Lecture Notes
Hydro meteorology

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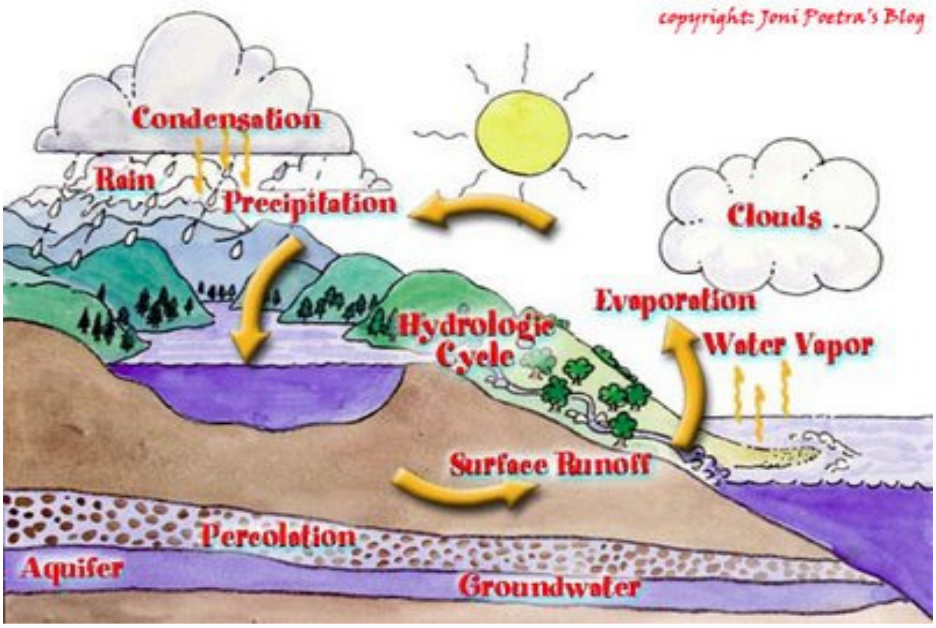
1. Hydrological Cycle



The Hydrologic Cycle

The hydrologic cycle describes the continuous recirculatory transport of the waters of the earth, linking atmosphere, land, and oceans. The process is quite complex, containing many subcycles. To explain it briefly, water evaporates from the ocean surface, driven by energy from the sun, and joins the atmosphere, moving inland. Once inland, atmospheric conditions act to condense and precipitate water onto the land surface, where, driven by gravitational forces, it returns to the ocean through streams and rivers.

The total amount of water on the earth and in its atmosphere does not change but the earth's water is always in movement. Oceans, rivers, clouds and rain, all of which contain water, are in afrequent state of change. This circulation and conservation of earth's water as it circulates from the land to the sky and back again is called the hydrological cycle. Hydrological cycle (Figure 1) can be understood in various stages as given below:

1.Evaporation

2.Transport

3.Condensation

4.Precipitation

5.Surface Run-off

6.Infiltration

1. **Evaporation**
   - endothermic process (requires energy input)
   - requires *relative humidity* $\leq$ 100

Water is transferred from the surface to the atmosphere through evaporation, the process by which water changes from a liquid to a gas. The sun's heat provides energy to evaporate water from the earth's surface. Land, lakes, rivers and oceans send up a steady stream of water vapour and plants also lose water to the air (transpiration). Approximately 80% of all evaporation is from the oceans, with the remaining 20% coming from inland water and vegetation.

Transpiration is evaporation from plants. Underside of leaves contain pores (stomata) which open for photosynthesis during the day. Water drawn into plant by roots to provide support and transport nutrients is lost via stomata. Hence length of day is an important constraint on transpiration

Evapotranspiration (ET) is combined bare soil evaporation and plant transpiration

2.Transport

The movement of water through the atmosphere, specifically from over the oceans to over land, is called transport. Clouds are propelled from one place to another by surface-based circulations. Most water is transported in the form of water vapour.

3.Condensation

The transported water vapour eventually condenses, forming tiny droplets in clouds.

4. Precipitation

The primary mechanism for transporting water from the atmosphere to the surface of the earth is precipitation. When the clouds meet cool air over land, precipitation, in the form of rain, sleet or snow, is triggered and water returns to the land. A proportion of atmospheric precipitation evaporates.

Precipitation denotes all forms of water that reach the earth from the atmosphere. The usual forms are rainfall, snowfall, hail, frost, and dew.

For precipitation to form :

(1) the atmosphere must have moisture,

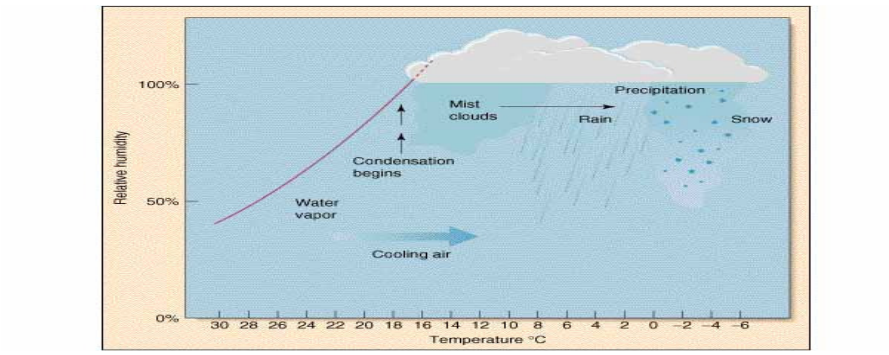
(2) there must be sufficient nuclei present to aid condensation,

(3) weather conditions must be good for condensation of water vapor to take places

(4) the products of condensation must reach the earth.

The precipitation at a place and its form depend upon a number of meteorological factors, such as, wind, temperature, humidity and pressure in the area enclosing the clouds and the ground surface at the given place.

As warm, moist air is cooled, the amount of water it can hold decreases. Cooling air beyond the point where relative humidity (RH) reaches 100% forces excess moisture to condense, forming clouds. Further cooling and condensation result precipitation.



- All liquid or solid phase aqueous particles that originate in the atmosphere and fall to the earth's surface.

- The amount, usually expressed in millimeters or inches of liquid water depth, of the water substance that has fallen at a given point over a specified period of time. As this is usually measured in a fixed rain gauge, small amounts of dew, frost, rime, etc., may be included in the total. The more common term rainfall is also used in this total sense to include not only amounts of rain, but also the water equivalents of frozen precipitation. For obvious reasons, precipitation is the preferred general term.

5. Surface Run-off

In the time of rainfall soil moisture zone gradually gets saturated and water flows on overland as surface runoff. Different surfaces hold different amounts of water and absorb water at different rates. As a surface becomes less permeable, an increasing amount of water remains on the surface, creating a greater potential for flooding.

6. Infiltration

Some of the precipitation soaks into the ground and traveled to subsurface through infiltration process. Water which originates from the infiltration of fluids through the soil profile and accumulates below the earth's surface in a porous layer is called groundwater. Water when encounters impermeable rock then travels laterally. The

locations where water moves laterally are called ‘aquifers’. Groundwater returns to the surface through these aquifers, which empty into lakes, rivers and the oceans

Aquifers

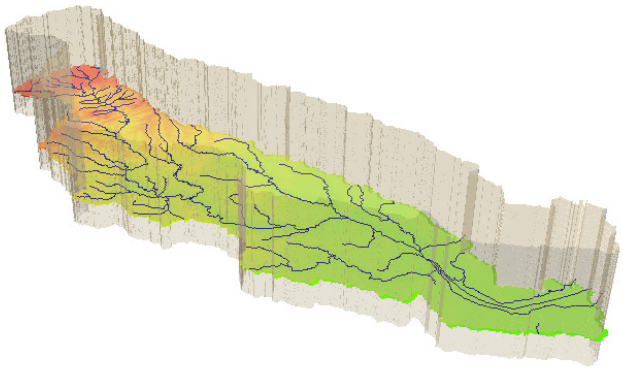
A geological unit which can store and supply significant quantities of water.

Principal aquifers by rock type:

Unconsolidated
Sandstone
Sandstone and Carbonate
Semi consolidated
Carbonate-rock
Volcanic
Other rocks

Hydrologic System

A hydrologic system is “a structure or volume in space surrounded by a boundary, that accepts water and other inputs, operates on them internally, and produces them as outputs”



The water-holding elements of the hydrologic cycle are
1. Atmosphere
2. Vegetation
3. Snowpack and icecaps
4. Land surface
5. Soil
6. Streams, lakes, and rivers
7. Aquifers
8. Oceans

Liquid-transport phases of the hydrologic cycle are
1. Precipitation from the atmosphere onto land surface
2. Through fall from vegetation onto land surface

3. Melt from snow and ice onto land surface
4. Surface runoff from land surface to streams, lakes, and rivers, and from streams, lakes, and rivers to oceans
5. Infiltration from land surface to soil
6. Exfiltration from soil to land surface
7. Interflow from soil to streams, lakes, and rivers and vice versa
8. Percolation from soil to aquifers
9. Capillary rise from aquifers to soil
10. Groundwater flow from streams, lakes, and rivers to aquifers and vice versa and from aquifers to oceans and vice versa.

Vapour -transport phases of the hydrologic cycle are

1. Evaporation from land surface, stream, lakes, river, and oceans to the atmosphere
2. Evapotranspiration from vegetation to the atmosphere
3. Sublimation from snowpack and icecaps to the atmosphere
4. Vapor diffusion from soil to land surface

Hydrologic Budget

Hydrologic budget is simply an H_2O mass balance

$$\left\{ \begin{array}{c} rate\ of \\ mass\ in \end{array} \right\} - \left\{ \begin{array}{c} rate\ of \\ mass\ out \end{array} \right\} = \left\{ \begin{array}{c} change\ in \\ storage \end{array} \right\} \quad (1)$$

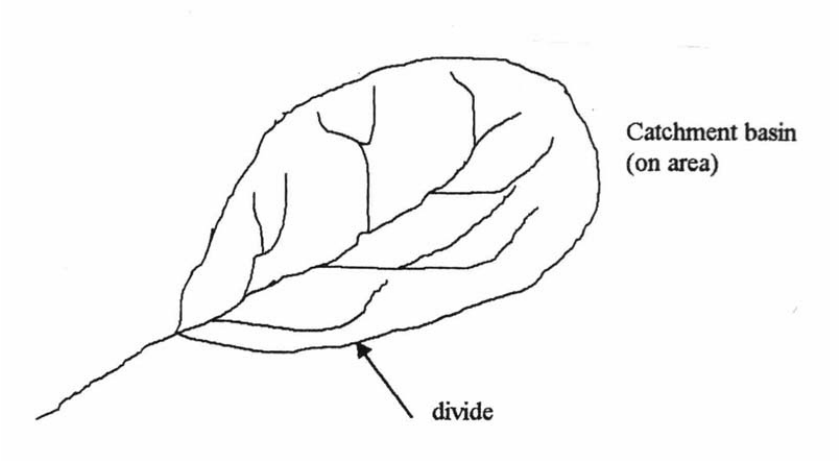
Basic equation:

$$\mathbf{P - ET - R - G = \Delta S}$$

P = Rain
ET = Evapotranspiration
R = Run off
G = Groundwater recharge
ΔS = Change in storage

Catchment Area

The area of land draining into a stream on a water course at a given location is known as catchment area. It is also called as drainage area or drainage basin. It is known as watershed in some countries. A catchment area is separated from its neighboring areas by a ridge called divide. The area extent of the catchment is obtained by tracing.



Hydrometeorological Disasters

Flood

Definition: According to the meteorological point of view, a flood is defined as a quantum of rainfall/precipitation received over an area in excess of long period average precipitation over that area during the period when it is expected to occur. Generally if the precipitation for a particular period exceeds the long period average precipitation (referred as normal) by one standard deviation, meteorological floods occur. Meteorological floods are Seasonal

Hydrological Floods :

- Flood occurs not in a seasonal scale but in most cases weekly or further smaller time scale. Considering the day to day and the extensive damages caused by the flood hydrologists define flood as a high river flow which overtakes the natural runoff, or a high flow which overtakes the natural or artificial embankments of a river or a stream. Excessively high water level in a river or discharge level above an threshold level known as flood level or danger level which are already decided for all the rivers considering several aspects.

  In India Central water Commission (CWC) is the nodal agency for water resources and CWC has fixed Danger Level or all important river catchment or discharge sites.

Causes of floods

Excessive precipitation is the main cause of flood. Synoptic situations like monsoon depressions, cyclonic storms, low pressure areas, position of monsoon trough over north Indian regions, movement of westerly trough play important roles in causing excessive precipitations. Main components responsible for the flood are as follows:

(i) Flash floods : In a short duration heavy to very heavy rainfall in a smaller catchment can create flash floods. Such floods develop so rapidly that there is little time to be left for the flood occupants to lean the affective area.

(ii) Direct runoff is the major cause of floods. Rain reaching the soil surface can infiltrate into the soil or runoff directly in streams and rivers. Once the absorbed rainfall exceeds the infiltration capacity, the excess water flows as a direct run off. During the course of monsoon season and continuous excessive rain for few days the soil becomes fully saturated and additional rain would then form direct run off.

(iii) Deforestation : It is a major influence in developing countries that increases run off and in turn causes flood. The trees hold the soils of the forest flood together and make a deep litter of fallen leaves. Both of these cause increase in infiltration capacity. Due to the deforestation, soils are soon eroded resulting in increase in runoff of sediment – laden water. The resulting erosion of hillsides is very deleterious and this also leads to increase sediment loads in rivers and sitting up of reservoirs downstream. Overgrazing cause loss of grass covers on hillsides, which in turn increases faster runoff and erosion.

(iv) Sedimentations: Sediments from the erosion settle at the river bottom, increase the depth of river and gradually raise water level.

(v) Due to the increased urbanization, ground absorption of water is prevented and this leads to increase in runoff and contributes to flash floods in urban areas.

(vi) Poor farming techniques also increase soil erosion.

(vii) Flood Plains : Due to less and inexpensive land values and high soil fertility, land, proximity of water, availability of construction materials such as sand and gravel and flatness of land flood plains are attracted by poor urban dwellers and farmers, industrialist etc. During the flash flood these cause more and severe damages and loss of life.

(viii) Storm Surges : Storm surges are the major causes of flood in coastal areas and in river estuaries. A cyclonic storm with intense low pressure in the center over the sea causes the rise of sea level due to barometric effects and also the strong winds associated with the cyclonic storm if directed to the onshore, drives the sea to the land. Coastal areas like Orissa and Andhra Pradesh are occasionally affected by the storm surges. In the Super Cyclone of 29th October, 1999, strong winds of speed 250 kmph lashed most parts of Orissa coast and storm surge of height 12 – 14 meter inundated low lying areas along Orissa coast causing deaths of nearly 10,000 human lives.

Drought : Rainfall deficiency is the main cause of drought. Based on the cause and impacts on society drought is classified in four categories.

Meteorological drought: Droughts generally start with a lack of precipitation, possibly in combination with high evapotranspiration, resulting from the natural variability of the weather. This is called a meteorological drought.

Agricultural drought : The meteorological drought causes a lack of soil moisture, which is called a soil moisture drought and which affects agricultural crops and/or

the natural vegetation. The soil moisture drought is also frequently called agricultural drought.

Hydrological drought : Lack of precipitation may also cause low stream flows: the stream flow drought. The soil moisture drought causes a decrease in the amount of recharge, which in turn causes lower groundwater levels and decreasing groundwater discharge to the surface water system, which is a groundwater drought. Both the stream flow drought and the groundwater drought are part of the hydrological drought.

Socio-economic drought: The socio-economic drought expresses the deficit of water as an economic good and addresses the damage caused by all the different types of drought.

Physical, Biological and Social Indicators for monitoring drought:

- Physical indicators include

  Rainfall, Effective soil moisture, Surface water availability, Depth to groundwater, etc.
- Biological/ Agricultural indicators comprise

  Vegetation cover & composition, Crop & Fodder yield,

  Condition of domestic animals, Pest incidence, etc.
- Social indicators are mostly impact indicators and include

  Food and Feed availability, Land use conditions, Livelihood shifts, Migration of population, etc.
- In most cases only those indicators that measure the rainfall needs of following sectors are considered:

  (a) agricultural need,

  (b) drinking water supply, and

  (c) storage of reservoirs and ground water

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