LECTURE OBJECTIVES

- Discuss the human and physical factors that influence the occurrence of floods
- Discuss the socio-economic and environmental effects of floods
- Evaluate hard and soft engineering strategies to manage floods

(A) Different Types of Flooding in the Tropics

River (Fluvial) Flood occurs when the actual discharge in a river channel exceeds its bankfull discharge (Fig. 1) resulting in high flow of water overtopping the banks of a river channel onto the surrounding floodplain.

River floods occur when there is a sudden excess of input into the river channel which causes actual discharge to exceed bankfull discharge. Thus, river floods tend to occur during instances of prolonged and/or intense rainfall as well as when there has been abundant snowmelt.

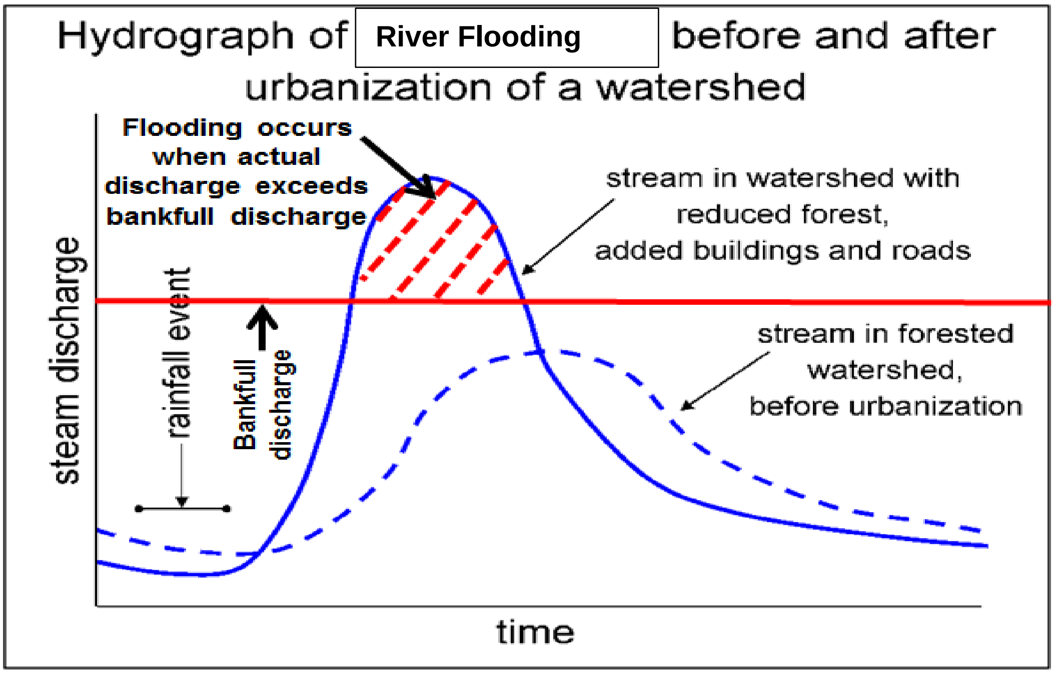


Figure 1: Hydrograph illustrating when river floods occur

Coastal Flood occurs at coastal areas and it involves an area being inundated/flooded by seawater. This could occur due to **storm surges** from cyclones, or sea level rise from climate change. Naturally, these types of flood event take places near coastal areas.

We will focus more on fluvial flooding for this cluster and notes.

(B) FACTORS THAT CAUSE RIVER FLOODS

River floods occur when there is a ***SUDDEN EXCESS OF INPUT*** (precipitation) into the river channel which causes ***actual discharge to exceed bankfull discharge***. Therefore, river floods may occur during instances of prolonged and/or intense rainfall as well as when there has been abundant snowmelt.

1) Prolonged and/or Intense Rainfall

The **main cause** of most river floods is ***prolonged and/or intense rainfall*.** This is usually due to the occurrence of atmospheric processes such as monsoon rains or tropical cyclones. For example, in India, up to 70% of the annual rainfall occurs in 100 days during the summer south-west monsoon from June to September. This results in many instances of river floods during this period.

Prolonged rainfall may cause the ground to become saturated and result in **higher rates of** [1]***saturation overland flow***. On the other hand, intense rainfall may also result in flooding as the intensity of rainfall may exceed the [2]***infiltration capacity*** of the ground and generate [3]***hortonian overland flow/infiltration excess flow*** (water flow horizontally across land surfaces when the rainfall has exceeded infiltration capacity). As overland flow travels at high speeds into the river channel compared to throughflow and baseflow, this causes the discharge in the channel to behave in a flashy manner, with short lag time and high peak discharge. Due to the higher level of actual discharge present, the river discharge may then overflow its banks and result in a flood occurring.

[1] **saturation overland flow** refers to the water flow horizontally over land surfaces when the soil has become saturated with water

[2] **infiltration capacity** refers to the maximum rate at which the soil allows water to infiltrate

[3] **hortonian overland flow/infiltration excess flow** refers to the water flow horizontally over land surfaces when the rainfall has exceeded infiltration capacity

2) Abundant Snowfall Followed by Rapid Snowmelt

A less common cause of river floods in the Tropics is the occurrence of abundant snowfall at HIGH ALTITUDES during winter and subsequently the rapid melting of accumulated snow during spring. The rapid melting of the accumulated snow generates a very large amount of water to flow into the river channels in a very short period of time and this may cause actual discharge to exceed bankfull discharge.

Furthermore, as the ground may still be frozen and largely impermeable, the melted snow may largely flow as surface overland flow into the river. As surface overland flow travels at high speed into the river channel compared to throughflow and baseflow, this causes the discharge in the channel to behave in a flashy manner, with short lag time and high peak discharge. For example, in 2011, The Brahmaputra River in India experienced flooding due **IN PART** to the melting of large amount of snow from the previous winter as well as rainy weather during the summer.

3) Extreme Weather Events: El Nino and Tropical Cyclones

As we have learnt in previous lectures, extreme weather events such as El Nino and Tropical Cyclones can also lead to fluvial or coastal flooding. Tropical Cyclones can cause both types of flooding as the additional rainfall bought about by the spiralling rain bands can serve as additional input into the channel leading to fluvial flooding. It could also create storm surges that leads to coastal flooding.

Similarly, an El Nino event will bring about additional rainfall to places like Peru which could lead to fluvial flooding.

(C) THE FACTORS BELOW DO NOT DIRECTLY CAUSE RIVER FLOODS TO OCCUR BUT INFLUENCE THE FREQUENCY (LIKELIHOOD) AND MAGNITUDE (EXENT) OF FLOODING.

I. NATURAL FACTORS

1) Characteristics of the Drainage Basin

The characteristics of the drainage basin that can influence the frequency and magnitude of flooding include the

(a) extent of vegetation cover

(b) relief

(c) permeability of the ground surface

(d) antecedent soil moisture (conditions of the soil preceding a storm event)

(e) shape of drainage basin and

(f) drainage density.

The first four factors, namely, the **extent of vegetation cover**, **relief**, **permeability of the ground surface** and the **amount of antecedent soil moisture** ***influence the rate of infiltration*** taking place and the generation of surface runoff.

The extent of vegetation cover and permeability of the ground surface have a positive relationship with infiltration rates while relief and antecedent soil moisture have a negative relationship with infiltration rates. Thus, these factors may influence the frequency and magnitude of flooding as lower infiltration rates will result in greater amounts of surface runoff. This causes a river to become flashier and may cause actual discharge to exceed bankfull discharge, thus increasing both the frequency as well as the magnitude of flooding.

II. ANTHROPOGENIC (HUMAN) FACTORS that could influence/cause flooding

Human activities can influence the frequency and magnitude of flooding by creating conditions in the drainage basin that reduce infiltration capacity and encourage overland flow, resulting in a flashy response in river discharge to a precipitation event and increases the frequency and magnitude of flooding.

1) Modification of Characteristics of the Drainage Basin

Changes in land-use / surface cover refer to activities such as urbanisation, deforestation and agriculture.

- **Urbanisation** leads to many impermeable surfaces such as tarmac and concrete, which provide minimal surface storage capacity and have low infiltration capacity. This results in more overland flow occurring during precipitation events. Furthermore, urban areas have elaborate drainage networks which remove water quickly and efficiently. Due to these reasons, river discharge will be flashier and increases the frequency and magnitude of flooding.

- **Deforestation** increases overland flow as it reduces the amount of interception and evapotranspiration. Protected soil have much higher infiltration capacities than soil on barren land. Dense forests intercept raindrops and protect the soil from compaction by rain and deliver water at a more even rate for infiltration due to stemflow. This decreases the amount of overland flow that occurs. With deforestation, the amount of overland flow increase. Furthermore, with less evapotranspiration occurring, more water will end up in the river channel, potentially increasing the peak discharge, thus increasing the frequency and magnitude of flooding.

- **Agriculture** may also influence the frequency and magnitude of flooding. Poor farming practice such as overgrazing reduce vegetation cover and compacts the soil, decreasing the infiltration capacity of the ground, and increasing the potential for overland flow to occur. Such practices may also result in increased transportation of sediments into the river and reduce the channel's level of bankfull discharge, thus increasing the frequency and magnitude of flooding.

2) Modification of the River Channel [Channelisation, Dam Failure, Levee Breach]

- **Channelisation** is the straightening of the river channel. While this is intended to increase the discharge of the river, this fixes the bankfull discharge of river channels and they cannot naturally adjust their shape in response to the amount of discharge flowing through them. Thus, the frequency of flooding is greater in such areas, especially if the canal is old, and there have been rapid urban developments to increase the discharge of the river upstream.

  Channelisation also increases the risk of flooding downstream as the smooth surface of the channelised rivers, coupled with their hydraulically efficient cross-sectional designs, allow discharge to flow at a faster rate than normal, increasing the likelihood that the actual discharge downstream may exceed the bankfull discharge.

- **Dams** are structures built to impound water, generate energy through hydropower and also to control flooding. Dams help to control flooding by storing water upstream during times of high discharge and only releasing the water slowly during times to low discharge to prevent downstream areas from flooding. However, when dams are not built or maintained well, it can be breached or overtopped, leading to fluvial flooding. A recent dam failure would be the Laos Dam collapse in 2018 where Saddle Dam D, part of a larger hydroelectric dam system, collapsed due to poor construction resulting in 40 deaths and over hundreds reported missing and unaccounted for.

- **Man-Made Levees** are another type of structure built to prevent rivers from overflowing their banks and causing floods. However, levees can <u>**breach and fail**</u> which lead to flooding as well. The massive impact of flooding from Hurricane Katrina is also due to numerous levee breaches and failures along the Mississippi river.

3) Human Activities which Influence Climate

Human-induced climate change due to excessive emissions of greenhouse gases results in <u>***ENHANCED GREENHOUSE EFFECT***</u> which causes average global temperature to rise and increases the number of <u>extreme weather events</u> such as the occurrence of tropical cyclones which bring with it very intense rainfall. Thus, this increases the likelihood of river floods occurring.

[<u>**Synoptic Idea:**</u> *Human induced climate change leads to warmer sea surface temperature and also increases the frequency of El Nino events which could lead to different types of flooding.*]

(C) <u>WHAT ARE THE EFFECTS OF RIVER FLOODS?</u>

Environmental effects of flooding → Social, Economic, Political effects

1) Increasing Nutrient Levels of Soil

A positive impact of floods is that floods leave nutrient-rich soil behind. Floods distribute and deposit river sediments over large areas of land. These river sediments replenish nutrients in topsoil and make agricultural lands more fertile.

For example, the populations of many ancient civilizations concentrated along the floodplains of rivers such as the Nile, the Tigris and the Yellow because periodic flooding resulted in fertile, productive farmland. The construction of the Aswan High Dam in Egypt prevented the Nile from flooding major population centres downriver but it also depleted once fertile agricultural lands along the banks of the river.

2) Preventing Erosion and Maintaining Land Mass Elevation

Another positive impact of flooding is the preventing of erosion and maintaining of land mass elevation. For example, the land of the Mississippi River Delta is disappearing because dikes and levees prevent floods from depositing new soil. Alluvium (soil) deposited by flood waters prevents erosion and helps maintain the elevation of land masses above sea level. The rapidly receding land of the Mississippi River Delta is a direct result of man-made flood controls and levees that prevent topsoil-replenishing sediments from being deposited in the delta.

3) Recharging and Replenishing Ground Water

Another positive impact of flooding on the natural environment is that flooding recharges and replenishes the ground water. Many population centres depend upon ground water and underground aquifers for fresh water. Flood waters infiltrate into the ground and percolate down through the rocks to recharge these underground aquifers which supply natural springs, wells, rivers and lakes with fresh water.

4) Destruction of Lives and Property

The negative impacts of flooding include the destruction of lives, crops, infrastructure and properties, the disruption of the local economy, as well as the contamination of wells. This can be observed in the case of the Pakistan flood. In August 2010, Pakistan experienced devastating river flood, when at the end of July 2010 the north-west province of Khyber Pakhtunkhwa (KPK) was hit by a five-day period of exceptional precipitation, including 60 hours of continuous rainfall. While Pakistan is used to receiving intense rainfall especially during the wet monsoon months from June to September, the precipitation level in this case was described as 'once in a century'.

As a result, one-fifth of the country was submerged by the floods. More than 11,000 villages were inundated and 1.2 million houses were damaged or destroyed. Furthermore, an estimated 7 million hectares of the most fertile arable land was obliterated. The cost to agriculture was put at US$2.4 billion. However, the number of deaths attributed to the flooding remained surprisingly low, at 1600. Nonetheless, the overall number of people affected by the floods at 14 million made this a disaster on a scale unmatched in recent years, more than the number of people affected by the 2004 Indian Ocean tsunami. Many were left homeless, starving and some suffered diseases such as cholera due to the flood. Many farmers also lost their livestock, their main source of income.

(D) FACTORS INFLUENCING THE DEGREE OF IMPACTS OF RIVER FLOODS

I. NATURAL FACTORS

1) Magnitude and Frequency of Flood Events

A physical factor that can affect the degree of impact of floods is the frequency and magnitude of the flood events themselves. In general, large magnitude floods have lower frequencies than smaller magnitude floods. This can be calculated using flood recurrence intervals (see next section). Thus a 1 in 10 chance would be a 10 year flood, 1 in a 100 chance would represent a 100 year flood. Larger magnitude floods can be assumed to be more dangerous in terms of its impacts due to its scale of flooding, as well as its rarity which may have caught populations off-guard and unprepared.

For example, at the end of July 2010, the north-west province of Khyber Pakhtunkhwa (KPK) was hit by a five-day period of exceptional precipitation, including 60 hours of continuous rainfall. While Pakistan is used to receiving intense rainfall especially during wet monsoon months, such precipitation was described as 'once in a century' levels of rainfall that had resulted in one-fifth of the country being submerged by the floods.

2) Time of Occurrence of Flood Event

Another physical factor that can affect the degree of impact of floods is the time of occurrence of the flood event itself. This is because emergencies which occur at night tend to result in greater casualties as people may be sleeping and are thus less alert and responsive to events which are occurring.

For example, in 2012, the town of Krymsk in Russia was devastated by flash floods during the night. More than 200 people were hospitalised. Flood warnings were given using sirens, SMS messages and loudspeakers but many people were asleep at that time and did not hear them. Thus, this shows how the time of occurrence of the flood event may have caused the damage to be greater than if it had occurred during the day.

3) Presence of Secondary Impacts (Outbreak of Diseases)

Another physical factor that can affect the degree of impact that floods may have is the potential outbreak of diseases, which is a secondary impact of flooding. This is because people are vulnerable to various diseases following a flood event. Water supplies are disrupted and become contaminated. A major threat comes from cholera, which is an infection of the gut causing severe diarrhoea and vomiting. It can also lead to dehydration and, in extreme cases, even death. For example, the 2010 flood in Pakistan has led to more than 100 reported cases of cholera affecting the flooded areas.

II. <u>ANTHROPOGENIC (HUMAN) FACTORS</u>

1) Level of Development of a Country

Besides physical factors, there are also human factors which can affect the degree of impact of floods. One such human factor is the level of development of a country. All things being equal, a poor country, with its less rigorous building and planning standards and its inability to cope with the aftermath of a flood, will suffer greater loss of life, homelessness and loss of livelihood (not to mention extensive damage to properties) than a rich country.

For example, in the case of Hurricane Katrina (2005) and its associated flooding of the Mississippi River, the US government has spent over US$800 million on rebuilding flood defences as a form of long-term response. Around US$34 billion has also been set aside for the re-building of common properties like houses and schools. This is unlikely to be carried out in a less developed country that have much fewer resources (in terms of monetary capital, technological expertise or know-how) and thus are unable to be dedicated towards recovery from such a flood event.

2) Level of Preparedness / Management Available to Mitigate (Lower) the Impacts of Flooding

Another human factor which can affect the degree of impact of flood is the level of response carried out in the case of occurrence of floods, especially in terms of search and rescue. This is because quick and adequate response allows lives to be saved and victims to return back to their normal lives.

In the case of Pakistan in 2010, its flood response was criticised for being slow, uncoordinated and ineffective. After a week of flooding the government had still failed to provide any emergency supplies: no food, water, tents, blankets or medicines. It was also late in setting

up camps to house refugees. Furthermore, funds for aid were short as only a mere 5% of Pakistanis pay taxes. The Pakistan relief fund only raised US$1.4m within the country and there were accusations that the government was pocketing aid money. Hundreds of thousands of military personnel were also involved in fighting the Taliban in north-west Pakistan and could not be diverted to help with flood relief.

(E) RIVER FLOOD MANAGEMENT STRATEGIES

Strategy	Strengths	Limitations
(1) Statistical Prediction - Flood Recurrence Interval The flood recurrence interval shows the frequency with which a particular flood magnitude can be expected to occur in any one year. Thus a 1 in 10 chance would be a 10 year flood, 1 in a 100 chance would represent a 100 year flood.	A flood recurrence interval is useful when planning for land-use zoning, or the construction of engineering projects close to river environments. Defences can then be constructed once knowledge of the potential frequency and magnitude of floods are understood (e.g. a levee built and designed to withstand a 50-year flood of a particular magnitude). **Example:** For the city of Austin (USA), there are strict regulations on buildings on floodplains. For example, for a 25-year floodplain (i.e. likely to flood once every 25 years), the construction of buildings and parking areas is prohibited.	Its usefulness depends on how much data is available to extrapolate from: 100-year flood values may change as more data is collected. The more data, the more accurate the flood value will be. Also, anomalous events may occur that render studies of flood recurrence intervals and subsequent flood defence efforts useless. This is especially so today, where due to the impacts of global warming there are more extreme weather events occurring such as tropical cyclones. **Example:**At the end of July 2010 the north-west province of Khyber Pakhtunkhwa (KPK) was hit by a five-day period of exceptional precipitation, including 60 hours of continuous rainfall. While Pakistan is used to receiving intense rainfall especially during wet monsoon months, such unprecedented levels (described as “once in a century”) rendered existing flood defences useless.
(2) Scientific Prediction – Satellite Images The authorities monitor satellite images to create weather forecasts and warn people about possible floods.	People can be evacuated before the flood happens, thus saving lives. People can also move possessions and use sandbags to help reduce damages (economic and physical costs) if flooding occurs. **Example:** In early 1998, Chinese scientists predicted heavy rains for Southern China in the later part of the year. Authorities proceeded to strengthen and extend their levee systems along the Yangtze and other rivers, emptied reservoirs, and prepared personnel and materials to aid flood victims. As a result, the impact of the flood was reduced.	The level of accuracy of prediction is dependent on the resources available to the planning agency, including (but not limited to) the quality of the data, and the expertise of their technical experts. Also, mostly it can only deliver short term warnings and are not particularly useful in long term flood control. Thus, some people might not be able to access the communication network. Furthermore, flash floods may happen too fast for warnings. Lastly, people may also ignore warnings if they were inaccurate in the past. **Example:** In 2012, the town of Krymsk in Russia was devastated by flash floods during the night. More than 200 people were hospitalised. Flood warnings were given using sirens, SMS messages and

		loudspeakers but many people were asleep at the time and did not hear them.
(3) Scientific Prediction - Monitoring Tributary Streams Gauging stations are set up to measure the discharge of tributary streams. Some stations transmit data remotely to monitoring stations while others depend on manual reading of data by field officers.	By monitoring the discharge of tributaries, the authorities can predict the likelihood of flooding downstream, hence allowing time for evacuation and minimise number of casualties and costs of damage. **Example:** Bangladesh has a 72-hour advance flood warning of the Ganges River due to the monitoring of tributary streams in the Himalayas by the Indian authorities. High discharge levels in the Varanasi and Kanpur rivers (tributaries of the Ganges) would imply impending flooding of the Ganges in downstream Bangladesh.	Expensive. Many tributaries are located in remote areas which make their monitoring difficult. Also, large rivers with transboundary drainage basin would require cooperation between the riparian states and this cooperation may not always be available between neighbouring states.
(4) Hard Engineering Strategy – **Structural Mitigation (River Engineering)** **(a)Channelisation** is a deliberate attempt to alter the natural geometry of the river. One way this can be done is through channel straightening, where meanders are removed by building artificial cut-throughs. Another is by reshaping the channel to increase its hydraulic efficiency - by resurfacing the channel to reduce channel roughness (n)	Straightening: Cut-throughs makes the water flow faster, which reduces the risk of flooding as water drains downstream more quickly and there is a lesser chance of actual discharge exceeding bankfull discharge. **Example:** The Mississippi River (USA) has been shortened by 240km after re-alignment by cutting off the meander through its neck. By increasing channel efficiency (Rh) and reducing channel roughness (n), the velocity of the river can be increased, bringing about a higher velocity of flow, hence increasing the bankfull discharge.	• Engineering solutions are **expensive**. • Ecological impacts: There is also a loss of wetlands and habitants for aquatic life due to diversion of the river. Increased river velocity may also result in ecological feedback loops as some key species of the river ecosystem may be lost through channelisation. • Relocation of problem? Channelisation upstream may not fully address the flooding issue as flooding may happen downstream instead, especially when now discharge is carried downstream faster. There might also be more erosion occurring downstream as the discharge has greater velocity and energy. **Example:** The town of Abingdon in England has rejected channelisation and the construction of flood barriers for River Ock as it will increase the risk of flooding downstream.

(b) Levees are embankments built along rivers to increase the bankfull discharge of a river. They are the most common form of river engineering. **(c) Dams** are huge walls built across rivers and an artificial reservoir is formed behind the dam. Dams prevent floods from occurring by regulating the level of discharge in a river channel to be as steady as possible and below the bankfull discharge. This is done by controlling the amount of water stored in the reservoir.	**Levees** allow the floodplains surrounding the river to be built upon as it prevents floods from occurring. **<u>Example:</u>** Over 4,500 km of the Mississippi River has levees that have successfully prevented floods from occurring. By far, **dams** are the most effective means of mitigating flood effects as it effectively controls discharge in the river. Besides helping to prevent floods from occurring, dams are multi-functional. Turbines can be built into the dams to generate hydro-electricity. Furthermore, dams allow for the steady release of water throughout the year, enabling irrigation to take place, especially during dry seasons. **<u>Example</u>:** The construction of the Three Gorges Dam in China in 2012 reduces the frequency of major downstream flooding from once every ten years to once every 100 years. It also discharges its reservoir during the dry season, enabling agriculture and industrial activities to take place all-year round.	**Levees** are quite expensive to build. There is also a risk of severe flooding if the levees are breached. **<u>Example:</u>** In 2005, levees along the Mississippi River were breached in New Orleans (USA) due to structural problems in the levees when Hurricane Katrina hit the city. 80% of New Orleans was flooded and more than 100,000 homes and businesses were hit by the floods. **Dams** are very expensive. Furthermore, the creation of the artificial reservoir behind the dam requires the surrounding land to be flooded, destroying ecosystems and forcing people to move elsewhere. Dams can also affect wildlife, such as preventing salmons migrating upstream to their breeding grounds. Dams also trap sediments, resulting in water released to contain less sediments and nutrients. Lastly, clearwater erosion takes place immediately downstream of dams as the released water has more energy for erosion as sediments have been deposited behind the dam. **<u>Example</u>:** The construction of the Three Gorges Dam in China flooded archaeological and cultural sites and displaced some 1.3 million people.
<u>(5) Behavioural Mitigation – Landuse Planning and Zoning</u> Planning restrictions prevent buildings or roads being constructed on the flood plain. Use of the floodplain is restricted to things like playing fields or parks.	There are no new buildings or roads on the floodplain to be damaged so the impact of any flooding is reduced. The empty land also provides recreational opportunities such as being used as parks and football fields. **<u>Example:</u>** For the city of Austin (USA), there are strict regulations on buildings on floodplains. For example, for a 25-year floodplain (i.e. likely to flood once every 25 years), the construction of buildings and parking areas is prohibited.	It restricts development, which is a problem when there is a shortage of housing. This strategy also cannot be used in areas that are already urbanised. **<u>Example</u>:** The section of the Kallang River in Bishan-Ang Mo Kio Park (Singapore) has been restored from a concrete canal into a naturalized river. Buildings were prohibited along the floodplain of the river. In the event of a storm, the water level in the river will rise and the area adjacent to the river will be used as a flood plain to contain the rainwater. However, this takes up a lot of land space in land-scarce

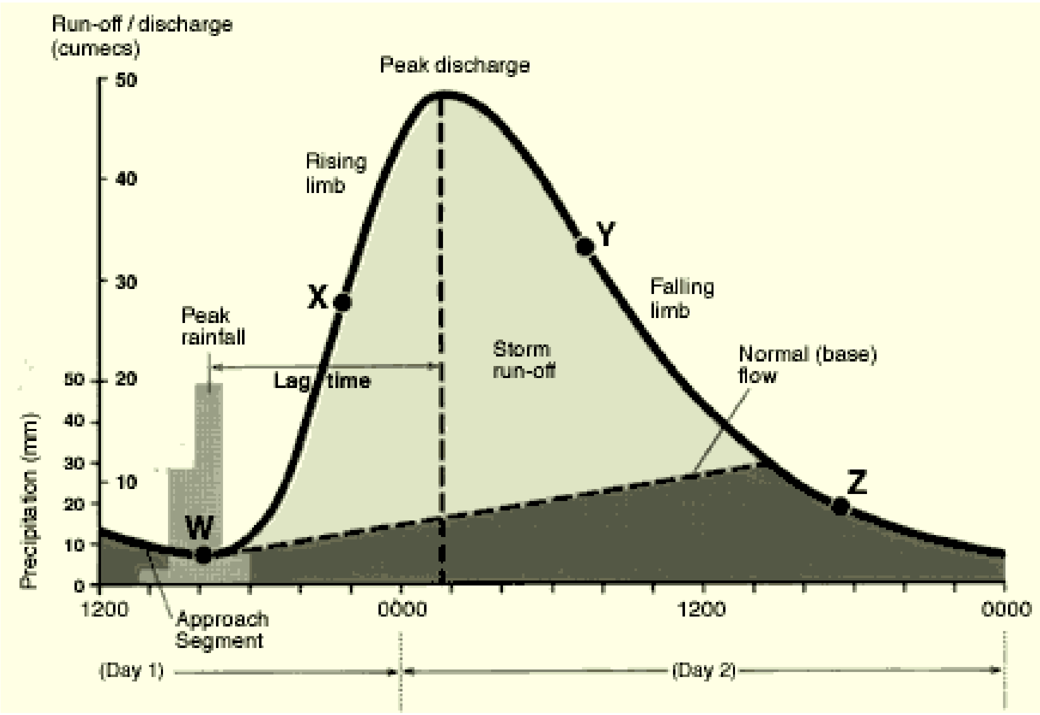
		Singapore and thus is not viable for all rivers in the country. Thus, if the government is not strict on its enforcement of landuse zoning, it could result in buildings to be built. This could negatively affect the quality of life of its residents. Example For example in England, United Kingdom, to manage the housing pressures, 1 in 10 buildings are built on flood-prone areas since 2013 despite government's planning policy stating that houses should be built at low-risk areas.
Strategy	**Strengths**	**Limitations**
(6) Behavioural Response – Shelters, Food, Basic Hygiene Amenities, Medical Care (Level of Preparedness) Immediate and long-term response/level of preparedness by the government and other organisations.	Quick and adequate response allows lives to be saved and victims to return back to their normal lives. **Example**: For Hurricane Katrina (2005) and its associated flooding of the Mississippi River - in terms of immediate response, the coast guard, police, fire service, army and volunteers rescued over 50,000 people. About 25,000 people were given temporary shelter at a sports stadium (the Louisiana Superdome) immediately after the storm. In terms of long-term response, the US government has spent over US$800 million on rebuilding flood defences. Around US$34 billion has been set aside for the re-building of things like houses and schools.	The amount of resources available to the government limits its ability to respond to the disaster. Furthermore, the capability of the government also affects the level of response that it is able to give to the victims. **Example**: The 2010 Pakistan flood response was criticised as being slow, uncoordinated and ineffective. After a week of flooding the government had still failed to provide any emergency supplies: no food, water, tents, blankets or medicines. It was also late in setting up camps to house refugees. Furthermore, funds for aid were short as a mere 5% of Pakistanis pay tax. The Pakistan relief fund only raised US$1.4 within the country and there were accusations that the government was pocketing aid money. Finally, hundreds of thousands of military personnel were involved in fighting the Taliban in north-west Pakistan and could not be diverted to help with flood relief.

How to read hydrographs:

(A) What is a STORM HYDROGRAPH?

A **storm hydrograph** is a graph showing the variation of discharge of a river at a particular gauging location over a period of time as a result of a precipitation event.

It can therefore reveal how long a stream's discharge takes to rise from baseflow level to maximum discharge, before returning to baseflow. A hypothetical hydrograph is shown in Fig. 1:



Baseflow

- the starting and finishing level of discharge is called the **baseflow**, which is that part of the river's discharge produced by groundwater seeping slowly into the bed of the river
- it is the main contributor of a river's flow during dry conditions, or when precipitation ends
- it is relatively constant in amount unless following a precipitation event or snowmelt. The amount of baseflow is determined by the amount of infiltration and percolation that can take place
- it is of a lower magnitude than surface overland flow because its low flow velocity does not allow it to fluctuate

Rising Limb

- it is the limb to reach **peak discharge** and indicates the highest flow in the channel
- the steepness of the rising limb is dependent on the amount of surface run-off that occurs, and also the intensity and duration of the storm

Peak rainfall

- the peak rainfall is the time of highest rainfall

Peak discharge

- **the peak discharge** is the time when the river reaches its highest flow. It is usually later than the peak rainfall because is takes time for the water to find its way to the river

Stormflow/Storm run-off

- The peak flow that occurs during or immediately following a rainfall event occurring as a result of overland flow and rapid subsurface flow.

Lag Time

- a delay between the **peak rainfall** and the **peak discharge**
- exists because water takes time to flow from the point where it hits the ground before reaching the gauging station, resulting in a time lag before the rise in discharge is recorded
- it is measured by subtracting the time taken to reach peak rainfall from the time taken to reach peak discharge

Falling/Recession limb

- measures the rate at which discharge decreases: the higher the rate of decrease, the steeper the falling limb; the slower the rate of decrease, the gentler the falling limb
- produced mainly by water flowing through the soil into the channel from baseflow
- when surface run-off ceases, water will continue to flow into the river via baseflow, and the amount of baseflow available will determine the steepness of the falling limb as well i.e. when there is a high degree of infiltration and percolation contributing to baseflow, the falling limb will be gentler.

Bankful discharge

- The maximum discharge that a channel can contain without overflowing onto its banks. Bankful discharge is the threshold discharge above which flooding is said to occur.
- Some hydrographs **may** show it, we will discuss this again in the floods lecture.

(B) FLASHY VS. NON-FLASHY STORM HYDROGRAPH

A storm hydrograph can be considered to be relatively flashy compared to other hydrographs based on several criteria, which are (1) duration of lag time, (2) level of peak discharge, and (3) steepness of rising and descending limbs.

For a <u>similar storm event</u>, a flashy hydrograph will tend to have a shorter lag time, higher level of peak discharge and steeper rising and descending limbs (Fig. 2).

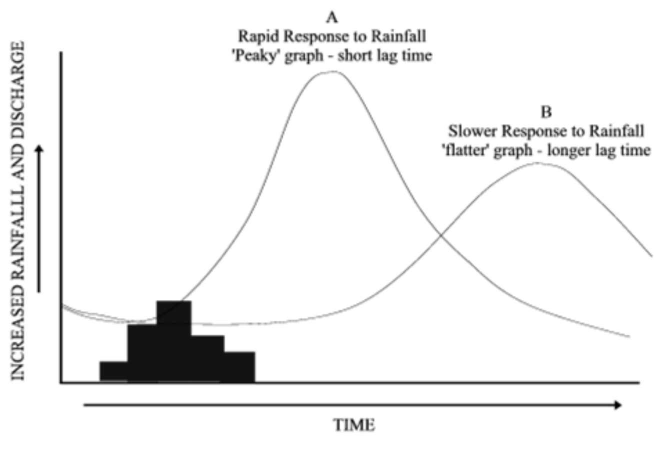


Fig. 2: Storm hydrographs showing a flashy (A) and a non-flashy (B) response

(C) CHARACTERISTICS OF AND FACTORS INFLUENCING THE STORM HYDROGRAPHS

Several factors **determine**, and can **modify** the shape of the hydrograph. Besides climatic factors, physical characteristics of the basin (natural) and human activities (human factors) can help in explaining variations in discharge in hydrographs.

A) Natural Factors

i) Precipitation characteristics

a) Duration of rainstorm

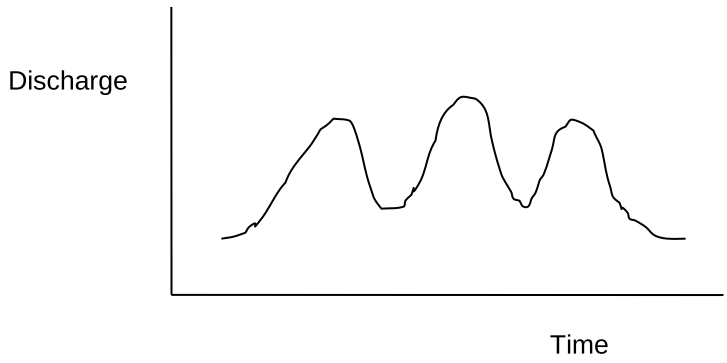
- A prolonged storm often leads to higher discharge, with a substantially high peak flow which may be sustained for some period of time (given the prolonged nature of the rain). When the WT rises to the surface, infiltration capacity (IC) has reached its maximum and surface runoff kicks in. (IC=0, ST at field capacity).
- A prolonged drizzle results in a lower, flatter hydrograph than a short heavy rain though the amount of P could be the same.

b) Rainfall intensity

- In intense rainstorms (e.g. convectional storms), IC is easily reached and there is high run-off, leading to a higher peak discharge and a shorter lag time, thus a steeper rising limb.
- Drizzles are easily intercepted by vegetation, which increases time for evaporation and infiltration, thus leading to a gentler rising limb.

c) Type of precipitation (snowmelt, rain, etc.)

- A consecutive continuous heavy shower can give rise to **multiple peaks** as intensity of rain will vary.



ii) Basin Morphometry (size, shape, relief and drainage density of a river basin)

a) Size: Small basin versus a big basin

- Discharge reaches the main channel more rapidly compared to a larger basin
- Therefore, there is a more rapid rise in discharge recorded in a smaller basin
- Because the basin is also smaller, there may be a smaller discharge and hence a lower peak flow/discharge

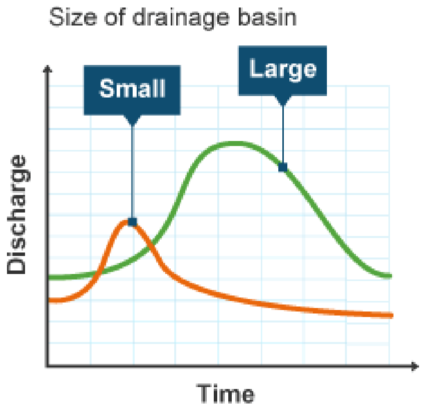


Figure 4

http://www.bbc.co.uk/staticarchive/da755ddae56f0e6109048a44830b2efe964e23b8.png

b) Relief & gradient: Steep-sided valleys vs gentle valleys

- On steep slopes, there is more and faster surface run-off, lesser infiltration and hence, water likely to reach the main river more quickly than in gently sloping lowland areas, resulting in steeper rising limbs and higher peaks.

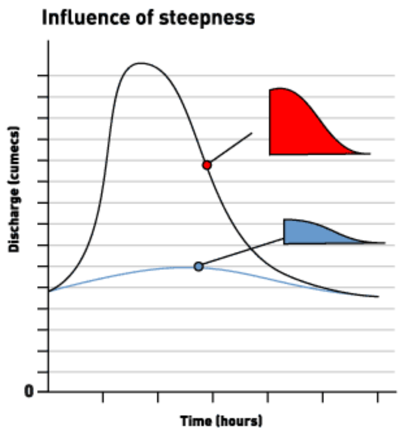


Figure 7

http://www.bbc.co.uk/scotland/education/int/geog/rivers/hydrographs/

iii) Vegetation

a) Vegetated versus non-vegetated areas

- Vegetated areas will intercept more rainfall than non-vegetated areas, resulting in more delayed infiltration, lower surface run-off to give a longer lag time since velocity of run-off is also slowed down by vegetation. There will be a lower peak discharge and longer time lag in comparison to non-vegetated areas.
- Density of vegetation is also important, for example, sparsely vegetated versus more densely vegetated areas (*explain why using your understanding from previous lectures*).

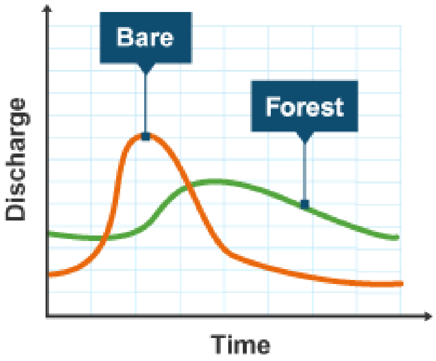


Figure 9: Influence of vegetation

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iv) Geology of drainage basin

a) Porosity & Permeability

- Highly porous and/or permeable rocks → more infiltration, less surface run off; more gradual increase in discharge (steady contribution from throughflow and baseflow) → results in a lower peak discharge, longer lag time, gentler rising and falling limbs. E.g. limestone (grikes and clints and jointed rock structure)
- Low porosity and/or impermeable rocks → high run-off due to less infiltration → more rapid increase in discharge → higher peak discharge, shorter lag time, steeper rising and falling limbs. E.g. clay (River Wallington)
- Also applicable to permeability of soil

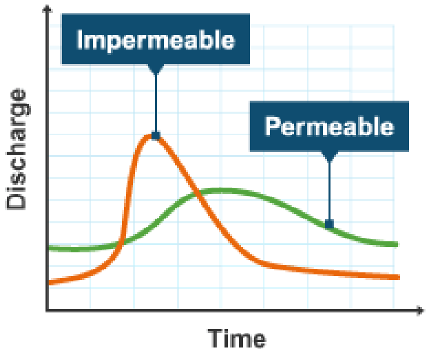


Figure 10: Permeability

http://www.bbc.co.uk/staticarchive/da755ddae56f0e6109048a44830b2efe964e23b8.png

b) Antecedent soil moisture

- If the soil is dry i.e. soil moisture storage (ST) =0 or is low, there will be higher infiltration, thus the hydrograph will be lower, flatter as there is lesser surface runoff.
  - If the soil is saturated (e.g. ST at field capacity), there will be higher surface runoff (SOF) as IC is reached. Thus the hydrograph will be higher, steeper.
  -

B) Modification by humans

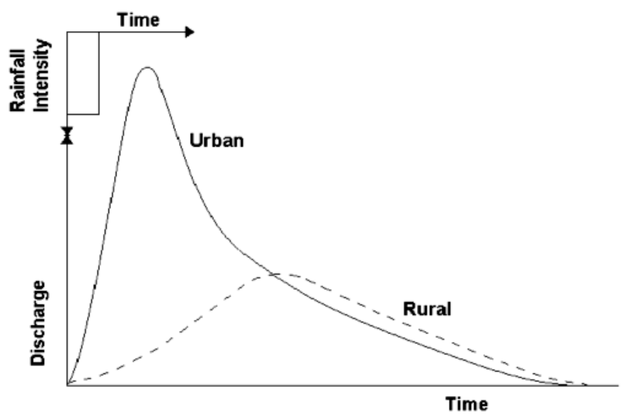
Most human activities tend to decrease infiltration, hence increase surface run-off and discharge. These would be recorded in the shape of the hydrographs as changes in steepness of rising and falling limbs, peak discharge and shorter lag time

i) Deforestation

- decreases infiltration due to an increase in compaction of soils due to raindrop impact once protective vegetation and leaf litter is removed→ increases run-off and hence increases peak discharge and sediment output into streams
- steeper rising limb, higher peak flow, shorter lag time

ii) Urbanization

- increases impervious ground surface, decreases infiltration
- run-off /overland flow generated very rapidly
- floods occur more often unless adequate drainage is provided
- usually, artificial drainage channels (canals) allows rapid drainage of run-off to prevent floods (artificial channels have smoother channel sides and hence less friction)
- this increases the peak discharge and decreases the lag time of the hydrograph (takes shorter time to reach peak discharge as ground is impervious), as well as giving a steeper falling limb since there is not much contribution to baseflow (more IEF).
- surface runoff of an urban area can be as high as 80-90% of total rainfall while an area under natural forest cover will only loose about 40-50% through its river channels.



iii) Building of dams

- Dams allows one to control/regulate stream discharge → can alter the shape of the hydrograph significantly. E.g. reservoirs smooth out variations in discharge by increasing infiltration and percolation to groundwater and increasing evaporation (increasing area of water surface when channel above dam floods) → gentler rising curve and less peak

(D) ***How might a Hydrograph look like in Arid Regions***

The characteristics of **desert areas** entails that infiltration rate is low due to crusting (layer of minerals formed over the surface layer) which makes runoff more likely, which leads to flash floods.
Flash floods is rapid flooding of geomorphic low-lying areas. It may be caused by heavy rain associated with a severe thunderstorm, hurricane, tropical storm of meltwater from ice or snow.

In desert areas, the river is often ephemeral, meaning that stream discharge are characterized as lacking permanent flow with extreme and rapid flood variations. In most arid and semi-arid locations, vegetation is sparse and the soil lacks organic matter allowing stream flows to generate greater amounts of erosion and runoff, increasing the magnitude of a flow.

The typical flood hydrograph of an ephemeral stream or stream in a desert area could look like figure 11 below where there is a **rapid and steep rising limb and falling limb over a short time frame.** The **initial peak discharge is reached rapidly and the** recession limb is considerably longer than the rising limb and takes a longer time to dissipate, often the entire hydrograph is the recession .

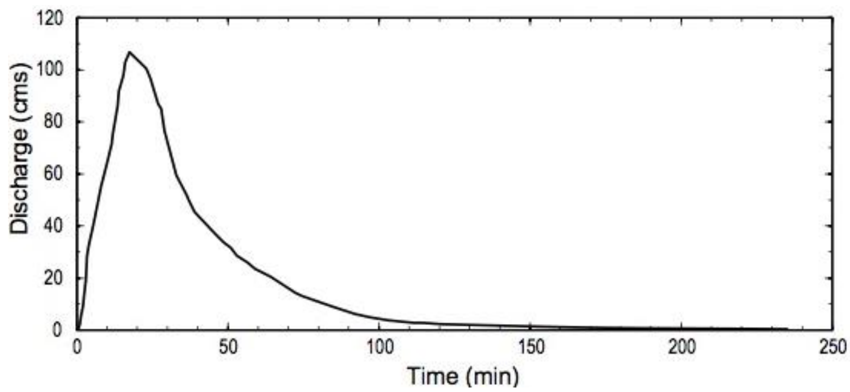


Figure 11. Flood Hydrograph of an ephemeral stream in desert areas

Desert areas often has **spotty rainfall** due to how storm cells migrate when they deliver rain and different rainfall events are more likely to wet different parts of a river catchment. In catchments of modest dimensions, a different part of the drainage basin will contribute water during each event. This could also lead to 'flashy' hydrographs with multiple peak discharge as different parts of the catchment is contributing to the **flood event at different times of the month** (see figure 12 below).

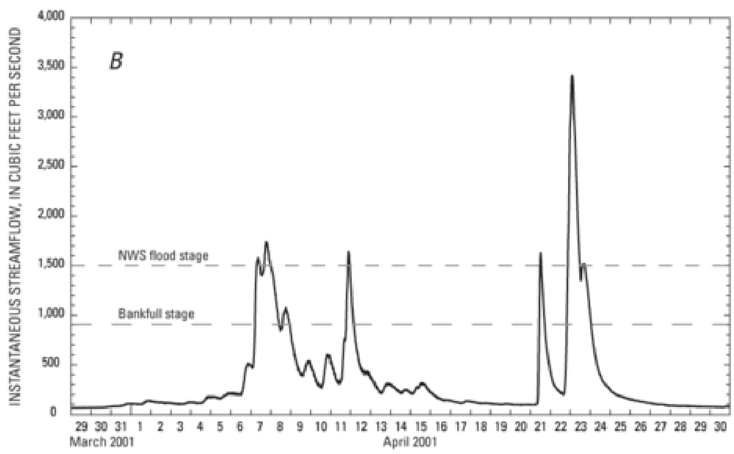


Figure 12: Flash flood hydrograph of a stream in desert area with multiple peaks