Lecture 10

Geomorphic Processes (I): Fluvial Processes and their Factors

KEY QUESTIONS:

✓ *What influence fluvial processes?*

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

Fluvial processes: erosion, transportation and deposition of materials by rivers

- Sources of materials in rivers
- Influence of river's energy on fluvial processes
- Natural and human factors influencing river's energy

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10.6 Factors Influencing a River's Energy

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10.1 Introduction: Rivers as energy systems

Rivers are energy systems. They derive their energy from:

- their volume of flow, or discharge (influenced by OVF, TF and BF; recall Lect 5)
- flow velocity (which is dependent on a number of factors, see Section 10.6)

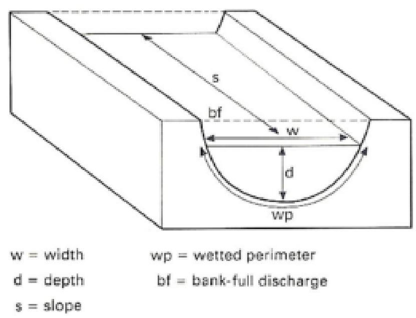
This energy is expended (or used) through fluvial processes of erosion and transport. Deposition sets in when river energy is low.

- At high flow, rivers have surplus energy which is expended on sediment erosion ("picking up" load; see Section 10.2) and transport ("moving" load; see Section 10.3).
- At low flow, rivers may deposit ("drop"; see Section 10.4) its load to ensure it has enough energy to overcome the frictional resistance of the channel and keep the water flowing.

At any one time, a river will be performing all these processes, but depending on the existent factors, there will be a dominance of one over the other.

Box 1: Some useful terms to do with channel morphology

- ✓ **Width** (w): width of the channel at the water surface
- ✓ **Depth** (d): the distance between the water surface and the channel bed
- ✓ **Cross-sectional area** (A): the area of water across a given cross-section of the channel. The calculation of A depends on the shape of the channel. While regular shapes (e.g. rectangular, circular) are easier to calculate using mathematical formulae, irregular ones may require additional steps.
- ✓ **Channel slope** (s): the change in elevation per unit length, also referred to as **gradient**



The dimensions of a river channel

- ✓ **Wetted Perimeter** (wp): the length of the channel's bed and banks that is in contact with the water. It serves as an indicator, or index, for friction within the channel.
- ✓ **Form ratio** ($\frac{w}{d}$): the width to depth ratio of a channel. There is a tendency for form ratio to increase in a downstream direction, as width increases more rapidly than depth.

10.2 Fluvial Erosion

Broadly, erosion refers to the progressive removal of load (i.e. rocks, sediments, and mineral material) from the bed and banks of the channel. Erosion is associated with high energy levels in the river.

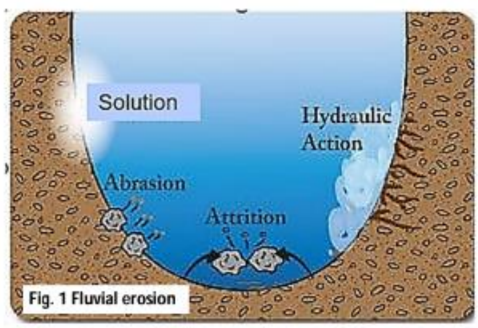


Fig. 1 Fluvial erosion

By the process of erosion a river can deepen (by eroding the river bed), widen (by eroding the river bank) or even lengthen its channel.

There are generally three ways through which fluvial erosion can take place (see Fig. 1). These are abrasion, attrition, solution and hydraulic action.

10.2.1 Corassion

Corrasion refers to the scraping away (like a sandpaper would) of the bed and banks by materials transported by the river. The main tools of corrasion are coarse bedload (like pebbles) and sand-sized particles. As these particles are transported (see Section 10.3), they scour the channel.

This process is responsible for much of the downcutting or vertical erosion that creates and deepens channels, and is likely to be most effective in upland channels in times of flood when the large angular fragments of bedload can be activated upon the exposed rock of the bed.

This process is also responsible for sideways cutting or lateral erosion that widens the channel of the river. If the base of the bank is eroded by abrasion it might result in collapse of the upper part of the bank of the river as well, thus also widening the river channel.

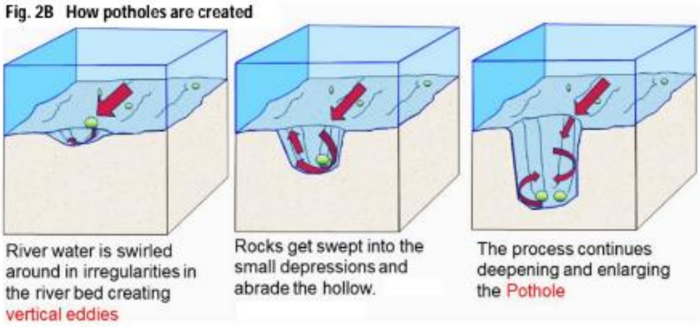
Active corrasion along a streambed can produce potholes (see Fig. 2A), especially in fast-flowing rivers with strong eddying (i.e. water moving in a circular manner).

- Potholes are cylindrical holes 'drilled' into the bedrock by turbulent high velocity flow. It occurs when fragments of load are whirled around in turbulent eddies to drill smooth depressions into the rock bed (see Fig. 2B).

Corrasion is a major cause of the bedload particles themselves becoming smaller and rounder as they move downstream (see also later, attrition).

Fig. 2A Potholes

Fig. 2B How potholes are created



10.2.2 Corrosion

Corrosion refers to the chemical action of water, which dissolves soluble materials and carrying them away.

It is most marked on carbonated rocks, such as limestone, where both river water and carbonic acid dissolves the lime in the rock and forms gaps, openings and hollow spaces on the bed and banks of the river. (We shall learn more about limestone in a subsequent lecture).

However, many other chemical compounds are soluble, and thus a wide range of rocks on the bed and banks of the river may be vulnerable to the process of corrosion.

Like corrasion, corrosion can serve to widen and/or deepen a channel.

10.2.3 Cavitation

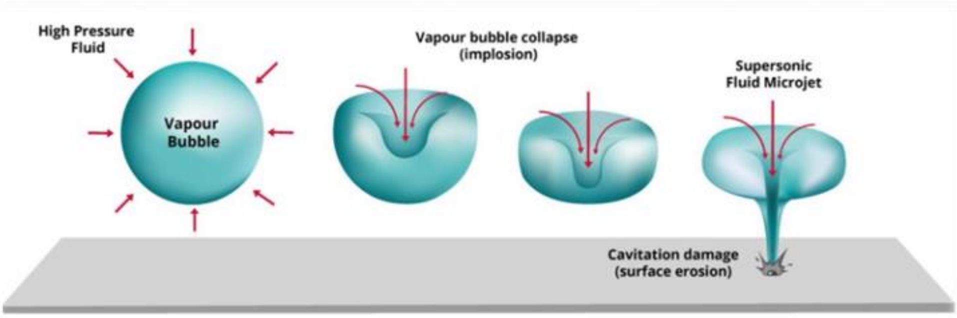


Fig. *Cavitation*

Cavitation involves **the formation and collapse of bubbles within the water**. As the bubbles burst, very tiny jets of water (microjets) are produced that move at intense velocities and hammer the river bed and banks (Fig. 4).

It involves shockwaves released by imploding bubbles, which are produced by pressure changes in fast-flowing streams, smashing into the channel walls, hammer-like, and causing rapid erosion.

Cavitation occurs when flow velocities are high, as **at the bottom of waterfalls** (Fig. 5) or **in rapids**

- **Cavitation** is an important process in rapids and waterfalls, and is generally accompanied by corrasion.

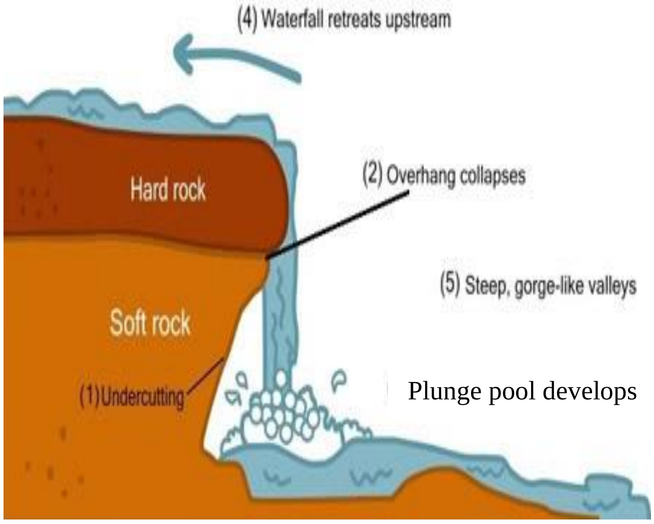


Fig. Waterfall (plunge pool)

Comparison of the Different Fluvial Erosional Processes (Table 3)

	Corrasion	Corrosion	Cavitation
Definition	The mechanical process of wearing away by friction.	Chemical erosion of specific soluble material in rocks by river water.	Cavitation involves the formation and collapse of bubbles within the river water.
Tools	**Coarse river load or materials from channel**	**Acidic water**	**Air bubbles in high velocity river**
Actions	Coarse and regular fragments or river load are rolled and dragged along the channel bed and banks.	Minerals dissolved in acidulated water in the river and are removed leaving pits in the bed and banks of the river.	It involves shockwaves released by imploding bubbles, which are produced by pressure changes in fast-flowing streams, smashing into the channel walls, hammer-like, and causing rapid erosion.
Landform it affects	Wears away rock outcrops, exposed rock of river bed. Scratches and smoothens channel Downcuts and deepens the bed of the channel Sideway cuts or widens the channel	All rocks with minerals Which are susceptible to dissolving action.	Forms depressions known as plunge pools, at the base of waterfalls or rapids.
Remaining Material	Angular fragments.		Rock fragments
Highly effective in	Upper course of the river or High flood	River beds and banks made of soluble minerals, Tropical rivers.	High velocity river mainly at the base of waterfalls and rapids.

Table 3

10.3 Fluvial Transportation

All rivers transport some rock material. These rock material often come from the erosion of river bed and banks, but may also be introduced into the river from external causes (such as surface runoff from nearby slopes; see Box 3). All the material transported by the river is called load.

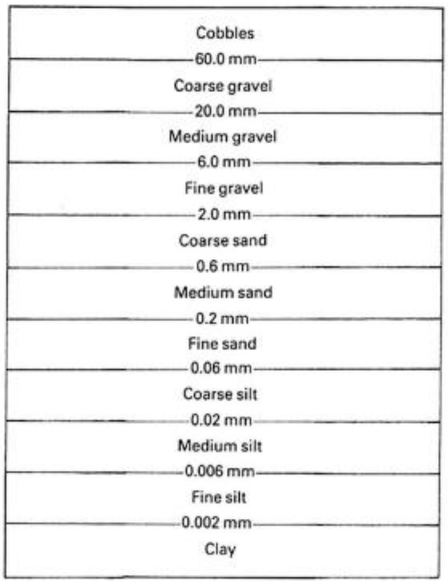


Fig. 3 Calibre of load

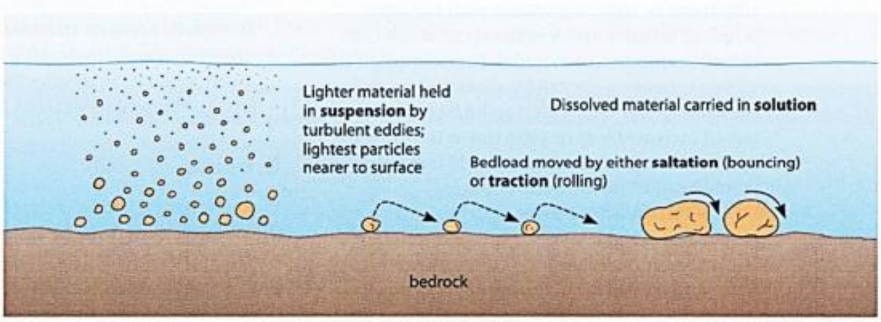
Thus, fluvial transportation is defined as the movement of river load in the river channel.

Load can be sorted by their sizes, or in more technical terms, their calibre (Fig. 3). As we shall see later (Section 10.5), the calibre of load and the river's energy determine how they are transported. The basic concept is that finer, lighter material is carried more readily than larger heavier particles.

Fig. 4 shows the different fluvial transportation processes in a river:

- Dissolved load is carried in solution
- Lighter load may be held in suspension (hence, also called suspended load)
- Bedload undergoes saltation and/or traction

Fig. 4 Transportation processes in a river or stream



10.3.1 Solution (cross-reference Section 10.2.2)

The load that is transported by solution is referred to as dissolved load (or solution load).

Most of the dissolved load is brought to a river by groundwater flow and is dispersed throughout the river.

- As water percolates through the ground, it first acquires soluble soil compounds.
- As the water seeps deeper through cracks and pores in the bedrock below, it may dissolve additional mineral matter.
- Eventually, much of this mineral-rich water finds its way into streams.

The velocity of streamflow has essentially no effect on a river's ability to carry its dissolved load. Once material is in solution, it goes wherever the river goes, regardless of velocity. This is unlike the other types of transportation processes.

The quantity of material carried in solution is highly variable and depends on such factors as climate and the geological setting. For example, the type of rock and how it reacts to climatic elements such as rain and temperature (as we shall learn in a subsequent lecture on rocks and weathering) can cause variations in volume of solution load.

10.3.2 Suspension

Most streams (but not all) carry the largest part of their load in suspension. We refer to this load as suspended load. Indeed, the visible cloud of sediment suspended in the water is the most obvious portion of a stream's load.

Usually only fine sand-, silt-, and clay size particles (refer to Fig. 3) can be carried this way, but during flood stage, larger particles are carried as well.
o Also during flood stage, the total quantity of material carried in suspension increases dramatically, as can be verified by people whose homes have become sites for the deposition of this material (recall: Lect 8 on consequences of floods).

10.3.3 Saltation and Traction

A portion of a stream's load of solid material consists of sediment that is too large to be carried in suspension. These coarser particles move along the bed of the stream and constitute the bed load.

The particles that make up the bed load move along the bed by saltation (bouncing) and/or traction (rolling and sliding).

- Sediment moving by saltation (saltare = to leap) appears to jump or skip along the river bed. This occurs as particles are propelled upward by collisions or lifted by the current and then carried downstream a short distance until gravity pulls them back to the bed of the stream.
- Particles that are too large or heavy to move by saltation either roll or slide along the bed, depending on their shape. This is referred to as traction.

The bed load usually does not exceed 10% of a stream's total load, although it may constitute up to 50% of the total load of a few streams.

- For example, of the load that the Mississippi River carries into the Gulf of Mexico each year, 67% is carried in suspension, 26% in solution, and the remaining 7% as bed load.

Table 2: Comparison of the Different Fluvial Transport Processes

Type of load	Sediments	Transport Processes
Bed load	Coarse particles: boulders, cobbles and pebbles	**Saltation** and **traction**. Particles bounce, slide and roll along the channel bed at high discharge
Suspended load	Fine particles such as silt and clay	**Suspension**. Particles are entrained (removed) at high discharge and in suspension in the flow
Dissolved load or solution load	Dissolved minerals from rocks such as limestone	Minerals are transported in **solution**. This type of transport does not depend on high river discharge.

Box 2: Capacity and Competence

- A river's ability to erode and transport solid particles is typically described using two criteria.
- First, the *maximum load of solid particles that a river can transport* is termed its *capacity*.
  - **The greater the amount of water flowing in a stream (i.e. discharge), the greater the stream's capacity for hauling sediment.**
- Second, the *competence* of a river indicates *the maximum particle size that a river can transport*.
  - **The river's velocity determines its competence; the stronger the flow, the larger the particles it can carry in suspension and as bed load.**
  - Research suggests that an increase in velocity gives a much larger increase in competence (e.g. *if velocity doubles, competence can increase by as much as 64 times*). Hence the large boulders that are often visible during a low-water stage and that seem immovable can, in fact, be transported during flood stage because of the river's increased competence.
- By now it should be clear why the greatest erosion and transportation of sediment occur during floods.
  - The increase in discharge results in greater capacity (i.e. *more* load); the increased velocity produces greater competency (i.e. *larger* load). Though not always, both changes often happen together.
  - In the course of just a few days, or perhaps just a few hours, a river in flood stage can erode and transport more sediment than it does during months of normal flow.
- However, as we shall see in **Section 10.5**, the relationship between velocity and competence is not always straightforward. It is possible that particles that are small in size require high velocities to be removed.

10.4 Fluvial Deposition

Fluvial deposition is the process by which river load settles out of the water that is carrying it, and is left in a different location. The type and amount of load deposited is dependent on velocity and discharge of a river, as seen in Box 2.

Whenever the velocity of a river slows down, the situation described in Box 2 reverses. Its competence is reduced and sediment begins to drop out, largest particles first.

- Each particle size has a critical settling velocity (see Section 10.5). As river flow drops below the critical settling velocity of a certain particle size, sediment in that category begins to settle out.
- Thus, river transport provides a mechanism by which solid particles of various sizes are separated. This process, called sorting, explains why particles of similar size are deposited together.

Similarly, if discharge is reduced, the capacity of the river also drops, resulting in more load being deposited.

It is often the case that when velocity is reduced, so will discharge, as Q = AV. This means that with lowered velocity, often, both capacity and competence will be reduced.

10.5 Tying fluvial processes together: The Hjulström Curve

The Hjulström curve shows the relationship between calibre (size) of material in water and the different velocities at which erosion, transport and deposition take place (Fig. 5). It shows the velocities necessary (i.e. critical) for the initiation of erosion and deposition respectively; and the area where transportation will continue to occur once movement has been initiated.

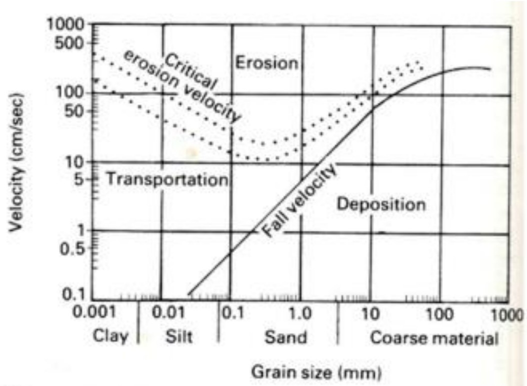


Fig. 5 Hjulström's curve of erosion and deposition for uniform material.

From the curve, notice that there are two critical velocities we need to know:

The critical erosion velocity curve is a band showing the critical velocities at which grains of a given size start to erode (that is, entrained or removed). The curve is a band rather than a single line because the critical velocity depends partly on the position of the grains and the way that they lie on the bed.

Once eroded, a particle will remain in transportation until the water velocity is reduced to the critical fall velocity, at which particles of a given size become too heavy to be transported and be deposited to the channel bed.

- As the river velocity falls, the heaviest bed load material, such as boulders, is deposited first, followed by gravel, sand and silt then the finest clay particles.
- In addition to size, the shape and weight of particles also influence the settling velocity. Flat grains sink through water more slowly than do spherical grains, and dense particles fall toward the bottom more rapidly than do less dense particles.

Also, notice the following:

Medium-sized particles such as sand are easiest to be entrained (or, to be carried away). Large particles such as cobbles and pebbles need high velocities to get them moving.

The critical erosion velocity is much higher for the smallest grains of clay than it is for sand-sized material, but as grain size increases above sand the critical velocity increases steadily.

- This apparent anomaly of high velocities for the smallest grains is explained by the fact that clay and silt particles are more cohesive (i.e. readily stick to each other).
- During times of high discharge and velocity, the size and amount of the river's load will increase considerably, causing increased erosion within the channel.

Overall, the velocity required to maintain particles in transportation is less than the velocity needed to pick them up. Indeed, for very fine clays, the velocity required to maintain them in transportation is virtually nil.

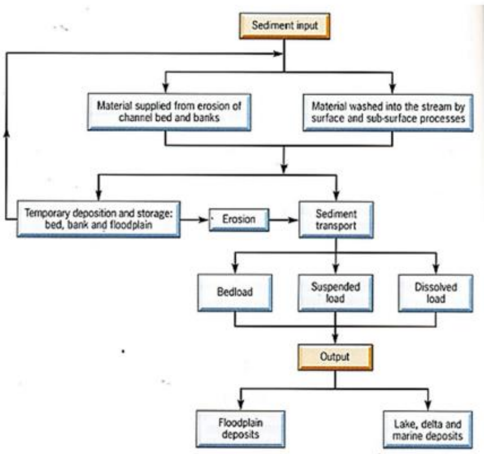
The region between the lower curve and the upper band defines the velocities at which particles of different sizes are transported. Or, phrased differently, the wider the gap between the upper and lower lines, the more continuous is the transport.

- For coarser particles, the boundary between transportation and deposition is narrow, indicating that only a relatively small drop in velocity is needed to cause deposition. Hence, a piece of gravel (coarse material) eroded at just above the critical erosion velocity will be in transit only briefly, and deposited as soon as it arrives in a region of slightly lower velocity.
- For fine particles, once entrained, they will be transported over long distances.

<u>Box 3</u>: **Where do materials in a river come from? And where do they go?**

- **Fig. 6** depicts the supply and movement of sediments within a length of channel.

Fig. 6 Key processes involved in affecting sediment input in a channel



- There are two main **sources** (or **inputs**) of sediments:
  - Materials eroded from bed and banks of river (see earlier sections in this lecture)
  - Materials transported from surrounding areas into the river through surface and sub-surface processes. We will however only consider these processes in **Lect 13**.
- Notice how the sediments will continue to be eroded and transported. Whether the sediments are transported as bed, suspended or dissolved load is determined by factors we saw in the Hjulström's Curve.
- The river can carry these sediments and deposit elsewhere as **output**. While some can be deposited in the **floodplain** (<u>recall</u>: this is an area of low-lying ground adjacent to a river, formed mainly of river sediments and subject to flooding), sediments can also be deposited as **deltas** at the river mouth. We shall learn about deltas in more detail in **Lect 11**.

10.6 Factors Influencing a River's Energy

Velocity is an important variable affecting the kinetic energy of a river, which is used to carry out a river's tasks (that is, the processes of erosion, transportation and deposition; see again, Fig. 5).

The channel is particularly important as it creates the friction which dissipates the energy and reduces the velocity. To help us consider the interrelatedness of the different variables, we use the following Manning's Flow Equation:

$$V = \frac{1.49\, R^{2/3}\, S^{1/2}}{n}$$

where **v** = velocity **R** = hydraulic radius
S = channel slope ***n*** = coefficient of roughness

While natural factors (e.g. climate, relief, and vegetation) and their influence on the above variables are clear, and human (e.g. landuse change and channel management) action can also modify them and as a result influence a river's energy.

For the purpose of this lecture, we shall only focus on the variables as stated in Manning's Flow Equation. You will have to evaluate the role of natural and human factors on your own.

10.6.1 Hydraulic Radius

Recall that in Lect 9, we mentioned the importance for channelisation to increase the hydraulic radius (HR, or R) so as to help reduce flooding. Some content from Lect 9 is intentionally reproduced here.

The hydraulic radius is a measure of the efficiency of a channel to transport water and its sediment load. This is measured through dividing the channel's cross sectional area (A) (index for water volume) by its wetted perimeter (WP) (index for friction) – the higher the value, and the more efficient it will be (i.e. HR = A / WP), the higher the velocity is likely to be.

Put in another way, if there is less energy loss through friction of water with the bed and banks, velocity will increase and more water will move quickly through the channel. (In Lect 9, we learnt that the likelihood of flooding will therefore be reduced.)

Fig. 7 and Fig. 8 below illustrate the effects on hydraulic radius due to changes in WP and A.

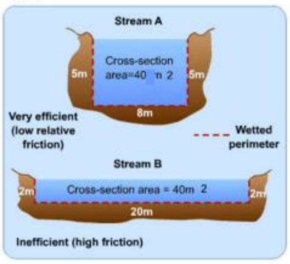
- Notice how the WP of a channel may change even as A is held constant in Fig. 7. In fact, as the width and depth changes along the course of the river, so will HR. The implications must be that channel velocity at different parts of the river will also change, and so will the dominance of various fluvial processes.
- With changes in the volume of flow in a channel, so will HR. An examination of Fig. 8 make clear why this is so. Velocity and energy at any point in a river's course is maximised when bankfull discharge is achieved, hence erosion is most dominant in such a situation.

10.6.2 Channel Slope

Steeper gradients should lead to higher velocities because of gravity, and for gentler gradients, a slower flow is to be expected. As such, the dominant fluvial process will change accordingly.

It is tempting to assume that velocities are always highest in the steepest sections of a river's course, but this is NOT always the case, bearing in mind that channel slope is not the only variable influencing velocity (recall Manning's Equation).

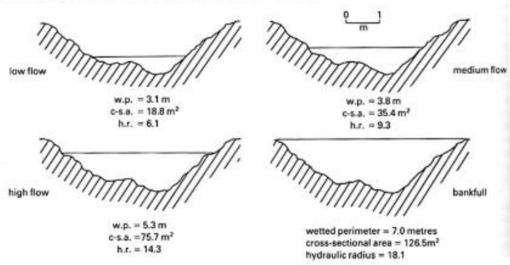
Fig. 7



$HR_A = \frac{40}{18} = 2.2$; $HR_B = \frac{40}{24} = 1.7$

Fig. 8 The same channel at a series of different stages of discharge

Note increase in hydraulic radius as discharge and channel efficiency increase.



10.6.3 Channel Roughness

Channel roughness is represented by the size and shape of the grains of the material forming the wetted perimeter. Generally, fine grains result in relatively low value of n and coarse grains in a high value of n.

A river flowing between banks composed of coarse material with numerous protrusions and over a bed of large, angular rocks (that is, rough surfaces, high n) meets with more resistance than a river with cohesive clays and silts (that is, smoother surfaces, low n) forming its bed and banks. (See Fig. 9)

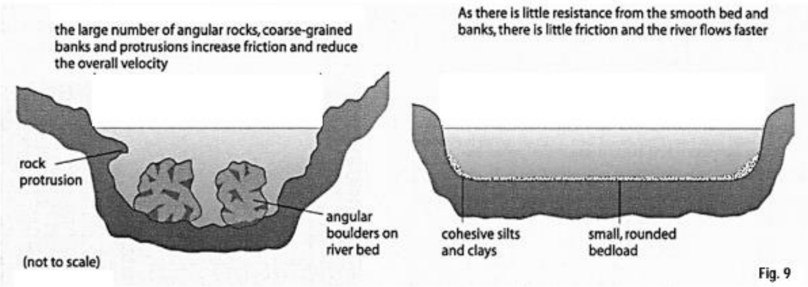


Fig. 9

Vegetation may also be regarded as a kind of surface roughness that increases the value of n. The effect of vegetation depends mainly on height, density and types of vegetation. (Recall that in Lect 9, reafforestation of banks had the possible limitation of slowing down flows)

In essence, the higher the value of n, the rougher the bed and banks,thusthe lower the velocity. Table 3 below shows the values of n for different types of surfaces.

Table 3: Manning roughness coefficients (*n*) for different types of surfaces

Types of surfaces	Manning Roughness *n*
Very smooth surfaces such as glass, plastic or brass	0.010
Smooth concrete	0.012
Straight unlined earth canals in good condition	0.020
Winding natural streams and canals in poor condition – considerable moss growth	0.035
Mountain streams with rocky beds and rivers with variable sections and some vegetation along banks	**0.041 – 0.050**

Source: Ritter (1987: 209)