Lecture 5
Drainage Basin Hydrology

KEY QUESTION:

✓ *How does water move within a drainage basin system?*

With the completion of this lecture, attached readings and tutorial, you should be able to understand the:

- Input of water into the drainage basin system
- Output of water from the drainage basin system
- Storage of water in the drainage basin system
- Movement of water through the drainage basin system

Lecture Outline

5.1 Drainage Basin Hydrology

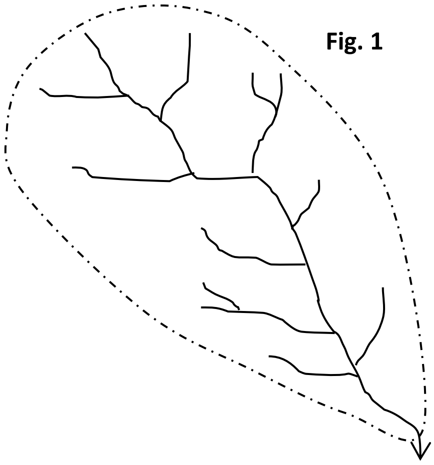


Fig. 1

- The **drainage basin** is **the area of land surface from which water and sediment are transferred by individual channels that join up to form a network** that eventually drains into an ocean, a sea or a lake (**Fig. 1**).
- The boundary of a drainage basin is known as the **watershed**, and is simply the highest contour of the land surrounding a river.
- **Hydrology** is the study of the distribution and movement of water both on and below the Earth's surface, as well as the impact of human activity on water availability and conditions.
- Therefore, **drainage basin hydrology** is the study of how water moves or is transferred within a drainage basin.
- Being a ***system*** defined by inputs, flows/pathways, stores and output working within the watershed, it is the basic unit for studying hydrological processes. The drainage basin system is an **open system** as water is not confined to a specific location and can move from one locality to the next at any given time. (See **Fig. 2** and **Fig. 3**)
    - The water enters the system as **precipitation or snowmelt** and leaves as **river discharge** or as **evapotranspiration**.
- The **drainage water balance** can be studied using the following simple equation, but it should be noted that the 'balance' is not a given as the basin is an open system:

$$\mathbf{P = E + R \pm S} \quad \text{(possible that RHS > LHS and RHS < LHS)}$$

in which **P** is precipitation, **E** is evapotranspiration, **R** is surface runoff (or overland flow), and **S** reflects gains or losses due to changes in storage. (See subsequent sections)

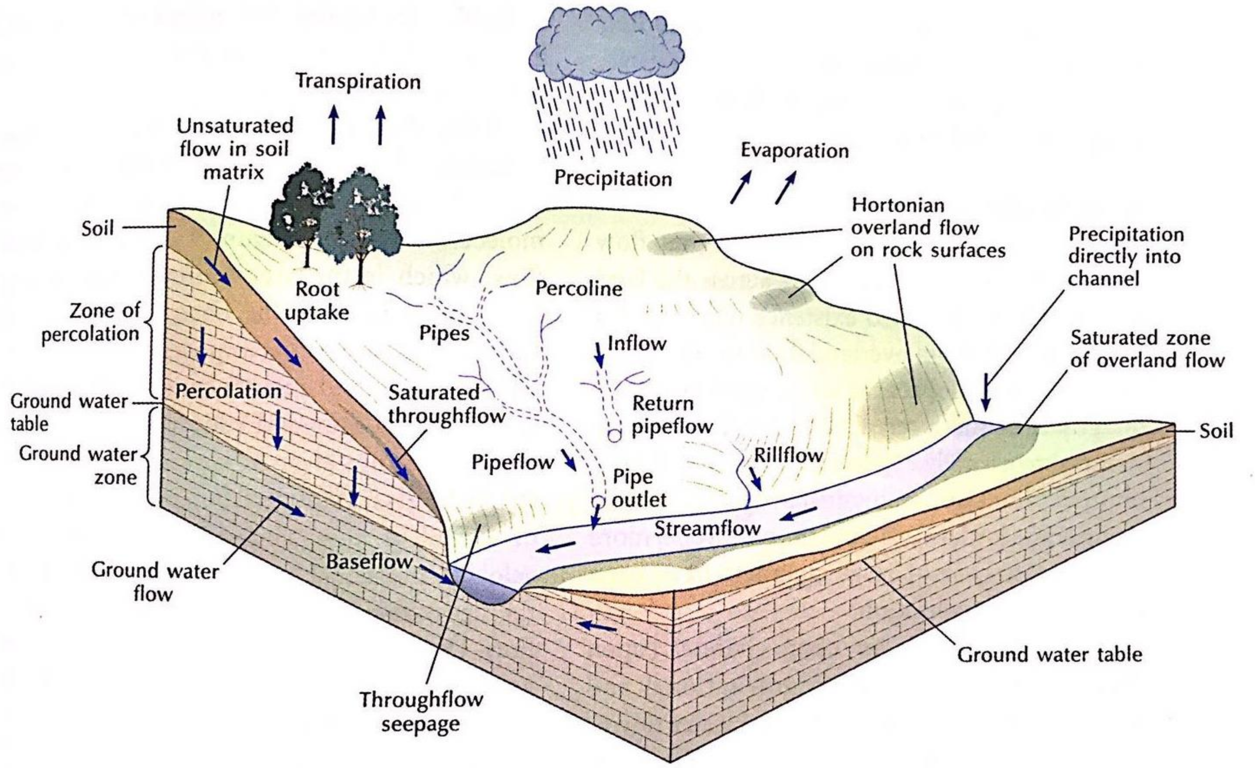


Fig. 2

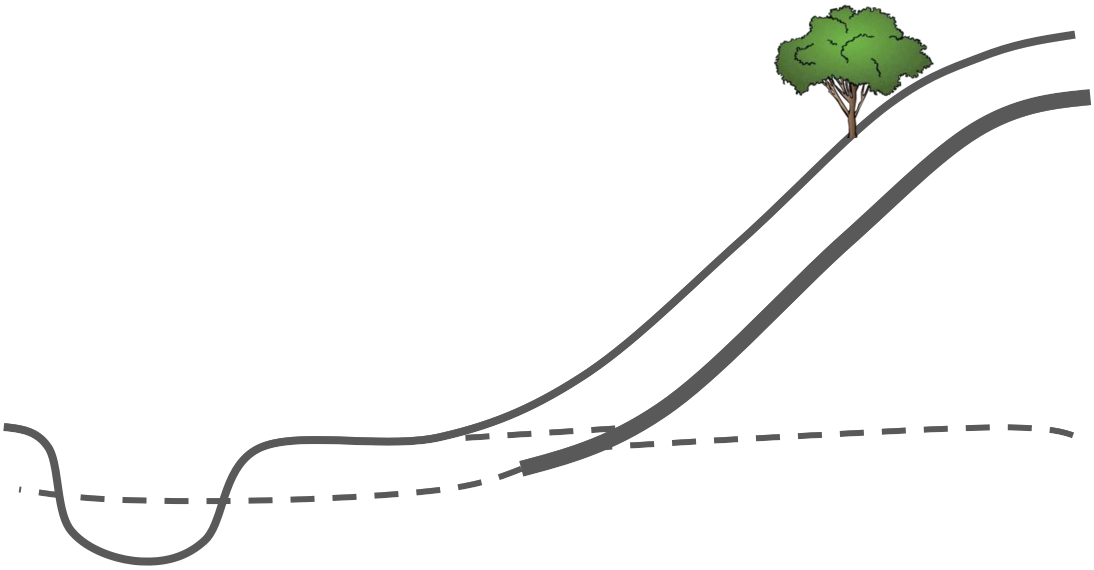


Fig. 3 A diagrammatic representation of drainage basin hydrological processes

5.2 Input of Water into the Drainage Basin System

5.2.1 Precipitation

- **Precipitation** refers to the conversion and transfer of moisture in the atmosphere to the land. It forms when vapour in the atmosphere cools to its dew point and condenses into tiny water droplets or ice particles to form clouds. Eventually these droplets or ice particles aggregate, reach a critical size and leave the cloud as precipitation.
- In the Tropics, precipitation is mainly in the form of rain (and snow at high altitudes) which provides the initial input of water into the hydrological system. It is also an important factor affecting how rivers behave.
- Depending upon the size of the drainage basin, precipitation totals will influence the **input** (the potential amount of water which can enter a system) and the **output** (the eventual channel flow).
- The basic understanding is that precipitation **varies over space and time** at all scales. This is largely climate-dependent (type, volume, intensity and timing; see **Lect 6** for more detailed explanation). It is important also that we separate water delivery to a river into two stages:
  (1) **the precipitation as it falls (i.e. direct input)**, and
  (2) **what happens to it when it arrives at the surface (i.e. entry into river channel via the various pathways).**

  As only around 10% of global precipitation arrives as channel precipitation, i.e. falls directly on to the river surface, the journey of this second stage is crucial.

5.2.2 Snowmelt

- At high altitude places in the Tropics, the precipitation in a drainage basin may fall as snow rather than rain.
  - For instance, at the summit of Mt Kilimanjaro and the Himalayas, there is a considerable buildup of snow cover during winter which can be considered as surface storage (see **Section 5.3.2**). Here, snow acts as a temporary store of water in the drainage basin. This delays delivery of the water input to the system, lowering river levels (see **Section 5.3.7**).

- Snow cover can be significant in influencing run-off when it melts, such as when in spring or summer. Once a thaw sets in, the volume of melt water can be very high and the speed at which water will rush into the channel is fast, making it prone to flooding (see **Lect 7**).

5.3 Pathways and Storages in the Drainage Basin System

- **Pathways (PW), consisting of different types of flows**, refer to *the paths taken by water as it travels from one storage to another*.
- **Storages (S)** are a vital control on the operation of the system. Storage refers to *the parts of the system that hold or retain water for periods of time*.
  - Each one can be envisaged as a sponge, capable of absorbing and holding water as it travels through the system, but liable to begin to release it while it is filling with water, and eventually becoming so saturated that it releases as much as it takes in.
- Pathways and storages in a water basin are summarised in **Fig. 2** and **Fig. 3**.

5.3.1 Interception Storage (S), Throughfall (P) and Stemflow (P)

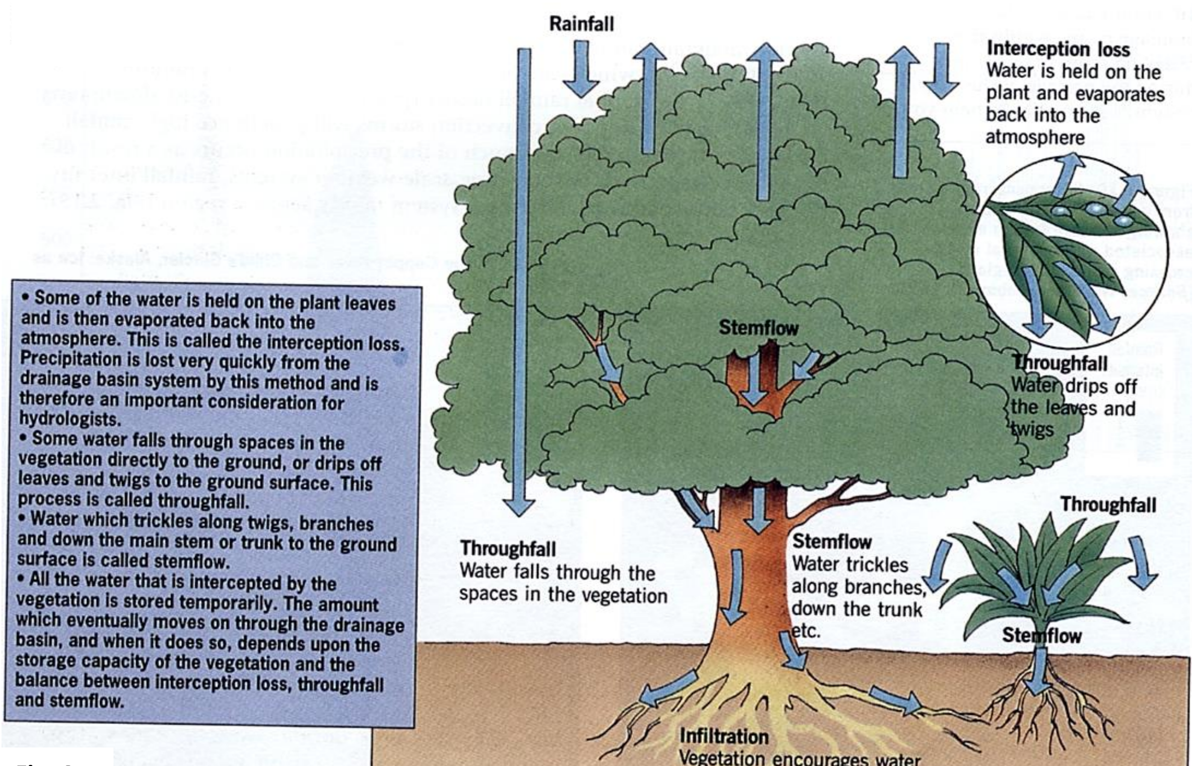


Fig. 4 Vegetation interception

- The amount of incoming precipitation input which reaches the ground surface directly depends not only upon its type, volume, intensity and timing, but also upon **surface cover**.
- <u>**Interception**</u> is ***the part of the rainfall that is intercepted by the earth's surface*** (**Fig. 4**); Earth's surface here includes everything that becomes wet after a rainfall event. It includes: vegetation, soil surface, litter, build-up surface, etc.
  - Interception can amount up to 15-50% of precipitation.
  - **Interception loss**: Water that is retained and later <u>lost as evaporation</u>, after the storm.
  - **Interception storage**: refers to the water that is caught and <u>stored/retained</u> on the surfaces.

- Also, some raindrops will run down branches and the trunks of trees as **stemflow.**

5.3.2 Infiltration (P) and Soil Moisture Storage (S)

- When rain falls on to the land surface, a proportion will, under most circumstances, sink directly into the soil; this is known as infiltration. So, **infiltration** is ***the vertical downward flow of water from surface storage to soil moisture storage***. (See Fig. 3)
  - The ability of a soil to allow the entry of water is referred to as its **infiltration capacity**; this is expressed in terms of the depth of water (in mm) that can infiltrate the soil in a unit of time (one hr) (also called, **maximum** infiltration rate).
- Entry of the rainwater is facilitated by the fact that soil comprises mineral and organic particles which are separated from each other by small spaces known as **pores**.
- These vary in size from less than 0.001mm to several mm in diameter, and interconnect to a greater or lesser extent, depending on the size and shape of the soil particles.
- They thus provide narrow passages, or capillaries, through which the rain water can pass vertically downwards (*percolation*, see later) or laterally on slopes under the pull of gravity (*throughflow*, see later).

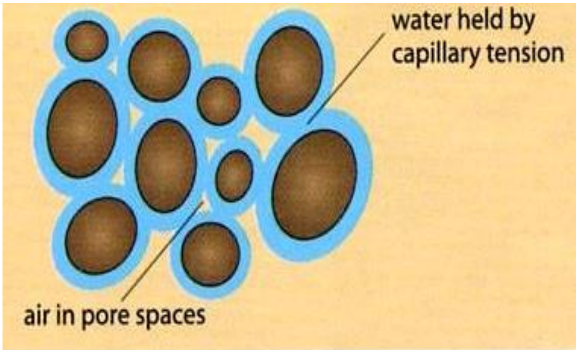


Fig. 5

- Alternatively, the water forms capillary water, held as thin films adhering to individual soil particles by surface tension (**Fig. 5**). The water held in the soil by the molecular attraction is also known as **soil moisture storage**.

5.3.3 Percolation (P), Groundwater Storage (S) and Baseflow (P)

- Water which infiltrates the soil, and is not subsequently removed or utilised by growing plants, will continue to migrate vertically downwards under the pull of gravity, to pass into and through the underlying rock, providing this is permeable. **Percolation is the vertically downward flow of water from soil moisture storage to groundwater storage**.
- This process of **percolation** results in the formation of groundwater (see **Fig. 6**).
  - At depth within the rock, the pores, joints, fractures and bedding planes become filled by this ground water, forming a *zone of saturation*.
  - The uppermost surface of this zone, dividing saturated rock below from unsaturated rock above, is known as the *water table* (this term is also sometimes used loosely to describe the zone of saturation as a whole).
  - The water table fluctuates seasonally in response to changes in recharge, which refers to the replenishment of ground water by percolation.
  - Between the ground surface and the water table lies the *zone of aeration*, as in this zone the spaces within the rock are aerated (unsaturated), but also contain some water which is in transit to the zone of saturation.

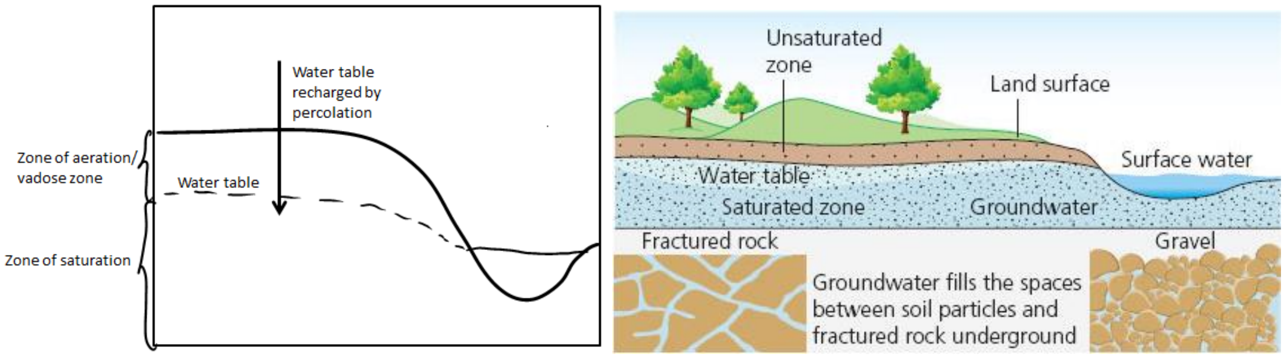
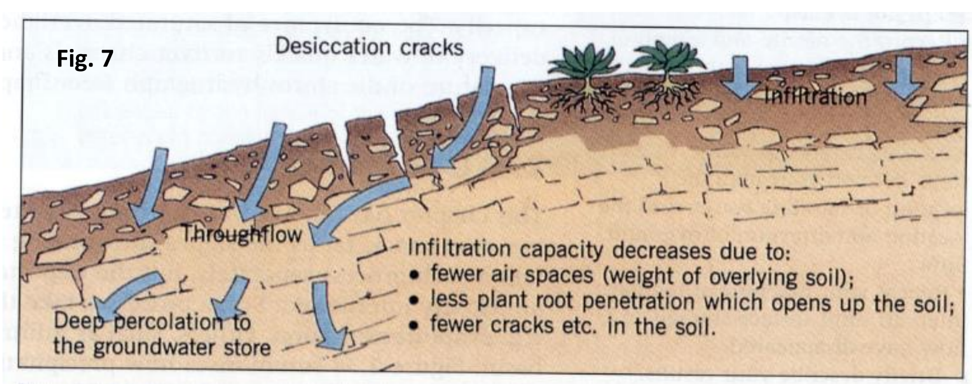


Fig. 6 Groundwater is water that collects underground in the pore spaces of rock

- This deep *groundwater* can, however, escape again to the ground surface (see **Fig. 3**).
    - For example, it can emerge at the base of an escarpment or on the floor of a deeply incised valley as ground water flow or **baseflow**, where the zone of saturation intersects the land surface. Thus baseflow is **the lateral flow of water from ground water storage to channel storage**.
    - In this way, ground water will eventually be returned to the oceans.
- Groundwater amounts to over 24% of the earth's fresh water, and with a further 75% frozen as ice and the tiny remainder making up all the rivers, lakes and soil moisture, groundwater can be seen to be the major supply of water for river flow and for man.

5.3.4 Throughflow (P)

- **Permeability** refers to *the ease with which water flows through a rock/soil/material by its pores and lines of weaknesses* such as joints and bedding planes.
- The permeability of the soil is frequently greater than that of the underlying parent material or bedrock, as in granite, which is largely impermeable. Sandy soils, with large pore spaces, are permeable and will allow water to pass through it easily.
- Alternatively, lower in the horizon of soil may contain a less permeable layer, which restricts the downward passage of soil water (**Fig. 7** on next page).
- In both instances, water will be forced to drain laterally, in a downslope direction. Thus **throughflow** is **the lateral downslope flow of water from soil moisture storage to channel storage.**



5.3.5 Overland Flow (P)

- **The proportion of total rainfall that is not intercepted by vegetation and does not infiltrate the soil, is likely to run over the ground surface as overland flow**. This is water that moves across the surface of the land (hence, also referred to as **surface runoff**) into channels rather than being absorbed by the soil.
- It should be emphasised that overland flow is a temporary process, active only during, and for a relatively short time after, rainstorms of sufficient magnitude.

Types of Overland Flow:

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

- In 1945, R E Horton accepted that when rain falls at a low or even moderate intensity on a slope, the resultant surface water will sink readily into the ground. **This is simply because the rainfall intensity (*i*), perhaps in the order of 1-2 mm/hr, will be less than the infiltration capacity (*f*) of the soil, which may have a capacity to absorb rainwater at a rate of 5-50mm/hr**.
- **However, if *i* is high, as during tropical thunderstorms, or *f* is low, as in clay soils which have been baked by the sun's heat, then surface water cannot penetrate the soil sufficiently rapidly.**
- The excess water therefore accumulates on the soil surface, where initially it will occupy small irregularities, giving rise to depression storage.
- **However, these will quickly fill and then overflow to form a continuous sheet of water flowing down the slope.**
- This type of surface run-off is termed infiltration excess flow (IEF) or **Hortonian overland flow (HOF)** (Fig. 8).
- The layer of water produced when *i* exceeds *f* will move downslope. At the slope base, overland flow enters the stream or river channel, thus contributing to channel flow. (See **Fig. 3**)

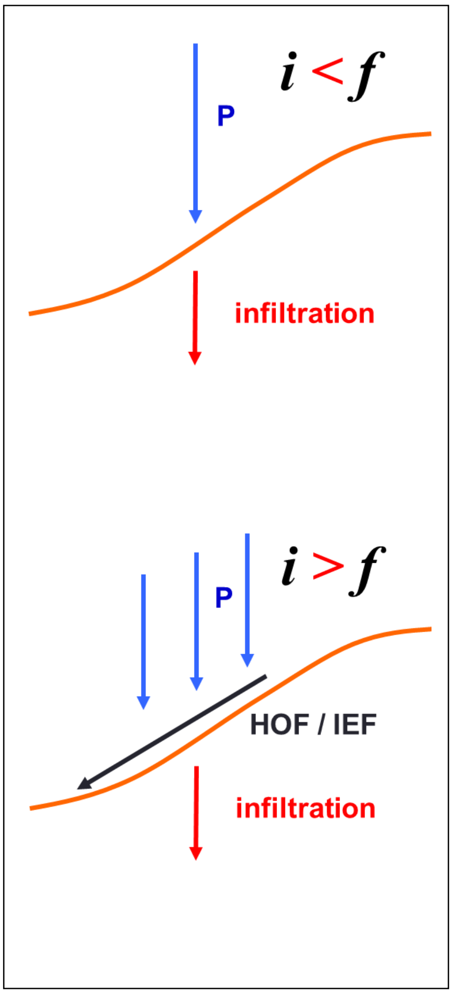


Fig. 8

(b) Saturation Overland Flow (SOF)

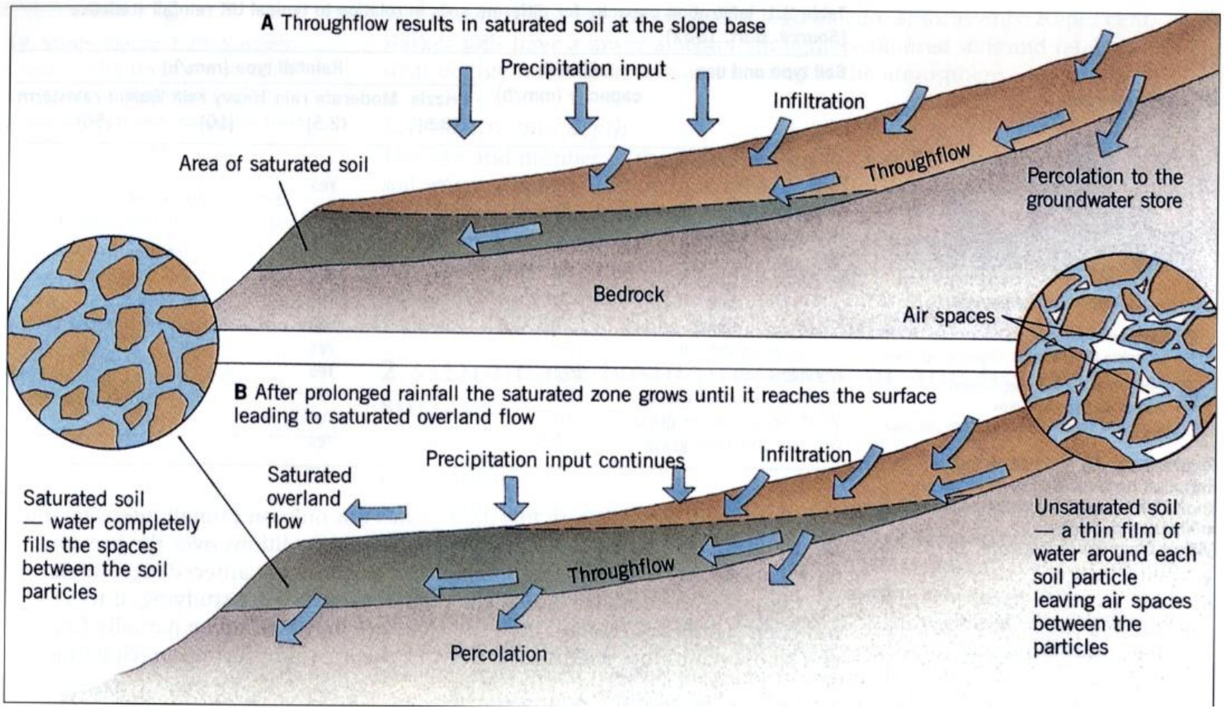


Fig. 9 Processes leading to saturation overland flow

- The presence of permeable top layers in the soil and less permeable lower horizons of the soil can cause **the build-up of water** at the bottom of the slope as the rainstorm proceeds.
- Throughflow will become active, resulting in the downslope migration of soil water. This will cause the soil to **become saturated at the base of the slope**, and then, with the passage of time, the saturated zone will be gradually extended upslope.
- On the lower parts of the slope, this surface flow will be increased because soil water which has migrated from upslope, by way of throughflow, will tend to seep out again (sometimes referred to as *return flow*).
- When **rain continues to fall on this saturated soil** (direct precipitation onto saturated area), it cannot be absorbed, with the result that surface water accumulates and hence overland flow will begin.
- **The combination of return flow and the direct precipitation falling onto the saturated areas** is known as saturation overland flow (SOF). (**Fig. 9**).

5.3.6 Channel Storage

- River channels also act as stores.

- Channels as stores are not always occupied (**Fig. 10**).
- Some channels are dry most of the time, and become occupied only after a rainstorm; these are known as **ephemeral channels**.
- Others are seasonally occupied by flowing water, as in basins when water table rises to the surface in one or more parts of the year; these are known as **intermittent channels**.
- However, many channels are always occupied by some flowing water, and these are known as **permanent** or **perennial channels**.

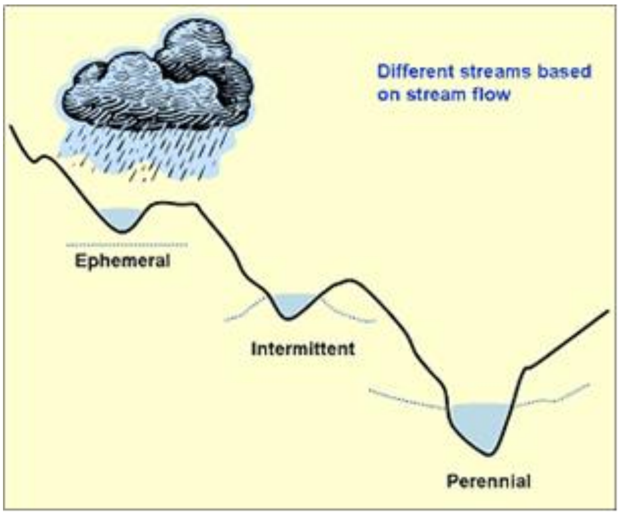


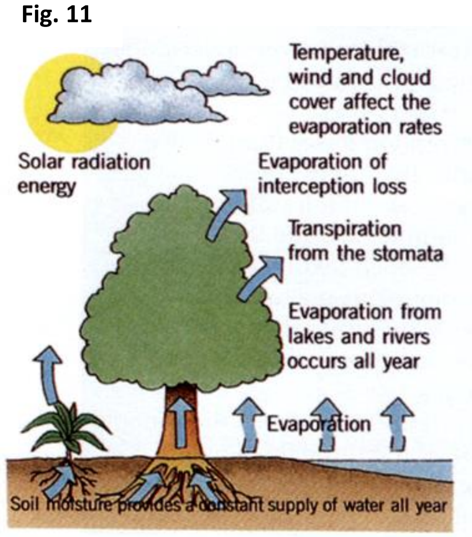
Fig. 10 Ephemeral, intermittent, and perennial channels in ***relation to the groundwater table***.

5.4 Output from the Drainage Basin System

5.4.1 Evapotranspiration

- **Evaporation** is **the return of water from bare soil or open bodies of water (largely ocean surface) to the atmosphere as water vapour.**
- Within drainage basins, evaporation occurs from intercepted water on vegetation surfaces, from bare soil, from artificial surfaces, and from water surfaces such as rivers and lakes.
- Equally important in the drainage basin is transpiration. **Transpiration** is **the transfer of water to the atmosphere through the stomata of vegetation**. Although this water has reached and penetrated the ground surface, it has been taken up by plants and so has not moved on through the basin system. For transpiration to occur there must be a supply of moisture from the soil.
- Except for unvegetated desert and snow or ice fields, the surface will consist of a mixture of bare ground and vegetation. **Thus, evaporation and transpiration are usually at work together as evapotranspiration** (see **Fig. 11**).

Fig. 11



5.4.2 River Discharge

- The channels receive their input indirectly through flows from other stores (see earlier sections), and directly from precipitation that drops into them.
- **River discharge** is a measure of the volume of water moving in a river. It can also be used to describe the output of river water from a drainage basin as the river flows/drains into the sea.

5.5 Glossary

Drainage Basin: The area of land surface from which water and sediment are transferred by individual channels that join up to form a network that eventually drains into an ocean, a sea or a lake

Precipitation: The conversion and transfer of moisture in the atmosphere to the land, which can fall as rain or snow in the Tropics.

Overland flow: The proportion of total rainfall that is not intercepted by vegetation and does not infiltrate the soil, is likely to run over the ground surface as overland flow. Overland flow can be categorised into Hortonian Overland Flow and Saturation Overland Flow.

Infiltration: Infiltration is vertical downward flow of water from surface storage to soil moisture storage.

Percolation: Percolation is a vertical downward flow of water from soil moisture storage to ground water storage.

Throughflow: Throughflow is a lateral downslope flow of water from soil moisture storage to channel storage.

Baseflow: Also known as ground water flow, baseflow is a lateral flow of water from ground water storage to channel storage.

Interception storage: Water that is retained by leaf surfaces and branches of the vegetation.

Soil water storage: Water held in the soil by molecular attraction. These forces acting to retain water in soil are adhesive and cohesive.

Ground water storage: Ground water storage refers to the water that completely fills pore spaces within the zone of saturation.

Channel storage: The volume of water contained in a river channel within the drainage basin.

River discharge: The volume of water moving in a river towards the oceans and seas. Also known as *stream flow*.

Evapotranspiration: Evapotranspiration is the combined loss of water to the atmosphere through transpiration and evaporation.

Water balance: The relationship between the precipitation, evapotranspiration, surface runoff (or overland flow) and storages. Within a basin, it is possible that one or more variables (e.g. precipitation, or evapotranspiration) cause an imbalance, resulting in situations of too much water (e.g. floods) or too little (e.g. droughts).