Lecture 6
Variations in Balance, Stores and Pathways in a Drainage Basin System

KEY QUESTIONS**:

- ✓ *How does the balance between input and output in the drainage basin system vary over time and space?*
- ✓ *How and why do stores in the drainage basin system vary in the tropics?*
- ✓ *How and why do pathways in the drainage basin system vary in the tropics?*

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

- Variations in the balance between input and output over time and space in the tropics due to natural factors
- Variations in stores in the drainage basin systems in the tropics over time and space due to natural and human factors
- Variations in pathways in the drainage basin systems in the tropics over time and space due to natural and human factors

*****Note that these three key questions can only be answered using materials in both Lect 5 and Lect 6.***

Lecture Outline

6.1 Some basics: River Discharge and the Hydrograph
Box 1: Different ways of interpreting river discharge
6.1.1 Components of the Hydrograph
6.1.2 Flashy vs Attenuated Hydrograph

Factors affecting Drainage Basin Hydrology

6.2 Climate
6.2.1 Precipitation
(a) Type **(b)** Seasonality and Amount
(c) Intensity of Rainfall **(d)** Duration of Rainfall
6.2.2 Temperature
Box 2: The effect of climate on the balance between input and output in a drainage basin
6.3 Geology
6.4 Soil Condition
6.5 Slopes of the Basin
6.6 Changes in Vegetation Cover

6.1 Some basics: River Discharge and the Hydrograph

- An important aspect of hydrology is how a drainage basin (recall **Lect 5**) *reacts* to a period of rain. This is important because it can be used to predict flood risks (see **Lect 7**) and make the necessary precautions to avoid damage to property and loss of lives.
- The response of a river can be studied by using the **hydrograph**, which is a means of showing the **discharge** of a river at a specific *gauging station* over time (see the small rectangle within the basin in **Fig. 1**).

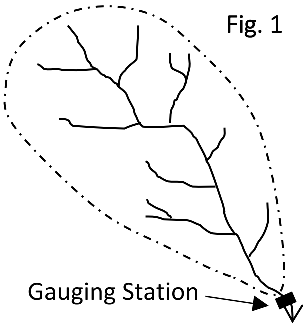


Fig. 1

- Hydrographs show variations in the discharge of a river for a particular rainfall event and for a short period of time, usually hours or days (rather than weeks or months).
- A hydrograph (see **Fig. 3** next page) only describes what happened to the river discharge (see **Box 1**, and also **Lect 5 Section 5.4.2**). **We need to be able to interpret the graph in order to explain what happened (to the other stores and pathways)**. In turn, this will help us to predict and forecast what might happen.

Box 1: Different ways of interpreting **river discharge**

- Discharge is the **volume** of water passing through a particular point of the main river or channel in a unit of time. Mathematically, it is expressed as **Q = AV**, where Q is the discharge (m^3/s), A is the cross-section area (m^2) of the channel, and V is the velocity (m/s) of the channel flow.
- This volume of water originates as precipitation which reaches the river or channel by surface *runoff (overland flow)*, *throughflow* and *baseflow* (see **Fig. 2A** and **2B**). Discharge is therefore also understood this way: **Discharge = Overland flow (or Surface flow) + Throughflow + Baseflow**
- Recall from **Lect 5** that, if P (precipitation) is the input, E (evapotranspiration) and R (channel flow/**discharge**) are the outputs, and S refers to the various storages within the basin, then **P = E + R ± S**. This reminds us that discharge (whether represented either by Q or R) forms an important part of the basin water balance.

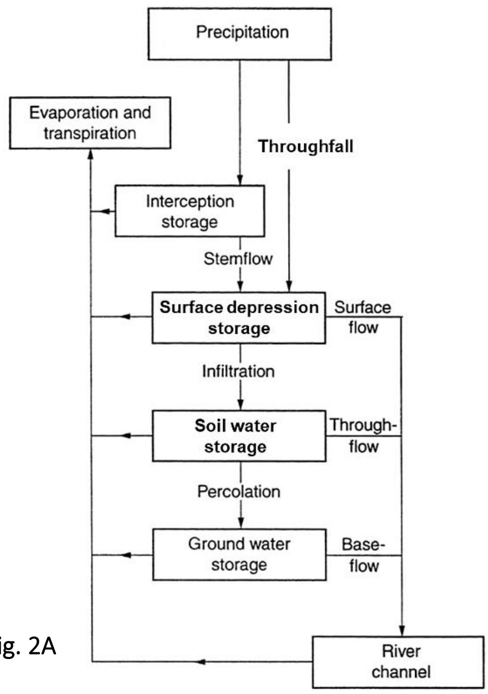


Fig. 2A

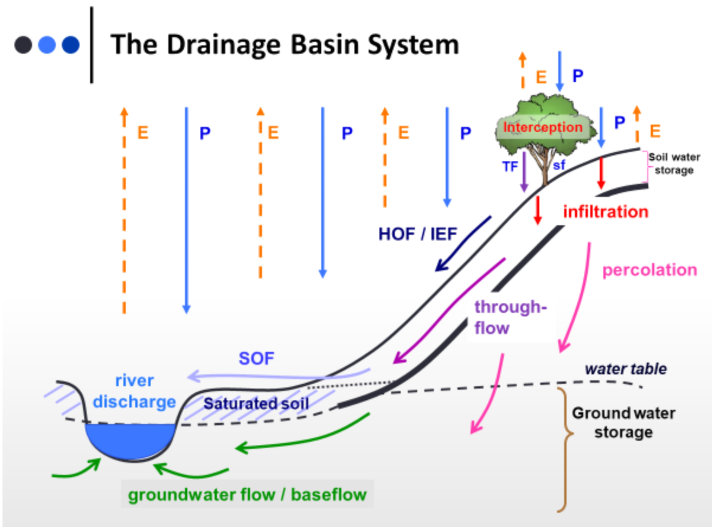


Fig. 2B

6.1.1 Components of the Hydrograph

- In order to show the relationship between the precipitation (input) and the channel discharge (output) past the gauging station, most (not all) hydrographs will include the **rainfall graph** (see **Fig. 3**). This relationship is important because it determines the speed and scale of the rise in discharge, and therefore the likelihood of flooding (see **Lect 7**).

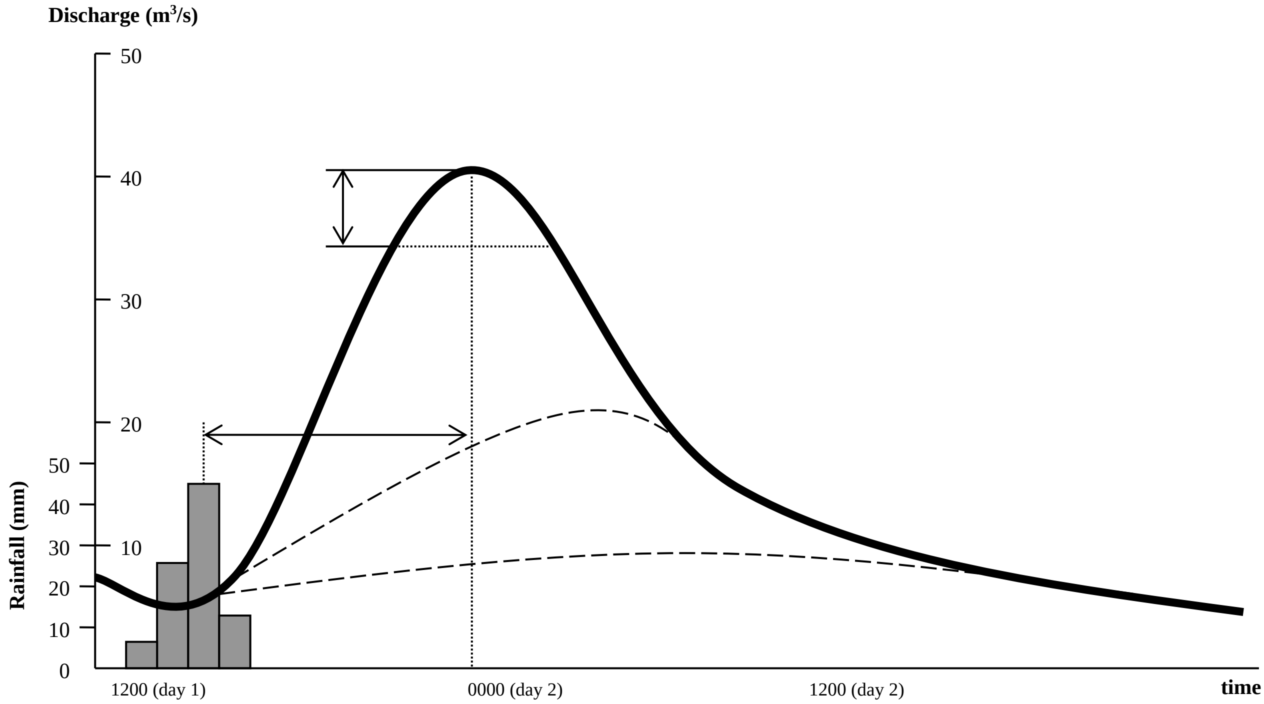


Fig. 3 Components of the hydrograph

- The discharge has three constituent parts (see **Box 1** again):
  - **When the rainstorm begins, the river discharge does not respond immediately** to rainfall inputs as only a little of the rainfall will fall directly into the channel while the rest falls elsewhere in the basin which either gets intercepted, stored on the surface, or infiltrated, and takes time to reach the channel.
  - **Surface flows reach the channel faster than the sub-surface flows.** The river will start to respond initially through inputs from **overland flow** (the fastest flow of water) and its discharge will later be supplemented through inputs from **throughflow** and **baseflow**.
- When the initial overland flow and, later, throughflow eventually reach the channel, there is increase in discharge in the channel. This rise in discharge (volume of water or water level) in the channel after a rainfall event starts is indicated by the **rising limb** in the hydrograph.
  - The steeper the rising limb means the faster the channel's response to rainfall i.e. water reaches the channel very quickly. This is usually due to overland flow and throughflow. (Collectively, overland flow and throughflow are known as **storm flow**.)
  - Conversely, the gentler the rising limb implies a slower response due to little storm flow.
- Baseflow is very slow to respond to a storm, but by continually releasing groundwater it maintains the river's flow during periods of low precipitation. Indeed, baseflow is more significant over a longer period of time than an individual storm.
- The **peak discharge** (or peak flow) is the *maximum discharge in the channel which occurs when the river reaches its highest level for a particular rainfall event*.

- Recall that storages delay the conversion of input to output, of precipitation to runoff. The time difference between maximum precipitation and peak discharge in a drainage basin is referred to as the **lag time**.
  - The lag time reflects the time needed both for the rain to generate overland flow, and for that overland flow to pass downslope into the channel.
- The **falling limb** is the segment of the hydrograph where water is still reaching the channel but discharge is decreasing and river level is falling. This segment is usually less steep than the rising limb as although the rainfall has stopped, the system of storages might be sufficiently well-filled to be discharging continuously (via throughflow and baseflow) and so response to the decline in input is much more gradual.
- By the time all the water from the rainstorm has passed through the channel at a given location, the river will return to its baseflow level (i.e. the level before the storm) unless there has been another storm within the basin.
- Finally, on the hydrograph, **bankfull discharge** (BD) occurs when a channel is completely filled with water from the top of one bank to the other. **In other words, when peak discharge (PD) or water level reaches the top of its channel, any further increase in discharge will result in flooding of the surrounding land (i.e. PD > BD ➔ flooding).**

6.1.2 Flashy vs Attenuated Hydrograph

- The shape of a hydrograph is determined by the *speed* with which rain water is able to reach the channel. This speed is in turn influenced by a range of factors (see **Section 6.2**).

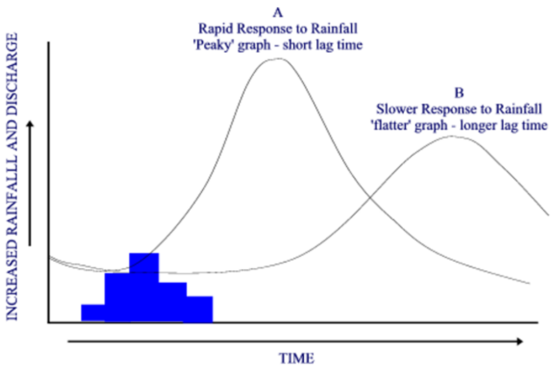


Fig. 4

- The fastest route of rain water to the river channel is via **overland flow**. If most of the rainwater in a drainage basin travels as overland flow, a river will respond quickly and the hydrograph shape will be **'flashy'** (graph A) with high discharge, steep rising and falling limbs. **The lag time will be short and there will be a greater risk of flooding**. (Floods will be our focus in **Lect 7-9**)
- Whereas if more rainwater in a drainage basin is able to pass into the soil via infiltration and travel to the river as **throughflow and baseflow**, there will be a slower rise in discharge and the river will respond slower and the shape of the hydrograph will be **'attenuated'** or **'flatter'** (graph B) with gentle rising and falling limbs. Compared to the flashy hydrograph, **the lag time will be longer and the risk of flooding will be much lower** (though not impossible!)

↓ infiltration ➔ ↑OVF (fast flow) ➔ Q increases rapidly ➔ 'flashy' hydrograph
↑ infiltration ➔ ↑ TF and ↑ BF (slower flows)➔ Q increases slowly ➔ 'flatter' hydrograph

Factors affecting Drainage Basin Hydrology

6.2 Climate

6.2.1 Precipitation

(a) Type of Precipitation

- The type of precipitation closely controls **the amount and timing of surface flow**.
- If the precipitation in a drainage basin falls as snow rather than rain, snow on the ground can act as a **store** producing an attenuated hydrograph with longer lag time and gentle rising limb with less possibility of flooding (see **Lect 5 Section 5.2.2**).
- Snow cover can be significant in influencing surface flow when it melts, such as when in spring or summer. Once a thaw sets in, the rising limb might become steep if the volume of melt water is high and the speed at which water will come into the channel is fast. Thus, with short lag time and high peak discharge, the channel might be prone to flooding.

(b) Seasonality and Amount of Rainfall

- The seasonality (i.e. wet and dry seasons) and the amount of rainfall associated with the different climates directly determines **how much input enters the drainage basin system**. (Eventually, the amount of input must be compared against the output to derive the water balance in a drainage basin system; see **Lect 5 Section 5.1**)
- For Af and BWh/BSh climates, there are no wet or dry seasons, so the amount of rainwater entering the drainage basins in these climate zones will be consistently high and very scarce respectively. The stores and pathways in these basins will not vary much over the year.
- In contrast, drainage basin systems in Am and Aw climates may undergo shifts between receiving more input in wet months and receiving very little in dry months. These seasonal changes will in turn influence the occurrence of the pathways as well as how much water gets stored in the various storages.

(c) Intensity of Rainfall

- The intensity of rainfall is one of the most important factors in determining **the proportions of the rainfall that go to the channel and how quickly this happens**. It has a significant effect on the route water takes through the drainage basin system, and eventually upon river discharge.
- Rain falling at **lower intensities** will be largely absorbed by the soil if the soil is permeable, so that water flow to the channel will be much delayed resulting in a hydrograph with longer lag time, gentle rising limb, low peak discharge and less possibility of flooding. For example, a steady drizzle of about 0.5 mm/hr will infiltrate more readily into the ground compared to even a moderate rainfall of 3 mm/hr.
- On the other hand, when rainfall **intensity is high** and exceeds infiltration capacity of the soil, it can produce rapid overland flow (HOF) resulting in a hydrograph with short lag time, steep rising limb, high peak discharge and more possibility of flooding.

(d) Duration of Rainfall

- If the duration of rainfall is **prolonged**, <u>initially</u> the infiltration rate will be high provided the soil is permeable. But <u>over time</u> the infiltration capacity of the soil will decrease, as the size of the saturated zone may increase over time.

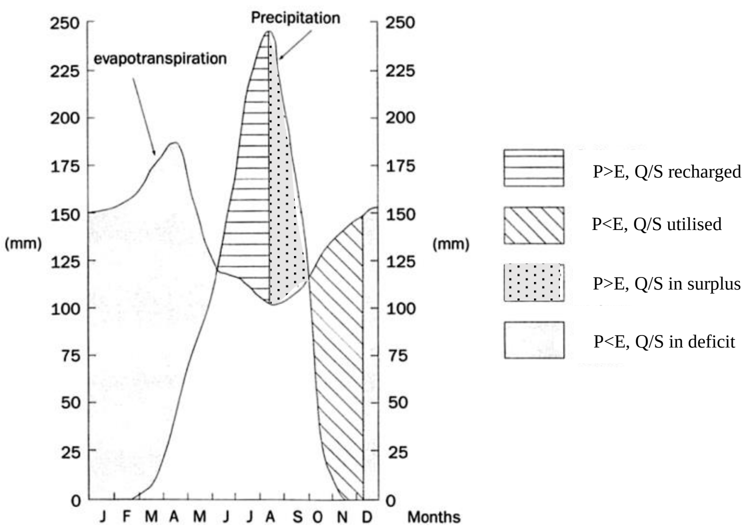
- Therefore, **the longer the rain** continues, **the infiltration capacity will be exceeded** as the storm progresses until the eventual saturation of the soil leading to the contribution of saturated overland flow (SOF) to the basin, as the rain continues to fall on the saturated soil.
- This gives the hydrograph a gentler rising limb at the beginning of the rainfall event but after the soil gets saturated the rising limb will become steeper due to high SOF flowing into the channel faster and flooding might be possible. (See **Fig. 9** later)

6.2.2 Temperature

- Extremes of temperature can **restrict infiltration** and **increase overland flow**. If there have been extreme temperatures, the ground can be hard (either baked or frozen) causing less infiltration and rapid HOF. Thus, the hydrograph will be flashy with short lag time, steep rising limb, high peak discharge, steep falling limb and higher possibility of flooding.
  - In B climates, grounds that have been baked in the sun discourage infiltration. This means that when rainfall intensity is high (as is often the case in such climates when rain does arrive), the soil is unable to absorb the rain, leading to HOF (and often, flash floods).
- Another way temperature affects drainage basin system is in how it **influences evapo-transpiration**. Overall, higher temperature would mean higher evapotranspiration.
  - *Evaporation*: Temperature is a key factor in determining the rate of evaporation. As temperature increases, evaporation increases. Warmer air can hold more water vapor, which further promotes evaporation. Therefore, higher temperatures generally result in increased evaporation from interception, surface, soil water and channel storages.
  - *Transpiration*: Transpiration refers to the process by which plants release water vapor through their leaves. In warmer temperatures, plants tend to open their stomata wider to allow for increased gas exchange and carbon dioxide uptake for photosynthesis. Consequently, more water is lost through transpiration.

<u>**Box 2**: The effect of climate on the balance between input and output in a drainage basin</u>

- In Box 1, we are reminded that **Precipitation – Evapotranspiration = Discharge ± Storages**
- By pulling together **Sections 6.2.1 and 6.2.2**, we can represent graphically how climate can affect the water balance in a basin, including discharge, over time.
- Example: The figure on the right shows a typical graph for a drainage basin in West Africa (i.e. northern hemisphere) which experiences the **Aw climate**. Precipitation is greater than evapotranspiration (P > E) between June and September, whereas evapotranspiration is greater than precipitation (P < E) between October and May.



6.3 Geology

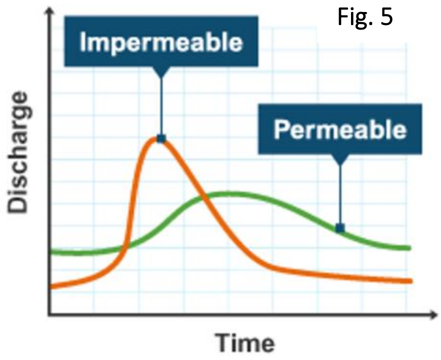


Fig. 5

- The geology of a catchment area will also exert a fundamental influence in overland flow. Especially important are the types of rock into which the basin has been eroded, and the main structural features of the area.
- Rocks vary in their permeability (that is, the ability to let water pass through). Permeable rocks mean rapid infiltration and little overland flow therefore gentle rising limb and low peak discharge (see **Fig. 5**), resulting in less possibility of flooding.
  - Rocks may transmit water efficiently if they are well-jointed. For example, carboniferous limestone (a hard sedimentary rock formed from the remains of organic matter) generally has joints and bedding planes which give it more permeability (see **Fig. 6**). Thus limestone will infiltrate more rainwater than other crystalline igneous and metamorphic rocks.
  - However, crystalline igneous and metamorphic rocks often have low permeability. In moist environments, drainage basins underlain by such impermeable rocks, which prevents percolation will encourage throughflow and overland flow. (More on rocks in **Lect 10**).

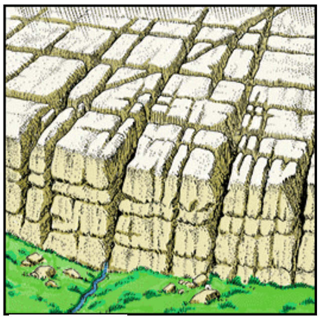


Fig. 6

6.4 Soil Condition

- Similar to the role of geology (see earlier), **by controlling the rate and volume of infiltration**, soil condition will influence the amount of soil moisture storage and the rate of throughflow, and in turn may affect surface runoff, hence determining whether hydrographs are flashy.
- Several factors control the infiltration capacity of a soil. These include:
  - **Soil texture**, which is determined primarily by the proportions of the constituent particles, such as sand, silt or clay, present in the soil. See **Fig. 7**.
    - ✓ Where the texture is coarse, as in gravels and sands, the pore spaces are large and have a high degree of connectivity. In this case the soil is both porous (that is, can hold water) and permeable (in other words, readily allows the entry and passage of water).
    - ✓ However, where texture is fine, as in clay soils, the pore spaces, though possible very numerous, are much smaller. Water which succeeds in entering the soil actually becomes trapped within the pores by surface tension, rather than passing through them, so that the soil is relatively impermeable.

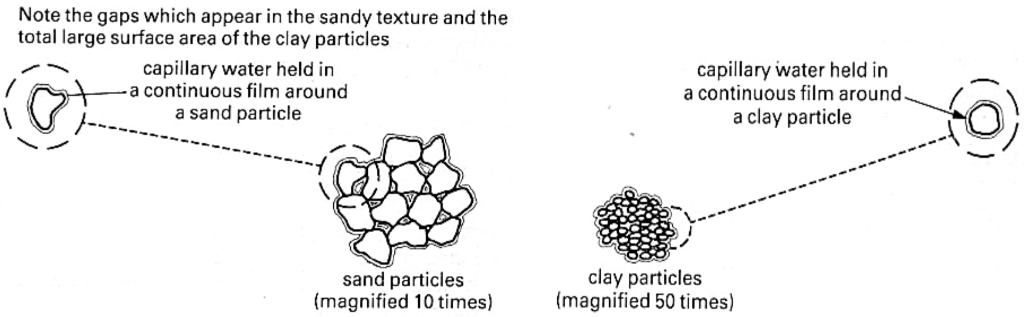


Fig. 7

- The **presence of plant roots, animal burrows and worm-holes** in the soil, which provide readymade passages for infiltrating rainwater.
- The **degree to which the soil has been compacted**, for instance, by agricultural vehicles such as tractors and harvesters, or trampling by humans and animals along well used tracks.
- The **presence of antecedent moisture**, that is, water from a previous rainstorm which still fills the soil pores, and thus impedes infiltration to generate more overland flow instead.

6.5 Slopes of the Basin

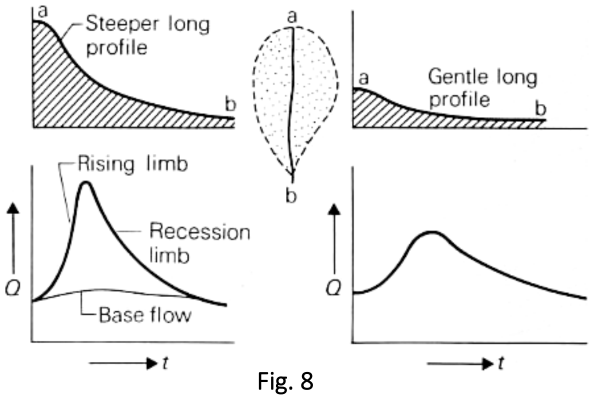


Fig. 8

- A drainage basin with steep slopes is likely to experience more and faster overland flow and less throughflow and baseflow because there is less time for water to be infiltrated from surface to soil-moisture storage.
- These would lead to a shorter lag time and higher peak discharge on the hydrograph as more water arrives downstream at about the same time, yielding higher discharge values. Thus steep slopes will have flashy hydrographs and more prone to flooding.
- On the other hand, a basin, which has gentle slopes and low relief, has its overland flow more spread out over time (see **Fig. 8**), leading to lower discharge values (hence an 'attenuated' hydrograph) and less possibility of flooding as the rainwater gets more time to infiltrate and flows slowly over the surface to reach the channel.

6.6 Changes in Vegetation Cover

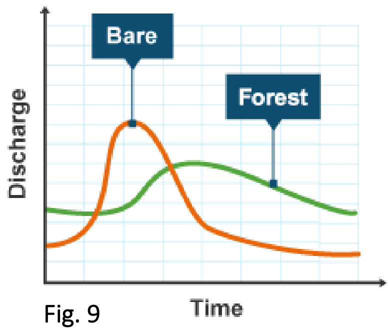


Fig. 9

- Vegetation influences the stores and pathways in a basin in significant ways (see **Fig. 9**), apart from **evapotranspiration**.
- Vegetation **intercepts rainfall** and can temporarily reduce the amount of water for subsequent stores and pathways.
- Vegetation **promotes infiltration**. Surface water movement is retarded (e.g. water cannot easily flow across a slope) and hence giving more time for infiltration. Plant roots form pathways in the ground for water to infiltrate, increasing infiltration capacity. Also, organic matter makes soil more porous (see **Section 6.4**).
- Changes in vegetation cover therefore affect interception, infiltration, overland flow and percolation. For instance, **deforestation** and **conversion of land use to agricultural land** can result in lower infiltration and hence higher overland flow. Thus, the hydrograph will be flashy.
- **Urban development** increases peak discharge and shortens lag time (**Fig. 10**). This is due to an increase in the proportion of impermeable ground (e.g. concrete, tarmac) in the drainage basin as well as the network of sewers and drains).

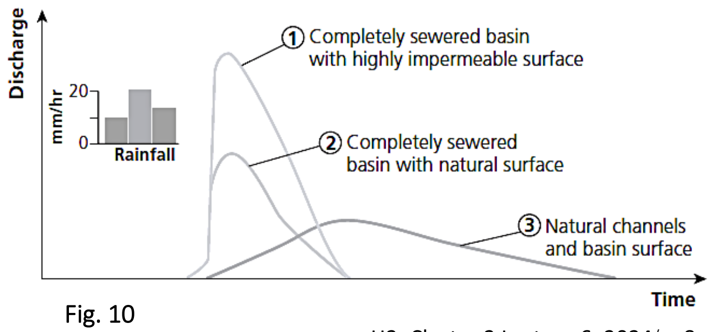


Fig. 10

Overview of Factors Affecting A Drainage Basin's Input, Stores, Pathways and Output

	Climate – Rainfall characteristics and Temperature			Geology and Soil conditions	Basin topography	Vegetation cover
	Af	Am/Aw	BWh/BSh			
Input (type, amt & characteristics)						
Infiltration						
Overland flow						
Soil water storage						
Percolation						
Throughflow						
Ground water storage						
Baseflow						
Channel storage / River discharge (Q)						
Evapotranspiration						