Lecture 14
Fluvial Landforms (I): Meanders and Braided Channels

KEY QUESTIONS:

- ✓ *How do natural processes and human activities influence landforms in the humid tropics?*

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

- the fluvial landforms found in the humid tropics like meanders and braided channels
- the features of meanders and braided channels
- the factors that influence the formation of meanders and braided channels in the humid tropics

Lecture Outline

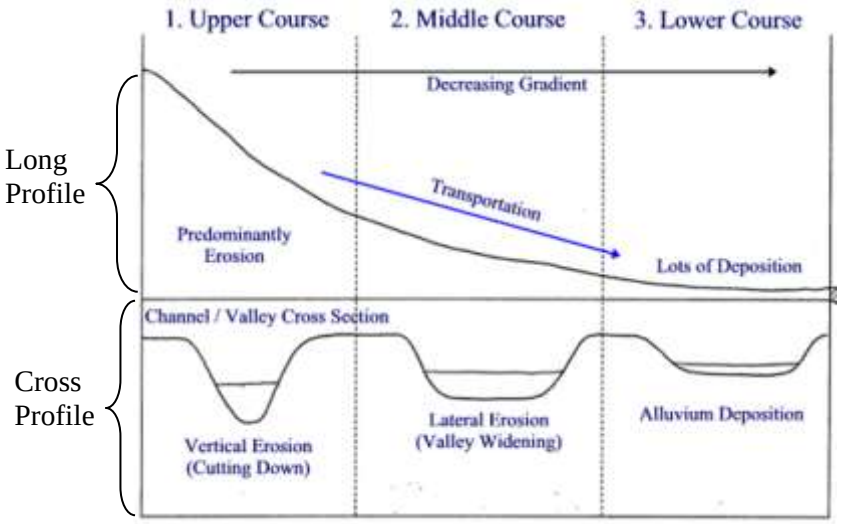
14.1 Introduction: Fluvial Landforms

- Present-day landforms are shaped by processes that have operated over very long timescales. These processes work together to shape the earth's surface, creating landforms that contribute to the splendor of the natural environment. As humans continue to build settlements in the natural environments, these landforms are impacted by human activities.
- Although in our syllabus we have three fluvial landforms namely meanders, braided channels (see **Lect.14**) and deltas (see **Lect.15**), in this lecture, we will examine fluvial landforms in the humid tropics. Specifically, we will build our understanding of what meanders and braided channels are. We should be able to describe and sketch meanders and braided channels. We will also seek to determine the relative importance of natural and human factors in the formation of these two fluvial landforms.

Box 1: Important Terms

The course of a river is conceptually divided into 3 parts, **upper**, **middle** and **lower**. Although erosion, transportation and deposition happen throughout the course, their rates change over the course of a river.

a) **Long Profile of a River**: The long profile shows how a river's gradient changes as it flows from its source in its upper course to its mouth in the lower course. A long profile is usually **concave** and the slope becomes more gentle towards the mouth of the river.



b) **Cross Profile**: A *cross profile* shows a cross-section of a river's channel and *valley* at a certain point along the river's course.
   - In the **upper course**, the river has less water and flows down the steep slope with high velocity. This causes more down-cutting or ***vertical corrasion***. Thus, the channel becomes **deep** and **narrow**.
   - In the **middle course**, the river has more water, and the slope becomes gentler. Thus, the velocity of the river reduces, and the river does less vertical corrasion and more side-cutting or ***lateral corrasion***, resulting in **widening of the channel**.
   - In the **lower course**, the slope is even gentler or flat and the river velocity is low. Thus, the river mainly deposits with very little erosion. The river channel becomes **very wide**.
   - Cross profile of the river is formed due to a combination of fluvial processes with some processes being dominant in certain stages of the course than others.

14.2 Meanders

- A meander is a **sinuous** (having many curves and turns) river channel that migrate downstream owing to riverbank **erosion on the outside of meander bends** and **deposition of bed material on the inner bank**. Thus, meanders are the result of both **fluvial erosional and depositional processes**.
- They are typically found in the **middle** and **lower course** of a river, because in these courses vertical corrasion is replaced by a lateral corrasion and corrosion, along with deposition.
- Meanders are typically found in areas where river **discharge is stable** (e.g. areas with the Af climate) as it ensures that erosion and deposition processes remain balanced over time.
- Example of a meandering river is Madre de Dios river in Peru (see **Fig. 1**). There are many rivers in the tropics which meanders such as, Amazon River in South America, Yangtze River in China, Orinoco River in Venezuela.

Fig. 1 Madre de Dios river, Peru

14.2.1 Features of a Meander

- A meandering river typically has a **sinuous channel** with a sinuosity index of more than 1.5 (see **Fig. 2**). In general, the meander length is on average 11 times, the bankfull channel width. Channel width remains same.

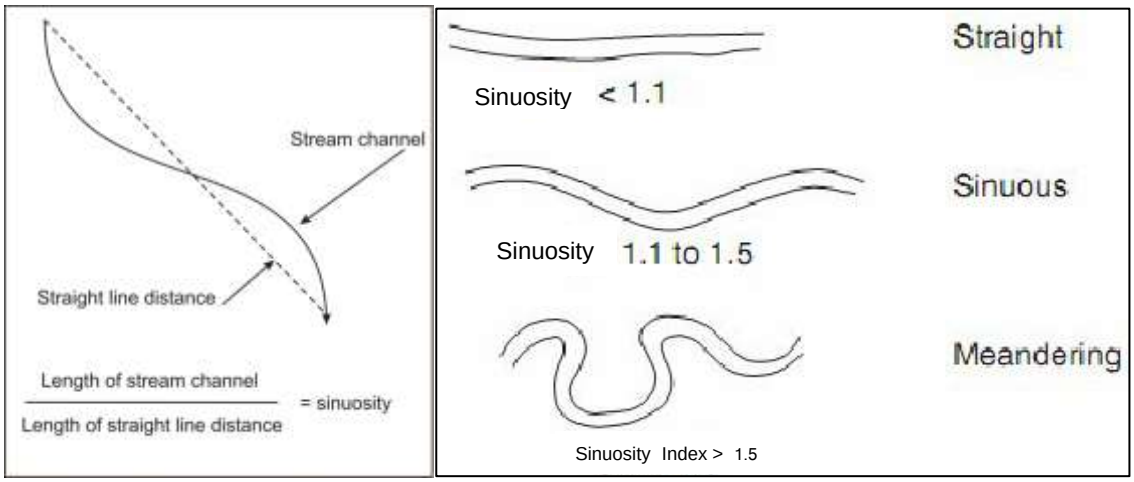


Fig. 2 Sinuosity Index

- Each meander bend is **asymmetrical in cross-section** (see **Fig. 3**).
- The outer bank has a steep slope called a **river cliff**, where the channel is the deepest forming a pool (accumulation of more water).
- The inner bank has a gentle **slip off slope**, where the channel is very shallow forming a depositional feature called a **point bar**.

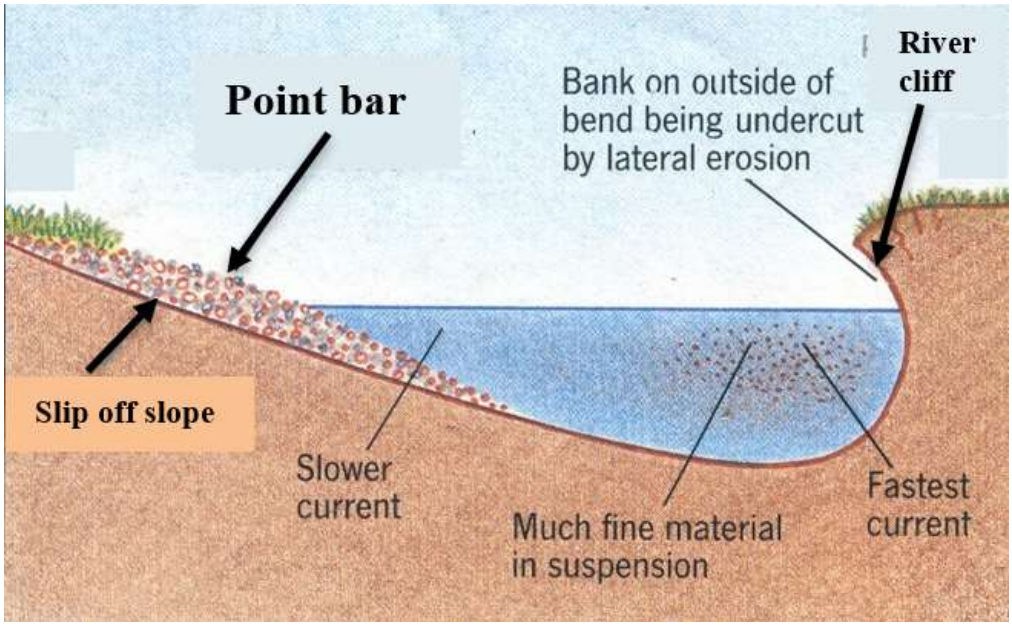


Fig. 3 Cross-section of a Meander

14.2.2 Conditions Necessary for the Formation of Meanders

- Stable discharge
- Gentle slope in middle or lower course of the river
- Presence of pools and riffles
- Cohesive bank materials (clay)

14.2.3 Formation of Meanders

The role of pools and riffles

- In an initially straight river channel, the flow is disrupted by irregularities such as boulders, leading to **variations in velocity**.
- These variations in velocity forms alternate **pools** and **riffles** in the river channel (see **Fig. 4**).
- As the river flows over areas with boulders, the **friction increases reducing river velocity**. This encourages more **deposition** of sediments forming a shallow channel known as riffle. After depositing the sediments in the riffle, the river gains back energy and flows with **higher velocity**. This encourages **fluvial erosion** processes like corrasion and corrosion, forming a deep channel known as pool.
- Pools experience greater erosion due to increased velocity and reduced friction, while riffles encourage deposition of coarse sediment.

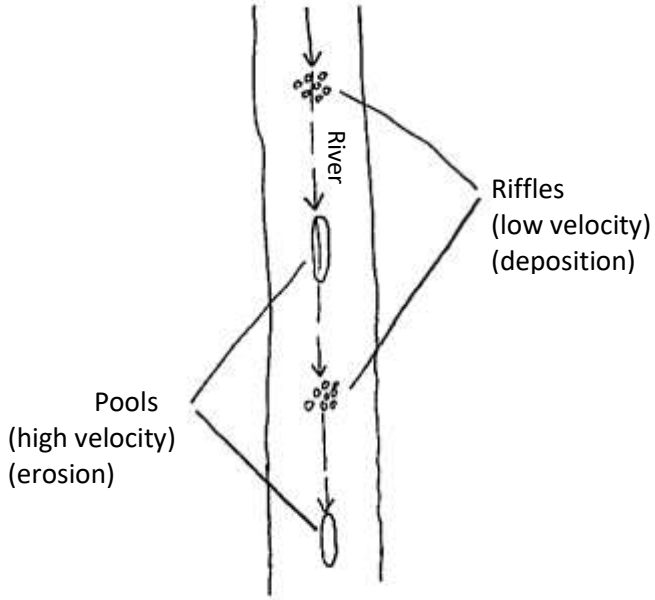


Fig. 4 Straight River channel with pools and riffles

The role of swinging thalweg

- The variations in velocity between pools and riffles causes the **thalweg**, which is the line of fastest velocity in the river, swings from bank to bank moving in a sinuous manner forming a meander bends which have an outer bank and an inner bank.
- Meander starts to develop when there is **erosion on the outer bank** and **deposition of bed material on the inner bank** of the bend.
- As the **thalweg swings** to the **outer bank**, high velocity causes fluvial erosion on the outer bank by lateral corrasion and corrosion. Over time, undercutting of the outer bank by fluvial erosion causes the overhang to collapse (mass movement) forming a steep slope known as **river cliff** (concave slope) (see **Fig. 5**).
- Deposition on the inner bank occurs due to lower velocity. Sediments accumulate to form a depositional feature called **point bar** (see **Fig. 5**). The sediments are derived from erosion of weathered material, mass movement and lateral erosion at the outer bank.

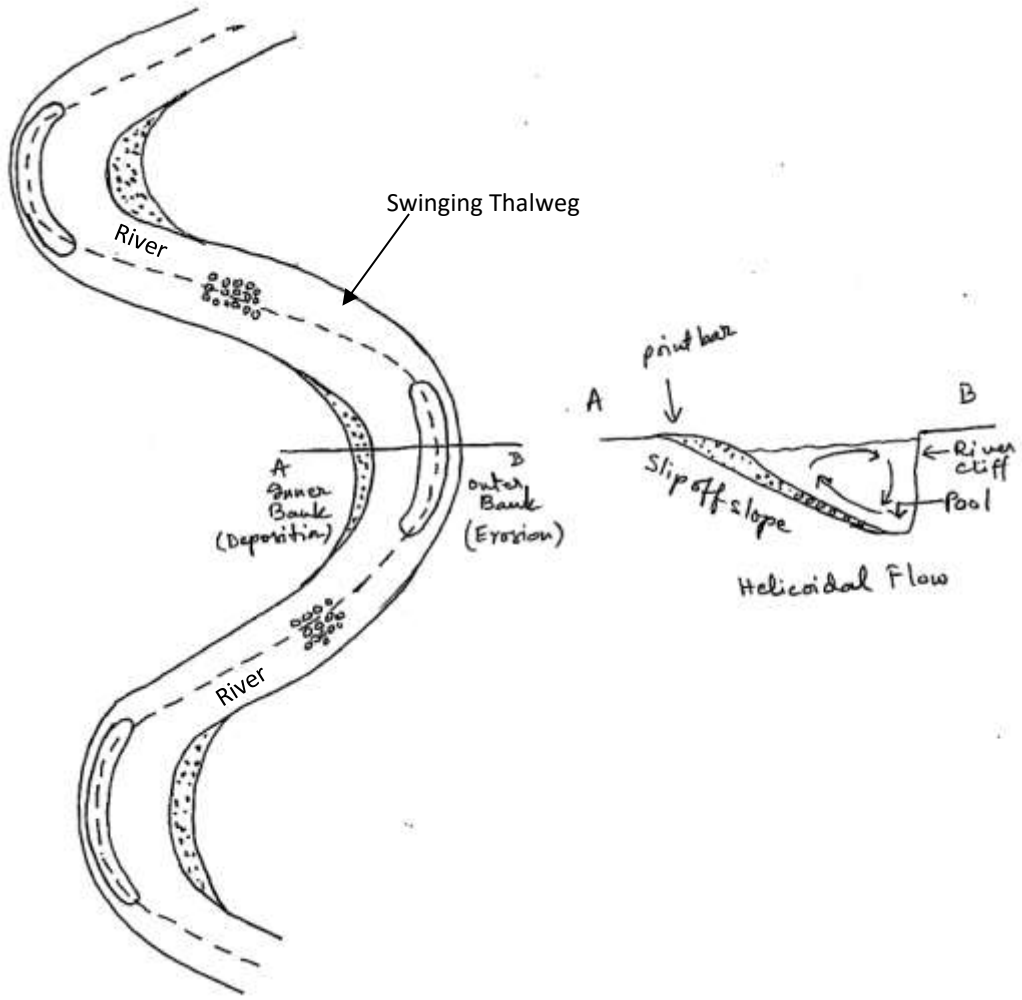


Fig. 5 Meanders with river cliff and point bar

The role of helicoidal flow

- The cross-section of a meander bend is asymmetric in shape with deep outer bank and shallow inner bank. Differential pressure between the outer bank and the inner bank causes river water to move in a circular manner bringing water from outer bank to inner bank. This circular motion of water along with downstream motion forms helicoidal flow in the river (see **Fig. 6**).
- **Helicoidal flow** is a "corkscrewing motion" of river water which plays a crucial role in sediment transportation. It moves eroded sediments from the **outer bank of one meander bend** and deposits it on the **inner bank of the next meander bend**.
- With ongoing erosion on the outer bank and deposition on the inner bank, meanders become more pronounced and continually change their position.
- The thalweg remains concentrated along the outer bank, sustaining high flow velocity and erosional power.
- **Lateral migration** (see **Fig. 7**) occurs as meanders shift downstream over time.

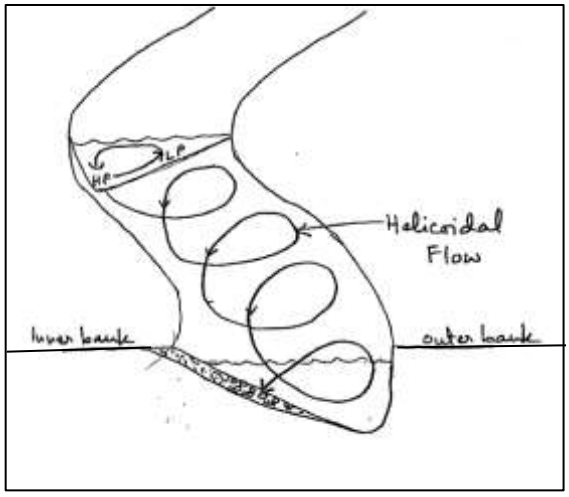


Fig. 6 Helicoidal flow

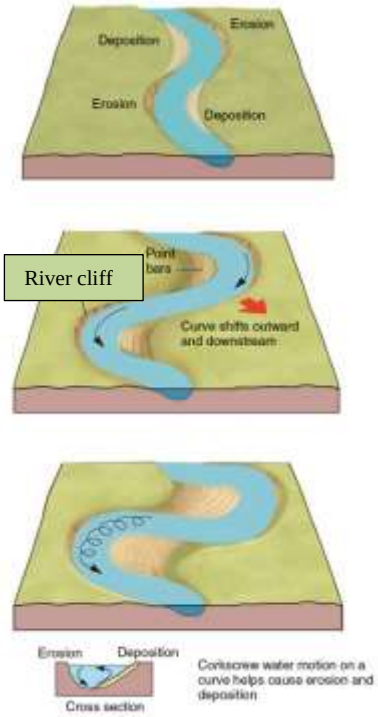


Fig. 7 Lateral migration

- Meanders form from complex interactions between water flow, sediment transport, and riverbank characteristics, often involving lateral erosion and sediment deposition processes.
- Factors such as water discharge, sediment type, landscape gradient, vegetation and human activities influence the formation of meanders. These elements work together to create the characteristic meanders in rivers.
- Meanders form through a sequence of thalweg-controlled flow variations, pools and riffles, helicoidal flow, lateral erosion, and sediment deposition, progressively increasing in curvature and migrating downstream. Stable discharge plays a crucial role in maintaining the balance between erosion and deposition, preventing abrupt changes in meander evolution.

14.3 Braided Channels

- A braided channel is a river channel consisting of **separate, but interlinked, migrating channels** (see **Fig. 8**) flowing either side of active unvegetated **bars** that change position owing to bed load transport.
- These bars are dynamic, as they continuously form, erode, and reform in response to **variations in discharge**, significant amount of sediment load, and nature of bank material. **Seasonal variations in rainfall** (e.g., in humid tropics like Am/Aw climates) lead to variation in discharge, causing **erosion during high discharge in wet seasons** and **deposition during low discharge in dry seasons**. Also, snowmelt in high-altitude regions provides episodic high discharge, promoting braiding.
- Example of a braided channel is Brahmaputra River in India and Bangladesh (see **Fig. 8**).

Fig. 8 A Section of the Brahmaputra River that Flows Through Tibet, India and Bangladesh

14.3.1 Features of Braided Channels

- Braided channels are characterised by their **larger width**, **high width-depth ratio** and the **frequently changing position of the smaller channels and mid-channel bars** (see **Fig. 9**).

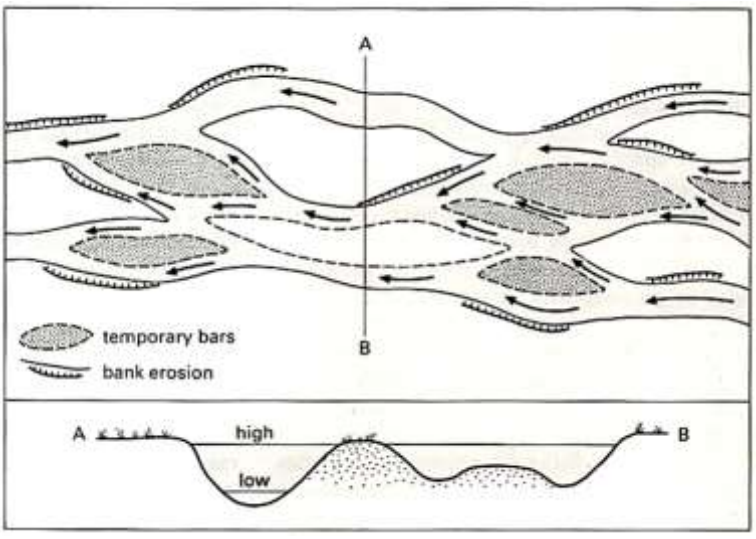


Fig. 9 Fluctuating discharge

14.3.2 Conditions Necessary for the Formation of Braided Channels

- Variation in discharge (high discharge in wet season, low discharge in dry season)
- Steep slope in upper course of the river
- Abundant supply of coarse sediments (heavy sediments)
- Less cohesive bank materials (sand and gravel)

14.3.3 Formation of Braided Channels

The role of high discharge, fluvial erosion and sediment transportation

- During periods of **high discharge** (e.g., during heavy rainfall of wet monsoon season or summer snowmelt), the river has **greater energy to erode** the bed and banks of the river through corrasion and corrosion (see **Fig. 10**).
- High discharge also **increases the capacity** of the river to transport large amounts of bed load and high velocity **increases the competence** to transport large sized and coarse sediments such as sand, gravel, and pebbles.
- If the river is not restricted by valley walls, artificial embankments, or resistant banks, it spread laterally and distribute sediment unevenly across the channel.

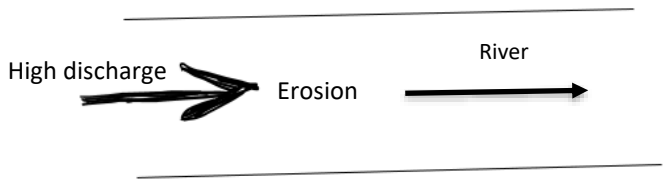


Fig. 10 High discharge causing erosion

The role of low discharge and sediment deposition

- As **discharge recedes** (e.g., during the dry season), the river's capacity to transport sediment decreases. This leads to the **deposition of coarse sediment** in areas where the flow loses energy, forming **mid-channel bars** (see **Fig. 11**).
- These bars further increase channel roughness, causing localised reductions in velocity, promoting further deposition of sediments.

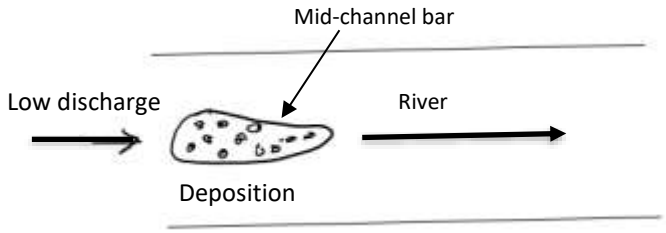


Fig. 11 Low discharge causing deposition of coarse sediments

The role of alternate cycles of high and low discharge

- As the mid-channel bars grow both upward and in the downstream direction, the bars begin to occupy a significant portion of the channel area. The channel is no longer wide enough to contain the total flow during high discharge. Thus, during high discharge the flow of the river is obstructed by the bars and gets deflected towards the banks thus accelerating bank erosion by lateral corrasion and corrosion (see **Fig. 12**). This widens the banks.
- However, when discharge reduces, more deposition of sediments happens forming more mid channel bars (see **Fig. 13**). Thus, the main channel gets divided into multiple smaller sub-channels (see **Fig. 13**), forcing the water to bypass around the mid-channel bars.
- Bank erosion widens the channel, allowing more sediment to be transported and deposited downstream.

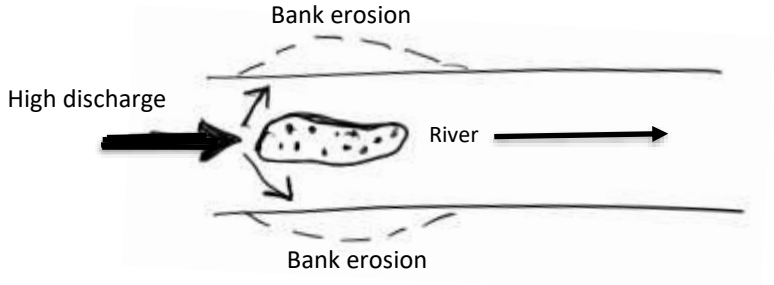


Fig. 12 High discharge causing deflection and bank erosion (bank widening)

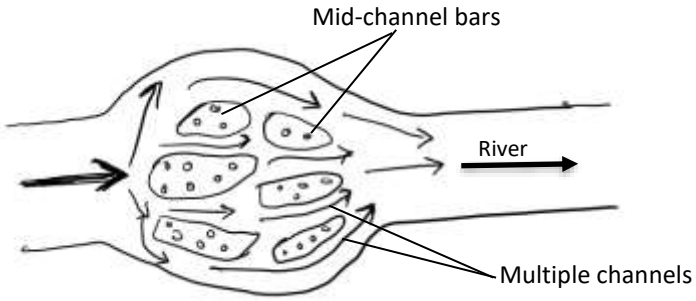


Fig. 13 Multiple smaller sub-channels and mid-channel bars

The role of vegetation colonisation and stabilisation

- Some mid-channel bars persist over time and may become colonised by vegetation, which helps to stabilise the sediments.
- These vegetated bars gradually evolve into islands that further modify flow patterns.
- However, due to the loose and unconsolidated nature of the sediments, these islands are temporary and may be eroded during the next high-flow event.

The role of continuous channel shifting and bar migration

- Braided channels are dynamic—as discharge levels fluctuate, some bars erode while new ones form further downstream.
- This results in a constantly shifting network of interwoven channels, characteristic of a braided river system.

- Braided channels are formed due to **fluctuating discharge, high sediment load, and easily erodible banks**. The process involves **erosion, deposition, and sediment transport**, resulting in **dynamic channel shifting and the formation of mid-channel bars**. These channels are most common in environments with **seasonal variations in water supply** (e.g., monsoonal rivers and glacial meltwater streams).
- The formation of braided channels is influenced by **natural factors** (climate, discharge, sediment type, slope, and bank composition) and **human activities** (such as dam construction and flood control measures). Understanding these interactions is essential for managing rivers and mitigating risks associated with channel instability.

14.4 Factors Influencing the Formation of Meanders and Braided Channels

Natural Factors	*Meanders*	*Braided Channels*
Climate Climate affects discharge as it is dependent on input like rainfall and snow melt water. More rainfall means more discharge in a river.	All A climates are possible. Af experiences rainfall throughout the year. Thus, provides stable discharge suitable for meander formation. Though Am and Aw climates experience seasonal rainfall, meanders are still possible where discharge varies less drastically.	Seasonal rainfall in Am/Aw climates in the humid tropical result in fluctuating discharge which causes braided channels. Erosion happens during wet season and deposition happens in dry season. Also possible in high altitudes which receives snow melt water in summers and are dry in winters.
Velocity Velocity affects type of fluvial processes. High velocity causes erosion, low velocity causes deposition.	Variation in velocity causes thalweg to swing. High velocity promotes greater lateral erosion on the outer bank, increasing meander curvature. Low velocity promoted deposition in the inner bank.	
Discharge Discharge affects the rate of fluvial processes. Higher discharge increases the capacity of the river (to carry more water and load).	Stable discharge is ideal for meander formation. A stable discharge regime ensures that erosion and deposition processes remain balanced over time. Stable discharge also ensures sustained sediment transport without excessive deposition or erosion imbalance. If discharge fluctuates excessively, strong floods may straighten the channel, while low flows may lead to channel choking due to deposition. Both disrupts meander formation. Relatively more regular, to sustain helicoidal flow.	Highly variable, to promote both erosion and deposition. High discharge causes more erosion (widening the channel) and transportation of more loads. Low discharge causes more deposition (mid-channel bars) of such loads.

Sediment Size / Load Type Sediment size decides the velocity of the river. Larger and coarser particles increase channel roughness and thus high friction reduces velocity of the river. Finer particles reduce friction and increases velocity of the river. High velocity causes erosion and low velocity causes deposition. High velocity also increases river competency.	Coarser particles are found in the riffle and slip off slopes of meander bends. Finer (suspended load) particles are found in the outer bank of the meander bend. Coarser particles are deposited in the riffle and slip off slope. Finer particles reduce friction and increases erosion at the river cliff. Fine sediments (e.g., silt and clay) encourage smooth bends, while coarser materials can reduce meandering tendencies.	Large, coarse sediments (bed load) encourage braiding as they require high energy to be transported but settle easily when velocity decreases. Sediments are often supplied by mass movements along the riverbanks.
Channel Gradient or Slope Slope decides the competency of the channel. Steep slope results in higher velocity causing more erosion and transportation of larger-sized load.	Meanders form primarily in low-energy environments with gentle slopes, as steep gradients favor straight, high-velocity channels. Gentler slope so more lateral corrasion than vertical corrasion along with deposition.	Steep gradients increase velocity, enhancing sediment transport and erosion. Ensures that the river has sufficient energy to sustain multiple channels.
Bank Composition Soil type determines erodibility and sediment availability. Cohesive materials are difficult to erode as they are tightly bonded and vice versa.	Meanders are formed where banks material is highly cohesive (made of clay) which resist erosion and help to maintain shape of meander. Non-cohesive soil promotes rapid erosion and channel straightening. Softer or loose bank materials erode more swiftly which might disrupt meander formation.	Braided channels form where banks consist of less cohesive materials (e.g., sand and gravel), making them easily erodible and allowing for continuous widening of channel by bank erosion and channel shifting.
Bank vegetation Bank vegetation either stabilises or enhances erosion, affecting the meander evolution.	Vegetation stabilises riverbanks with roots, reducing erosion and influencing sediment deposition patterns, thus affecting meandering.	

Human Activities (factors)	*Meanders*	*Braided Channels*
	Human activities, such as urbanisation, agriculture, and construction of levees and dams, alter sediment supply, water flow, and vegetation patterns, potentially changing the natural meandering processes. These activities can increase erosion or stabilise banks, ultimately affecting the frequency and extent of river meanders.	Human activities such as construction of dams and levees, mining of sediments from the riverbed etc. might affect formation of braided channels.
Dam construction Dams are constructed to store excess water which otherwise will drain into the river and cause flood. This will affect the discharge of the river.	If dams released water throughout the year in a stable manner, meanders can be maintained. If dams controlled the flow of water causing discharge to fluctuate, the migration of meanders would be impeded due to reduced rates of bank erosion.	If dams released water throughout the year in a stable manner, braided channels cannot be maintained. If dams control the flow of water causing discharge to fluctuate, braided channels might be formed. Dams also will reduce the sediments supply necessary for mid-channel bars to form in times of low discharge. This would reduce the possibility of braided channels.
Flood Management	Channel straightening cuts meanders off to expedite the flow of water away from an area to reduce the possibility of flooding. As part of river restoration, which controls floods by increasing natural storage capacity through re-connecting streams and rivers to floodplains, former meanders and other natural storage areas, meanders may be restored to a river.	Artificial flood control measures like levees made of hard concrete, can restrict the widening of the channel, preventing the development of braiding.

14.5 Conclusion

- For both meanders and braided channels, variations in a river's energy result in erosion and deposition occurring along different parts of the river or at different times.
- A river's energy is affected by a range of natural and human factors. The relative importance of the two types of factors can be determined based on the interconnections between the factors, the immediacy of the factors in bringing about the respective landforms and the timescale over which the factors are dominant.