Higher 2 (9173)	Cluster 2: Tropical Environments	TMJC
C2 Lecture 8	***Drainage Basin Hydrological Cycle***	2025

Hydrologic Cycle and Drainage Basin

A Catchment is also known as a drainage basin and both define an area of land in which water flowing across the surface drains into a particular stream or river. A catchment is a convenient unit because it is normally well defined topographically and it is an open system for which inputs and outputs of mass and energy can be defined and measured. Large drainage basins, like the area that drains into the Mississippi River contain thousands of smaller drainage basins.

One important concept to remember is that the Drainage Basin Hydrological Cycle would consist of Inputs, Outputs, Pathways (flows) and Stores.

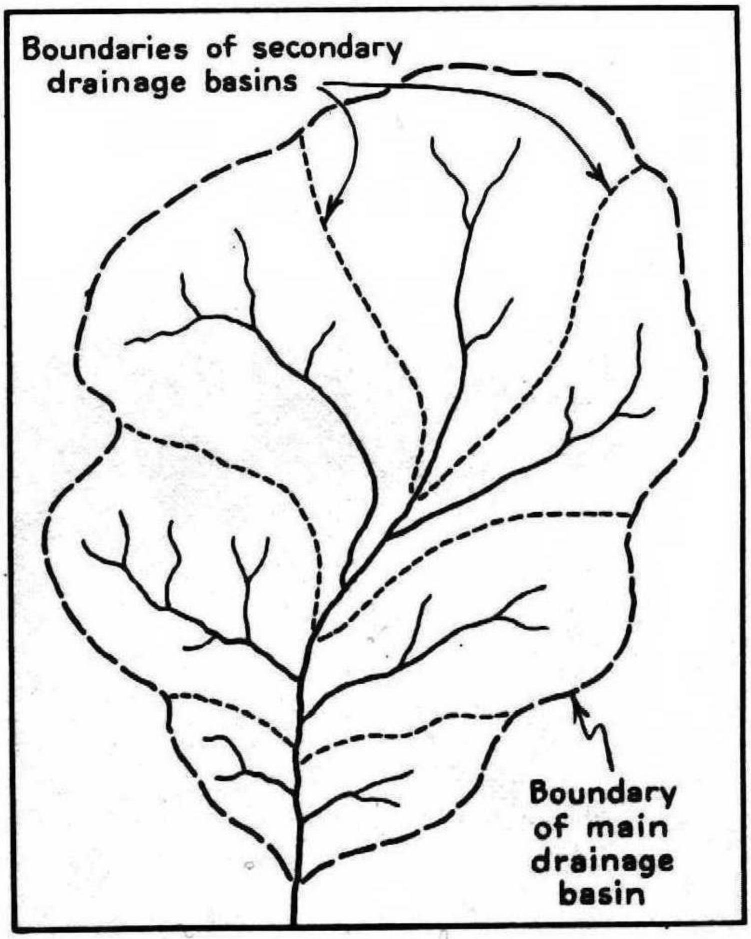


Figure 1: Each stream, no matter how small, has its own drainage basin, the area from which the stream and its tributaries receive water. This basin displays a pattern reminiscent of a tree leaf and its veins.

The **basin hydrological cycle** depicts the movement of water among storage places for discrete areas of the earth, for example ecosystems or most often drainage basins. Drainage basins are by definition closed to inputs of surface water thus the number of inputs is minimized or essentially reduced to one, precipitation, although inter-basin transfer of groundwater may occur, but is difficult to quantify and generally assumed to be insignificant. Outputs from drainage basins are by evapotranspiration, flow at the mouth of the main stream which ultimately accounts for all runoff, and possibly output (seepage) of groundwater.

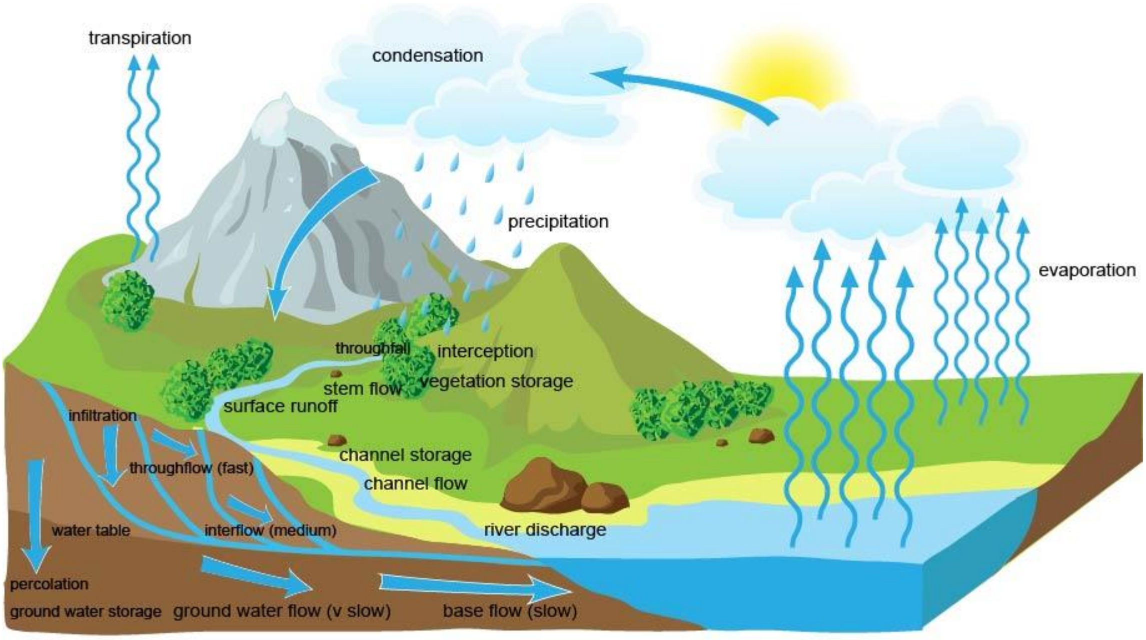


Figure 2. Drainage Basin Hydrological Cycle

Characteristics of the drainage basin:

1) inputs – in the form of precipitation
2) outputs – in the form of water lost from the system through river flow into the sea or through evapo-transpiration
3) stores – in lakes and / or in soil
4) pathways – in a series of transfers or flows: infiltration, percolation, throughflow, surface flows, etc…

1. Explain the Various Inputs and Outputs of Water into the Hydrological Basin

1.1 **Inputs** into the drainage basin usually come in the form of precipitation. Precipitation is usually expressed in units of length such as mm or cm. This is because it is assumed that precipitation has fallen uniformly over a given area and so the volume of water is divided by the surface area of the catchment to give a depth of water.

It is the deposition of atmospheric moisture at the surface of the earth in the form of rain, dew, mist, hail, sleet, snow. Water evaporates from water bodies like streams, seas, rivers, ponds and from land (evaporation) and vegetation (transpiration) in the form of water vapour.

Amount of precipitation received influences the overall scale of evaporation and runoff losses.

Variation of Precipitation:

- short term variations
  - variations in precipitation intensity during a rainfall event
- climatic regions
  - dependent on frequency of rain

Precipitation intensity is determined by raindrop size and the speed of the rain falling on the soil. The bigger the drops of rain and the higher the speed, the more intense the rain.

Precipitation also comes in other forms such as hail, snow or sleet and the time taken for them to be absorbed into the water cycle is also different.

At its core, *precipitation intensity* is determined by its raindrop size and the speed of the rain falling on the soil. The bigger the drops of rain and the higher the speed, the more intense the rain.

1.2 **Outputs** from the drainage basin hydrological cycle usually comes in the form of evaporation and transpiration (Evapo-transpiration).

It is the loss of moisture at the earth's surface by direct evaporation from water bodies and soil *AND* transpiration from growing plants.

As it is rather difficult to separate the 2, the term evapo-transpiration is used to describe the combined effect of both.

Evaporation – is the direct loss or diffusion of water to the atmosphere from surfaces of water bodies (lakes, rivers, wet roads, moist soil).
Relatively less evaporation takes place from large water bodies than small ones because more incoming solar radiation is used in heating the water to depth and not just the surface. High salinity water has lower evaporation rates than fresh water as impurities in the water reduces rate of evaporation.
Evaporation from soil surfaces is limited by the availability of water or evaporation opportunity. Soil texture also determines the rate of evaporation. Clays have a lower rate of evaporation than sand and gravel.

Transpiration – is a biological process involving the evaporation of water from leaves of plants (through the stomata). It occurs when vapour pressure in the leaf cell is greater than atmospheric vapour pressure.
Transpiration is controlled by atmospheric factors like temperature and by plant factors like leaf area, amount of soil moisture, etc.

River Discharge – is also an important form of output as the water is leaving the drainage basin into the sea.

***Factors affecting Evaporation (E) and Transpiration (T) (from water surface)*:**

- *Temperature*
    - E is highest when air temperature is at its maximum (e.g. summer) and lowest at night and in winter. Solar radiation is the most important factor involved in evaporation as it affects rate of water loss. As air temperature increases, potential for holding water vapour increases and hence greater E.
    - However, there must be temperature differences between the water body and the surrounding air for E, compared to just air temperature alone. This is because temperature differences control the vital vapour pressure deficit. Water vapour molecules flow from high to low vapour pressure areas.
    - Solar radiation also enhances photosynthesis, thus EVPT are greatest in the noon and in summer.

- *Atmospheric Humidity*
    - When relative humidity (RH) is high, EVPT is low, and vice-versa
    - When the air is saturated (RH=100%), there is little room for EVPT.

- *Wind speed*
    - EVPT is higher when winds speed increases, surrounding water vapor is blown away, reducing relative humidity which allows for more water vapor to evaporate.

- *Vegetation type and density*
    - Different types of plants have different rates of EVPT.
    - Deep-rooted vegetation transpires more water during droughts than shallow-rooted plants
    - Xerophytic desert plants transpires less as there are fewer stomata
    - Light colored plants with a higher albedo reflects solar radiation, thus have lower rates of EVPT.

- *Water Quality*
    - E decreases by 1% for every 1% increases in salinity.

- *Water body*
    - Shallow waters have higher E in summer and lower in winter (faster heating up of water body)
    - Deep waters have higher E in winter than in summer (slower cooling down of water body)
    - The larger the lake, the greater the total *volume* of water evaporated.

Factors affecting EVPT (from soil surface):

- *Soil moisture content*
    - E is higher when soil moisture content (on the surface) is higher
- *Soil color*
    - Darker the soil, the higher the E, because darker soils have a lower albedo (ability to reflect the sunlight), thus gets heated up faster.
- *Vegetation*
    - Vegetation will reduce soil evaporation by shading the soil and thus lowering surface temperature, reducing wind speed and increasing RH in the lower layers of air.

2 & 3. Explain the different flows/pathways and water stores

Another important aspect that we need to investigate about the drainage basin hydrological cycle is how water flows (pathways) and how it is stored throughout the cycle when it arrives as inputs and leave as outputs. This section will explain various pathways and stores. Try to classify them in terms of surface/sub-surface and also by their direction.

Interception/interception storage

Precipitation can be held up on the canopy or branches of trees and plants as interception storage. This is usually temporary, and will either fall to the ground or evaporated upwards when the sun comes out.
Interception varies with duration of the rainstorm and vegetation type:

Duration of storm – if the storm lasts a short time, a great proportion of rainfall remains as interception storage. This storage may be returned in part or whole to the atmosphere through evaporation as interception losses. It the storm is prolonged, the capacity of the foliage for storage will be exceeded and water may (i) drip from the canopy to the ground as throughfall or (ii) flow down the branches/ trunks as stem flow or (ii) be intercepted as secondary interception by undergrowth.

Vegetation type – interception helps to reduce the impact of rainsplash erosion on soils. The more vegetation cover, the higher the interception. In the Brazilian forest, only 60% of rainfall reaches the ground. This is due to its lush and continuous canopy cover. 40 % of it is evaporated back to the atmosphere or absorbed by the tree trunks.

Stemflow

In hydrology, **stemflow** is the flow of intercepted water down the trunk or stem of a plant. **Stemflow**, along with throughfall, is responsible for the transferral of precipitation and nutrients from the canopy to the soil

Surface Storage/Depression Storage

It is water stored on the ground surface. It includes surface detention (usually temporary storage) during or after a storm, before it moves down slope. Some of this water may infiltrate the soil, and some will be evaporated while the rest is lost as surface runoff.

Infiltration

It is the process by which water enters the surface horizon of the soil, the movement of water through the soil surface ***into*** the soil. The water which infiltrates the soil first fills the pores in the soil. If the soil is impermeable, it flows off the surface as surface runoff/ surface overland flow. The quantity of water held in soil is recharged during precipitation (P) via infiltration, and stored as soil moisture storage. This soil moisture is available to plants via their roots.

Infiltration capacity (IC)

Infiltration rate refers to the quantity of water per unit of time entering the soil; **Infiltration capacity** is the maximum rate at which water can enter the soil, and is measured in mm/hr (or cm/hr). IC is lower on bare/ unvegetated ground (less than 1cm/hr) as compared to 5cm/hr on more vegetated areas or when the ground is covered by organic litter.

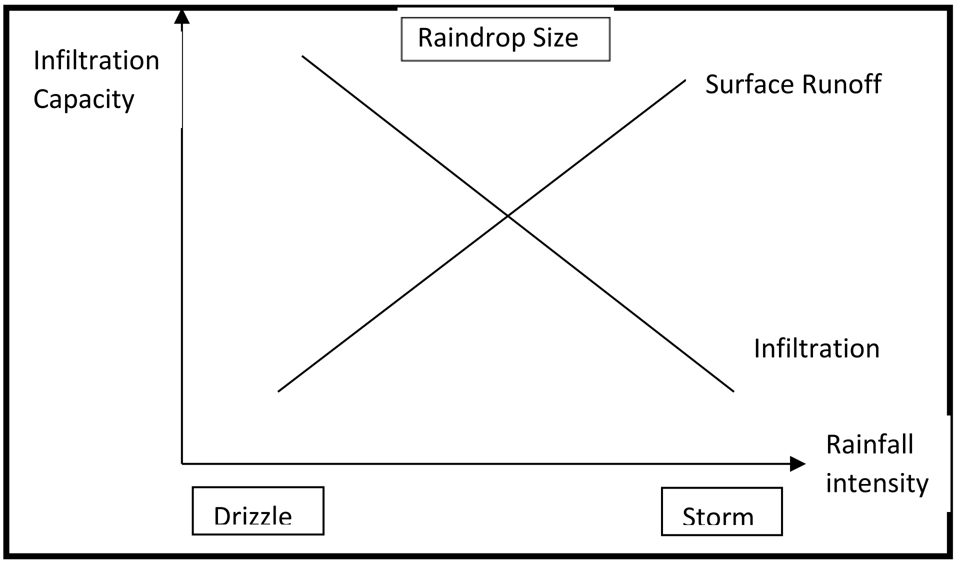
When rainfall intensity exceeds infiltration capacity (PI > IC), the rainwater is arriving at the soil surface faster than it can enter the soil. Thus, rainfall intensity is greater than IC, and surface runoff (infiltration excess flow) occurs.

IC changes over space and time. In the early stages of P, the rate is high because the soil is dry. When pores in the soil become filled with water, infiltration rates slow down.

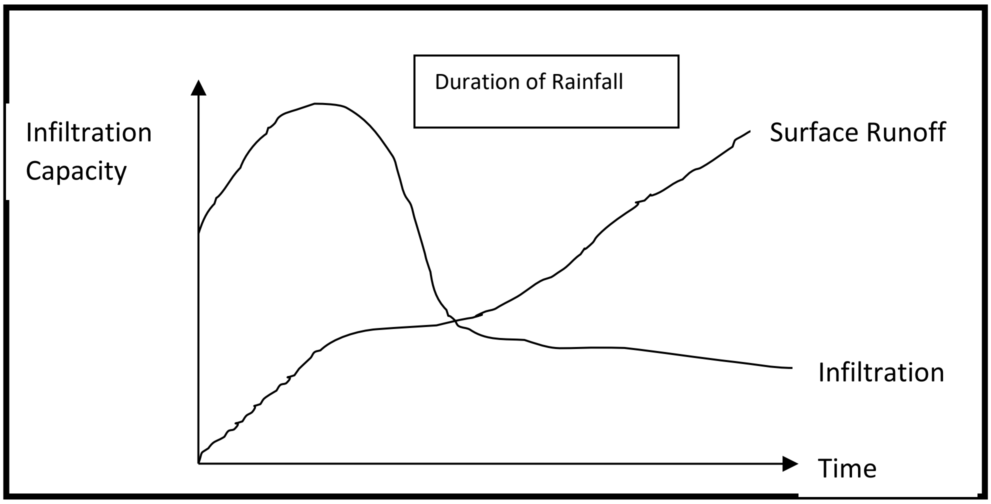
__Factors affecting Infiltration Capacity (IC)__

- Type, intensity and Duration of Precipitation
  - **Type**: rainfall is most readily available for infiltration to occur; snow will require melting before it can be infiltrated. (note: rapid rates of snowmelt when the underlying ground is still frozen – e.g. permafrost - can lead to large scale floods as frozen ground cannot be infiltrated)

  - **Intensity**: rate of infiltration is inversely proportional to rainfall intensity. The more intense the rain, the lesser the infiltration, and the greater the runoff. Soil aggregates are broken up by rain splash and these disintegrated particles fills up the voids in soil, leading to a decrease in infiltration. Light rainfall allows time for water to enter the soil, thus increasing IC.



- **Duration:** water from a short rainfall will be infiltrated more than that of a prolonged rainfall as the IC is exceeded after a period and no more water can infiltrate the ground. The rate of infiltration declines rapidly during the early part of a storm and reaches an approximately constant value after 1 or 2 hours of rain.



Vegetation

- **Type and density**: matured layered rainforest will intercept more rainfall than bare ground or agricultural land. Pine forest intercept 94% of low intensity P, but only 15% of high intensity. Deciduous trees intercept more P in summer than in autumn (shed leaves), given the same intensity of rain. IC can range from 57 mm/hr on permeable pasture to 13 mm/hr on heavily grazed land to 6mm/hr on bare crusted ground.
- **Stems** will increase infiltration by delaying time precipitation reaches ground, and **roots** makes soil more pervious, thus increasing IC.

Soil Properties

- **Antecedent soil moisture** (wetness of soil at start of rain) determines the IC - dry soil takes in more water than wet ones.
- A **porous** soil (possessing many pores or void) has a higher IC. A porosity of 30% means that 30% of the soil can be occupied by water. Clay, sand and gravel have high porosity, but clay has low IC because surface tension of clay (water clinging to clay) is high. Moreover, when wet, clay expands, thus reducing IC. Most igneous and metamorphic rocks have porosity of less than 5%, as there are few pores between these crystals. Granite and basalt have only 1% porosity.
- A **permeable** soil has higher IC as it allows water to pass through it. Permeability is increased by the presence of joints, faults and bedding planes.

- Human Activity
  - Activities that increases infiltration:
    - Ploughing / deep tillage
    - Terrace cultivation
    - Contour ploughing[1]
    - Cover crops
    - Planting of dense grass strips between cropped land
    - Reforestation and afforestation
    - Planting grass plots in highly built up areas
    - Usage of aeration concrete slabs in car parks instead of bitumen floor.
  - Activities that decreases infiltration:
    - Over grazing
    - Deforestation
    - Usage of farm machinery
    - Cultivation on steep slopes/ slope-wise cultivation
    - Extensive built up areas (esp. concrete and bitumen)

[1] farming practice of ploughing and/or planting across a slope following its elevation contour lines

Runoff/Overland Flow (more to be elaborated in next lecture)

Runoff is rainwater that leaves the drainage basin by surface routes, and can take the form of overland flow (sheetwash, rills, rivulets) or channel flow (streams and rivers). It is usually a result of rainfall and melting snow, but can also be a result of return flow and seepage.

Overland flow usually leads to soil erosion and is active in shaping slopes. It comprises a think later of flowing water of about a few mm in depth. On the upper part of the slope, sheet flow dominates. On lower parts of slopes, rills and rivulets becomes evident.

Saturation Overland Flow (SOF)

- Occurs when soil becomes saturated (where WT intersect the surface of slope) and is influenced by the total amount of rainfall than by the intensity or duration of rainfall.
- It occurs when pore spaces are completely filled with water through prolonged rainfall, and infiltration capacity has reached its maximum. Infiltration is inhibited and flows off as SOF. Rain failing on already saturated soil has no choice but to run off (DPSA direct precipitation on Saturated Areas)
- SOF can also occur when the rate of throughflow/interflow entering a saturated area from upslope exceeds the capacity for throughflow/interflow to leave the area by flowing downhill through the soil. The excess thus 'returns' to the surface as runoff. This is known as **return flow** seepage, and can continue as long as interflow excess exists.
- Factors that promote SOF includes:
    - High WT
    - Presence of vegetation (promote infiltration)
    - Light and prolonged drizzle
    - Gentle slope (retards runoff)
    - Impermeable soil strata (i.e. soil strata is generally impermeable. This retards percolation close to surface so that soil is saturated faster)

Hortonian Overland Flow (HOF)/ Infiltration Excess Flow (IEF)

- occurs when rainfall intensity is so great that not all the water can infiltrate into the soil strata
- named after R.E. Horton (1933), who argued that overland flow can be started without saturation of the ground, as long as rainfall/ precipitation intensity is greater than infiltration capacity (PI>IC).
- HOF is most common in semi-arid areas where there are flashfloods with sparse vegetation cover and thin impermeable soil. There is compact of the soil surface by washing of disintegrated fine soil particles into pore spaces between coarse particles. In some cases, HOF/ IEF can occur very soon after the beginning of the storm, even over low gradient slope.
- Frozen soil also promotes HOF/ IEF as the frozen ground prevents infiltration.
- Factors that promote HOF/IEF includes:
    - Intense rainfall
    - Small sediment grain sizes and pore size
    - Steep slope angle (reduces time for infiltration)
    - Absence of vegetation (no protection from raindrop impact)
    - Little/no root passages

Soil Moisture Storage

The ability of a soil to absorb and retain moisture is crucial to the hydrology of an area. The soil water store will vary seasonally and will depend on soil properties, soil depth and precipitation. Deep permeable soils can store large quantities of water, providing a moisture reserve through times of drought and helping to sustain river flow during dry periods.

Throughflow

When water infiltrates the soil, several things can happen:

-It can be taken up by plants and transpired (or be lost from the soil by evaporation)
-It can continue to percolate down into the bedrock,
-it can travel laterally downslope through the soil or rock- this is called throughflow

Worldwide, most water reaches river by throughflow, through the soil layers or through bedrock. Throughflow can both maintain low flows (**baseflow**) in rivers by slow subsurface drainage of water and also contribute to peak flows (**stormflows**) through its role in generating saturation excess overland flow and as an important process in its own rights.

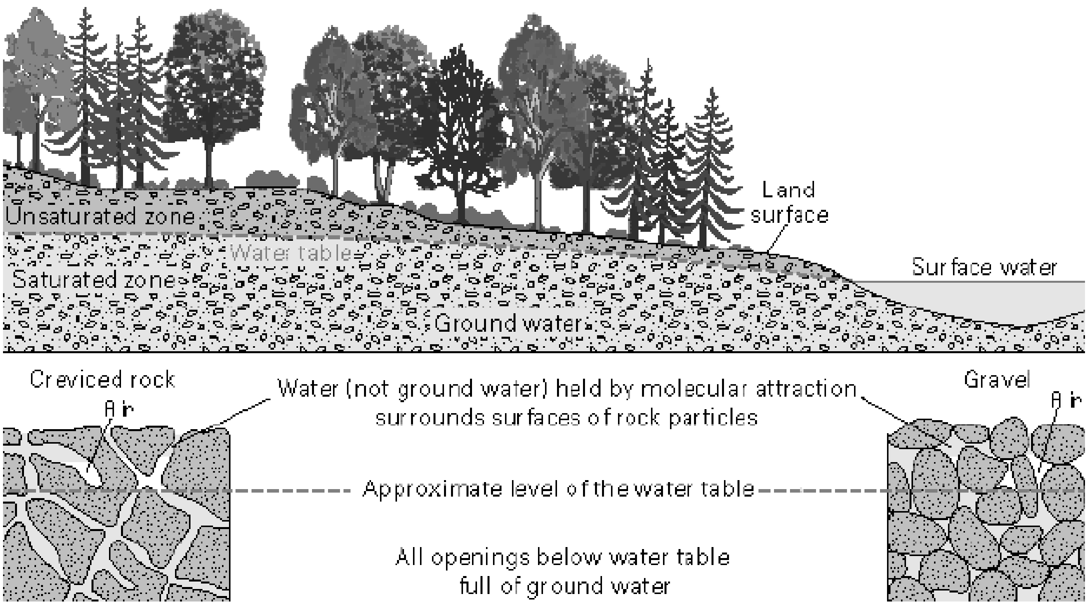
Throughflow usually moves laterally, and this movement of soil moisture usually occurs in the zone of aeration.

Percolation

It is the movement of water ***through*** the soil (beneath the surface horizon). The excess water from infiltration percolates downwards due to gravitational pull, and is stored as groundwater, and/or removed in baseflow. It can also flow off as throughflow (or interflow) as it is moving through the Zone of Aeration or Unsaturated Zone (vadose zone).

Groundwater Storage and Water Table

Infiltrated water, after recharging the soil moisture storage, will move vertically down the soil strata under gravitational pull. This constant movement, called percolation, creates groundwater storage. Water that collects below the **water table** (Zone of Saturation) is known as groundwater. This is then removed as groundwater flow or baseflow.



Factors affecting Groundwater/ WT

- **Overpumping** – when water is pumped out too rapidly than rate of recharge, a cone of depression can form around a well.
- **Increased surface runoff** – when there is an impermeable concrete layer, rainwater is channeled to the sea rather than infiltrate through the concrete, leading to a drop in WT and possible saltwater intrusion.
- **Deforestation** – rapid removal of trees reduces infiltration and recharge, thus decrease in WT.
- **Pollution** – agricultural fertilisers may seep into the ground to pollute the aquifers.
- **Climatic factors** (as mentioned above)

The groundwater is important because in some areas it is the only source of water for humans and it represents virtually all (97%) of the Earth's non-saline and non-frozen water resources (Price, 2002). However, measuring exactly how much water is in any groundwater store is very difficult and requires an estimation of the porosity of the rock/soil.

Baseflow/Groundwater Flow

In the saturated zone, water is not only stored as groundwater but it also a moving through saturated soil and rock. For water to flow as groundwater, the rock or soil need to be not just porous but permeable. Groundwater flow is a lateral movement of water that reaches many streams and river. However, it is usually a slower movement of water as compared to throughflow. It is important to remember that it refers to water moving through the zone of saturation (Nagle, 2000).

Spring

A natural discharge of groundwater at the earth's surface. It can occur when the water table is exposed on a valley side. Occurrence of springs is determined by climate as well as geological factors

Channel Storage

Water from runoff, throughflow and groundwater flow will reach the river channel. The water can now be stored as channel storage. Water stored in the channel storage are exposed to different forms of output such as evapotranspiration and channel flow/river discharge.

Channel Flow/River discharge [Output]

Nevertheless, water can also move along the river channel and leave the drainage basin hydrological cycle. As water moves downstream in the river channel, it will eventually flow into the oceans, which are at the sea level.

<u>Factors influencing the hydrologic cycle at basin scale</u>

a) Climate
    - Refer to factors affecting IC and factors affecting EVPT
    - Refer to elements of hydrologic cycle – (a) precipitation

b) Vegetation
    - Refer to factors affecting IC and factors affecting EVPT
    - Human factors – e.g. deforestation

c) Soil conditions
    - Refer to factors affecting IC and factors affecting EVPT
    - Human action – e.g. Urbanization/development and concretization of land; building of dams and drains

d) Geology
    - Type of rock
        - Rock structure (joints and bedding planes) → more joints and BP, more subsurface flows and stores, and vice versa (v.v.)

- Mineral composition → determines strength of rock and susceptibility to W processes.

e) Relief
  - Steep slopes → higher SR, lower infiltration
  - Gentle slopes → lower SR, higher infiltration

f) Human activities

Think carefully, how does each of the factors above affect the hydrological cycle in terms of its
a) inputs
b) outputs
c) flows
d) stores

4.1. Runoff/Overland Flow

Runoff is rainwater that leaves the drainage basin by surface routes, and can take the form of overland flow (sheetwash, rills, rivulets) or channel flow (streams and rivers). It is usually a result of rainfall and melting snow, but can also be a result of return flow and seepage.

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Factors controlling surface runoff:

- vegetation
- permeability of rock/ soil; antecedent soil conditions
- rainfall intensity and type of rainfall
- slope factors
- human activities – agricultural and urban activities*