

EVAPORATION AND EVAPOTRANSPIRATION

Evaporation and transpiration constitute the primary abstractions of water from the hydrologic cycle. It will be helpful to define these first. Evaporation is the process by which water is changed from the liquid or solid state into the gaseous state due to the involvement of heat energy. Evaporation is an important component of the hydrologic cycle, since a large fraction of the precipitation is returned to the atmosphere by this process. Transpiration is a natural process

occurring in plants in which water is picked up from the soil moisture storage by the plant roots. This water is used in photosynthesis and it is finally evaporated from stomata which are the pores found in the leaf and stem epidermis of the plants and are used for gas exchange.

Evaporation takes place mainly due to heat energy and plants play the main role in transpirations. The combined effect of evaporation and transpiration is termed as evapotranspiration (ET). In hot climates, the transfer of water to atmosphere by evaporation from rivers, canals and surface-water storages (reservoirs & ponds) is of interest to hydrologists since evaporation is a significant proportion of all water supplies. It is significant and is concern in the sense that most of the water withdrawn from the sources for beneficial uses ultimately returns to streams and aquifers and becomes available for reuse, while the loss of water due to evaporation is entirely lost from the usable supply, at least for considerable time.

Over large land areas in India, about two thirds of the annual precipitation is lost to atmosphere through evapotranspiration. In arid regions of India, evapotranspiration may be even more significant and up to 90 per cent of the annual rainfall may be lost to the atmosphere. Problem of evaporation is more serious in periods of droughts when aridity is high. Storage reservoirs expose large water surfaces to direct radiation which causes evaporation and thus large quantity of water may be lost, particularly during hot and dry season. During flood season, reservoirs may lessen evaporation because water is confined to deep storages rather than thinly spreading over wide flood plains.

The meteorological factors controlling evaporation are air and water temperature, wind speed, atmospheric pressure, incoming solar radiation, humidity, and saturation vapor pressure deficit. In addition, water quality, depth, soil type and nature also influence evaporation. Meteorological factors that affect transpiration are essentially the same as for evaporation. In addition, vapour pressure gradient, available soil moisture and plant properties also affect transpiration. There is an important difference between ET and free surface evaporation. Transpiration is associated with plant growth (trees in a mature forest may grow slowly) and hence ET takes place only when the plant is growing. Thus transpiration has diurnal and seasonal variations. Consequently, ET will have seasonal variations. Evaporation also has large seasonal variations due to changes in radiation received and in other meteorological inputs.

MEASUREMENT OF EVAPORATION

Selection of a method for estimation of evaporation depends on the study area and its properties. Evapotranspiration from small water bodies and soil can be estimated with reasonable accuracy.

However, direct measurement of evaporation and evapotranspiration from large water bodies or catchments is not possible with present technology. For this purpose, indirect methods are applied and they give acceptable results. Evaporation pans and lysimeters are used for this purpose. For existing reservoirs and plots or small catchments, estimates can be made by water budget, energy-budget, and aerodynamic approaches. These latter techniques are discussed only from the point of view of instruments and observational requirements.

TRANSPIRATION

It is the process where water contained in liquid form in plants is converted to vapor and released to the atmosphere. Much of the water taken up by plants is released through transpiration. It is difficult to separate the processes of evaporation and transpiration, so this transfer of water is sometimes simply called evapotranspiration. The U.S. EPA estimates that an acre of corn transpires 4000 gallons of water each day.

Evapotranspiration (ET)

It is the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves. Evapotranspiration is an important part of the water cycle. An element (such as a tree) that contributes to evapotranspiration can be called an **evapotranspirator**

UNIT-4

INFILTRATION

INFILTRATION

It is the process by which water on the ground surface enters the soil. Infiltration rate in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation. It is measured in inches per hour or millimeters per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. It is related to the saturated hydraulic conductivity of the near-surface soil. The rate of infiltration can be measured using an infiltrometer.

INTERCEPTION

Interception refers to precipitation that does not reach the soil, but is instead intercepted by the leaves and branches of plants and the forest floor. It occurs in the canopy (i.e. canopy interception), and in the forest floor or litter layer (i.e. forest floor interception). Because of evaporation, interception of liquid water generally leads to loss of that precipitation for the drainage basin, except for cases such as fog interception. Intercepted snowfall does not result in any notable amount of evaporation, and most of the snow falls off the tree by wind or melts. However, intercepted snow can more easily drift with the wind, out of the watershed. Conifers have a greater interception capacity than hardwoods. Their needles gives them more surface area for droplets to adhere to, and they have foliage in spring and fall, therefore interception also depends on the type of vegetation in a wooded area. Interception may increase erosion or reduce it depending on the throughfall effects.

INFILTRATION CAPACITY

The infiltration capacity of a soil is dependent on a variety of soil properties, including the soil chemistry, water temperature and quality, vegetative cover, and reduction of top soil. The relationship between the latter two and infiltration capacity make this a good integrative indicator of soil quality.

INITIAL LOSS

In the precipitation reaching the surface of catchment, the major reduction in volume of water available for runoff is through infiltration. Apart from infiltration, there are two other processes that contribute to this reduction in volume. These two processes are

- Interception.
- Depression Storage.

Together they are called as *Initial loss*.

However, the reduction in volume of available water through initial loss is of less magnitude.

DEPRESSION STORAGE

When the precipitation of a storm or rain reaches the surface of catchment, it must first fill up all the depressions on the catchment before it can flow over the surface. The volume of water stored in these depressions is known as *depression storage*.

UNIT-5

RUNOFF

WATERSHED

The watershed is the basic unit used in most hydrologic calculations relating to water balance or computation of rainfall-runoff .

The watershed boundary (Divide) defines a contiguous area, such that the net rainfall or runoff over that area will contribute to the outlet .

The rainfall that falls outside the watershed boundary will not contribute to runoff at the outlet .

CHARACTERISTICS OF WATERSHED

- **Size:** It helps in computing parameters like rainfall received, retained, amount of runoff etc.
- **Shape:** Based on the morphological parameters such as geological structure eg. peer or elongated .
- **Slope:** Reflects the rate of change of elevation with distance along the main channel and controls the rainfall distribution and movement .
- **Drainage:** Determines the flow characteristics and the erosion behavior .
- **Soil type:** Determines the infiltration rates that can occur for the area .
- **Land use and land cover:** It can affect the overland flow of the rainwater with the improve in urbanization and increased pavements.
- **Main channel and tributary characteristics:** It can effect the stream flow response in various ways such as slope, cross-sectional area, Manning's roughness coefficient, presence of obstructions and channel condition .

HOW DOES RUNOFF OCCUR?

When rainfall exceeds the infiltration rate at the surface, excess water begins to accumulate as surface storage in small depressions. As depression storage begins to fill, overland flow or sheet flow may begin to occur and this flow is called as "Surface runoff"

RUNOFF MAINLY DEPENDS UPON

Amount of rainfall, soil type, evaporation capacity and land use :**Amount of rainfall:** The runoff is in direct proportion with the rainfall. i.e. as the rainfall increases, the chance of increase in runoff will also increases

Soil type: Infiltration rate depends mainly on the soil type. If the soil is having more void space (porosity), than the infiltration rate will be more causing less surface runoff (eg. Laterite soil)

Evaporation capacity: If the evaporation capacity is more, surface runoff will be reduced

UNIT-6

HYDROGRAPH

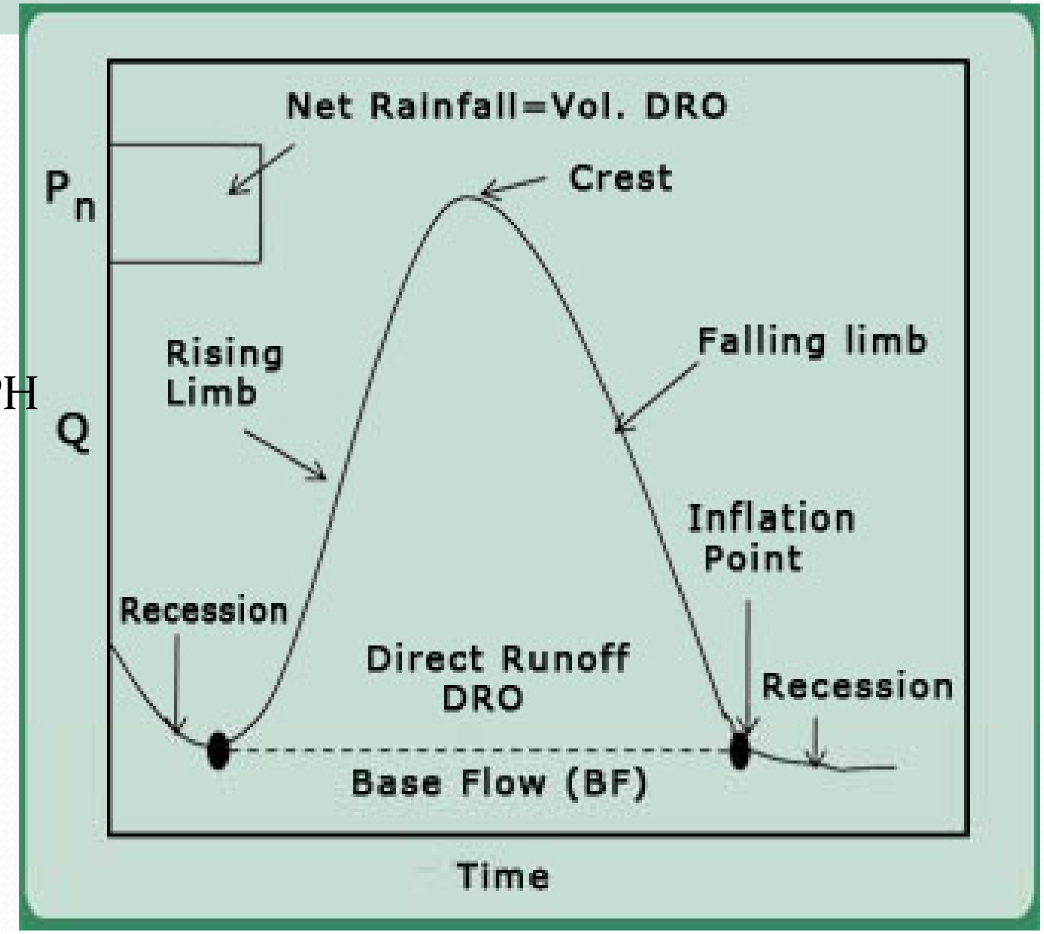
DEFINITION

Hydrograph is a continuous plot of instantaneous discharge v/s time. It results from a combination of physiographic and meteorological conditions in a watershed and represents the integrated effects of climate, hydrologic losses, surface runoff, interflow, and ground water flow.

FACTORS THAT INFLUENCE THE HYDROGRAPH SHAPE AND VOLUME

- Meteorological factors
- Physiographic or watershed factors and
- Human factors

A TYPICAL HYDROGRAPH



UNIT HYDROGRAPH (UH)

- The unit hydrograph is the unit pulse response function of a linear hydrologic system.
- First proposed by Sherman (1932), the unit hydrograph (originally named unit-graph) of a watershed is defined as a direct runoff hydrograph (DRH) resulting from 1 in (usually taken as 1 cm in SI units) of excess rainfall generated uniformly over the drainage area at a constant rate for an effective duration.
- Sherman originally used the word “unit” to denote a unit of time. But since that time it has often been interpreted as a unit depth of excess rainfall.
- Sherman classified runoff into surface runoff and groundwater runoff and defined the unit hydrograph for use only with surface runoff.

The unit hydrograph is a simple linear model that can be used to derive the hydrograph resulting from any amount of excess rainfall. The following basic assumptions are inherent in this model :

1.Rainfall excess of equal duration are assumed to produce hydrographs with equivalent time bases regardless of the intensity of the rain.

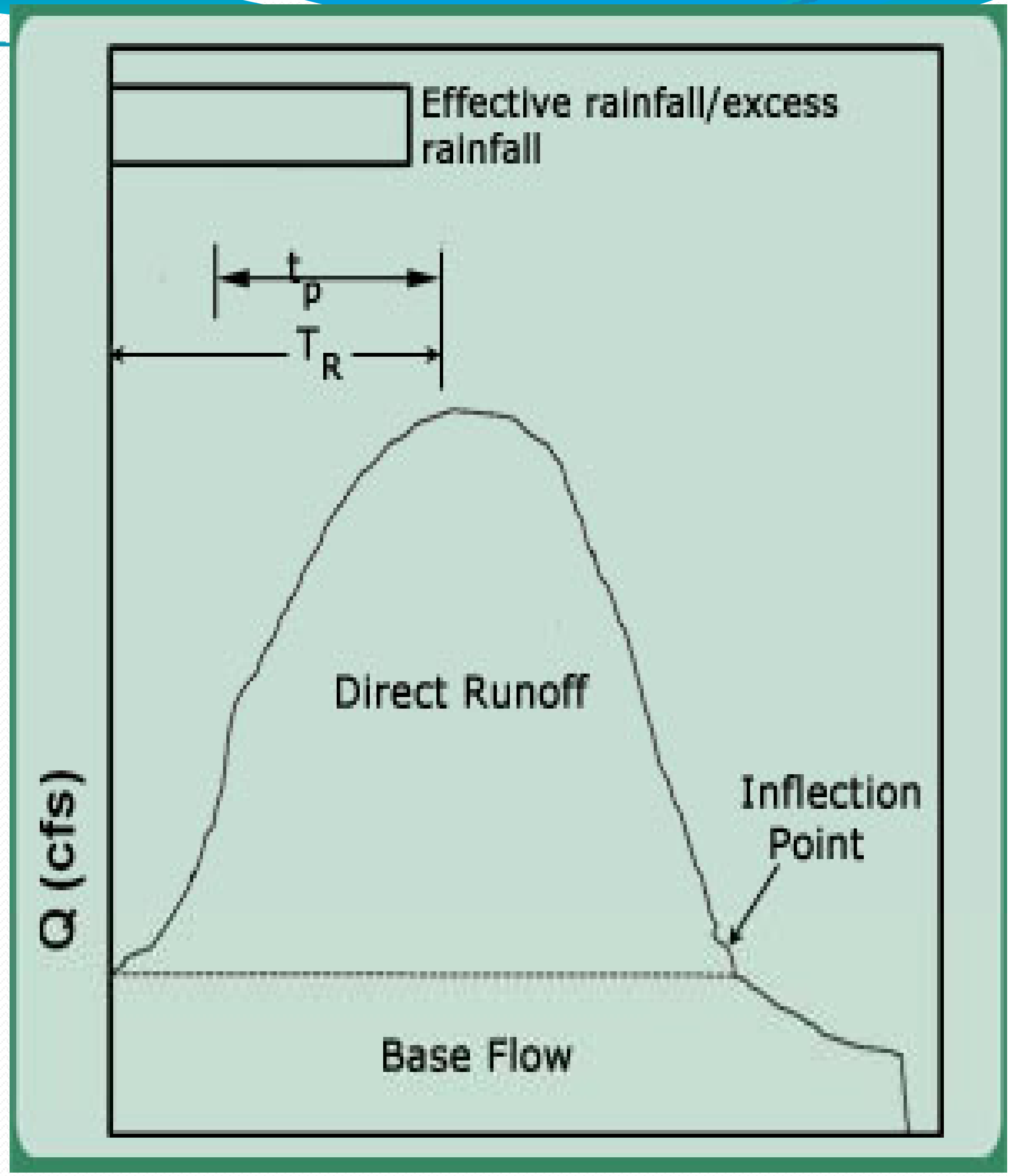
2.Direct runoff ordinates for a storm of given duration are assumed directly proportional to rainfall excess volumes.

3.The time distribution of direct runoff is assumed independent of antecedent precipitation.

4.Rainfall distribution is assumed to be the same for all storms of equal duration, both spatially and temporally.

TERMINOLOGIES IN UH

- Duration of effective rainfall : the time from start to finish of effective rainfall
- Lag time (L or t_p): the time from the center of mass of rainfall excess to the peak of the hydrograph
- Time of rise (T_R): the time from the start of rainfall excess to the peak of the hydrograph
- Time base (T_b): the total duration of the DRO hydrograph



ESSENTIAL STEPS FOR DEVELOPING UH FROM SINGLE STORM HYDROGRAPH

1. Analyze the hydrograph and separate base flow .
2. Measure the total volume of DRO under the hydrograph and convert time to inches (mm) over the watershed.
3. Convert total rainfall to rainfall excess through infiltration methods, such that rainfall excess = DRO, and evaluate duration D of the rainfall excess that produced the DRO hydrograph.
4. Divide the ordinates of the DRO hydrograph by the volume in inches (mm) and plot these results as the UH for the basin. Time base Tb is assumed constant for storms of equal duration and thus it will not change.
5. Check the volume of the UH to make sure it is 1.0 in.(1.0mm), and graphically adjust ordinates as required.

SYNTHETIC UNIT HYDROGRAPH

In India, only a small number of streams are gauged (i.e., stream flows due to single and multiple storms, are measured)

There are many drainage basins (catchments) for which no stream flow records are available and unit hydrographs may be required for such basins .

In such cases, hydrographs may be synthesized directly from other catchments, which are hydrologically and meteorologically homogeneous, or indirectly from other catchments through the application of empirical relationship .

Methods for synthesizing hydrographs for ungauged areas have been developed from time to time by Bernard, Clark, McCarthy and Snyder. The best known approach is due to Snyder (1938).

UNIT-7

GROUNDWATER

Groundwater is water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from, and eventually flows to, the surface naturally; natural discharge often occurs at springs and seeps, and can form oases or wetlands. Groundwater is also often withdrawn for agricultural, municipal and industrial use by constructing and operating extraction wells. The study of the distribution and movement of groundwater is hydrogeology, also called groundwater hydrology.

AQUIFERS

An aquifer is a layer of porous substrate that contains and transmits groundwater. When water can flow directly between the surface and the saturated zone of an aquifer, the aquifer is unconfined. The deeper parts of unconfined aquifers are usually more saturated since gravity causes water to flow downward.

The upper level of this saturated layer of an unconfined aquifer is called the water table or phreatic surface. Below the water table, where generally all pore spaces are saturated with water, is the phreatic zone.

Substrate with low porosity that permits limited transmission of groundwater is known as an aquitard. An aquiclude is a substrate with porosity that is so low it is virtually impermeable to groundwater.

TYPES OF AQUIFERS

There are two end members in the spectrum of types of aquifers; confined and unconfined (with semi-confined being in between). **Unconfined** aquifers are sometimes also called water table or phreatic aquifers, because their upper boundary is the water table or phreatic surface. Typically (but not always) the shallowest aquifer at a given location is unconfined, meaning it does not have a confining layer (an aquitard or aquiclude) between it and the surface. The term "perched" refers to ground water accumulating above a low-permeability unit or strata, such as a clay layer. This term is generally used to refer to a small local area of ground water that occurs at an elevation higher than a regionally extensive aquifer. The difference between perched and unconfined aquifers is their size (perched is smaller).

If the distinction between confined and unconfined is not clear geologically (i.e., if it is not known if a clear confining layer exists, or if the geology is more complex, e.g., a fractured bedrock aquifer), the value of storativity returned from an aquifer test can be used to determine it (although aquifer tests in unconfined aquifers should be interpreted differently than confined ones). Confined aquifers have very low storativity values (much less than 0.01, and as little as 10^{-5}), which means that the aquifer is storing water using the mechanisms of aquifer matrix expansion and the compressibility of water, which typically are both quite small quantities. Unconfined aquifers have storativities (typically then called specific yield) greater than 0.01 (1% of bulk volume); they release water from storage by the mechanism of actually draining the pores of the aquifer, releasing relatively large amounts of water (up to the drainable porosity of the aquifer material, or the minimum volumetric water content).

GROUND WATER DATA

The term "ground water data" is used to point to all the data that are required in assessment and management of ground water. Broadly, ground water related data can be classified under two headings: time invariant data and time-variant data. Aquifer properties, hydrogeological logs, and well locations are the data which do not change with time and constitute time invariant data.

Piezometer levels, discharge, and water quality are time variant or time-series data which are routinely observed and can be processed, validated, and stored using the techniques that have been discussed in previous modules. Ground water data can be classified in two broad categories:

- time invariant data and time
- variant data

WATER TABLE

The **water table** is the surface where the water pressure head is equal to the atmospheric pressure (where gauge pressure = 0). It may be conveniently visualized as the "surface" of the subsurface materials that are saturated with groundwater in a given vicinity. However, saturated conditions may extend above the water table as surface tension holds water in some pores below atmospheric pressure. Individual points on the water table are typically measured as the elevation that the water rises to in a well screened in the shallow groundwater.

PERMEABILITY

Permeability is the passage or seepage of water into the soil through its interconnecting voids. The flow of water can be laminar or turbulent but the flow of water into soil is mostly laminar.

The unit of Permeability is “cm/s”

It has a dominating influence on the total engg. behavior of soil

DARCY'S LAW

For laminar flow conditions in a saturated soil the rate of flow or discharge per unit time (q) is proportional to hydraulic gradient (i)

$q = k\,i\,A$ where,

q = discharge per unit time

A= Total cross sectional area of soil perpendicular to the direction of flow

k = coefficient of permeability

i = hydraulic gradient

Validity of Darcy's law

Darcy's law is valid only for laminar flow conditions of flow of water through soil.

Reynolds found that the flow is laminar as long the velocity of flow is less than lower critical velocity (v_c) expressed in terms of Reynold's number.

$$\frac{v_c d \rho_w}{\eta g} = 2000$$

Typical values of coefficient of permeability

Soil type	Co-efficient of permeability (mm/s)	Drainage properties
Clean gravel	10^{1} - 10^{2}	Very good
Coarse and medium sand	10^{-2} - 10^{1}	Good
Fine sand, loose silt	10^{-4} - 10^{-2}	Fair
Dense silt, clayey silt	10^{-5} - 10^{-4}	Poor
Silty clay, clay	10^{-8} - 10^{-5}	Very poor

Specific storage (S_s), **storativity** (S), **specific yield** (S_y) and **specific capacity** are physical properties that characterize the capacity of an aquifer to release groundwater. They are sometimes referred to as "storage properties". In the field of hydrogeology, these properties are often determined using some combination of field tests (e.g., aquifer tests) and laboratory tests on aquifer material samples.

Specific yield, also known as the drainable porosity, is a ratio, less than or equal to the effective porosity, indicating the volumetric fraction of the bulk aquifer volume that a given aquifer will yield when all the water is allowed to drain out of it under the forces of gravity.

UNIT-8

WELL HYDRAULICS

When a well is pumped water flows toward the well from storage,
so the head declines forming a cone of depression.

•The amount of decline is called drawdown so this is called the drawdown cone.

•The time required to reach steady state depends on S(torativity) T(ransmissivity) BC(boundary conditions) and Q(pumping rate).

•Monitoring the development and final form of this cone in observation wells around the pumping well allows us to determine aquifer properties (e.g. T and S)

WHAT IS A WELL?

Well is in direct hydraulic communication with aquifer conditions

a. Allows estimation of aquifer hydraulic properties

b. Provides direct access to ground water conditions

(1) Sampling

(2) Testing

(3) Resource Extraction

(4) Environmental Restoration

The Qualitative Viewpoint:

Infinite Aquifer, Initially hydrostatic

Water flows "more easily" in high T material vs low T,

Thus for the same Q steeper gradients occur in low T material
Initially water is removed from storage near the well bore

If S is high: we get more water for the same drop in head over the same area compared with low S

SOME INPORTANT TERMS USED

1. Static Water Level (SWL)

a. Equilibrium level of water in well (confined or unconfined aquifer) when no water is being removed from the aquifer via pumping or free flow

b. Common expression: depth to water from surface measuring point

(1) Artesian well: depth of water level above surface

c. SWL in well at equilibrium with aquifer is a reflection of the total hydraulic

head of the water table (unconfined) or potentiometric surface (confined)

2. Pumping Water Level (PWL)

a. Level at which water stands in a well when pumping/removal is in progress

b. aka "dynamic water level"

3. Cone of depression- if water is pumped from a well faster than it can be replaced, the level of the water table will be drawn down in the shape of an inverted cone.

4. Drawdown = (SWL - PWL) = s

a. Length difference between the SWL (water table or potentiometric) and the PWL

b. Head difference (drawdown) represents the force potential of aquifer that causes water to flow from the aquifer to the well at the rate of pumping/extraction

(1) s < as force potential > (and vice versa)

c. Unconfined/Water Table

(1) head = actual water level on water table along the drawdown curve

(2) Saturated thickness of aquifer decreases

5. Drawdown Curve
a. Shape of depressed potentiometric surface/water table in 3-D
6. Residual Drawdown (Recovery Curve)
a. After pumping ceases, water levels will recover in well as well equilibrates
with natural aquifer conditions
b. Residual Drawdown = (SWL - Recovery Level)
7. Falling Head Conditions
a. Active pumping and drawdown in well
8. Rising Head Conditions
a. Recovery of well and aquifer following cessation of pumping
9. Well Yield
a. Volume of water per unit time discharged from a well by pumping or free
flow
(1) Units of discharge: Gallons/Minute or m /day 3

UNCONFINED VS. CONFINED AQUIFERS

a. Unconfined Aquifers

(1) Drawdown of water table and saturated zone of aquifer

b. Confined Aquifers

(1) Saturated zone of aquifer generally not affected

(2) Potentiometric surface is lowered (reduced head)