Why Study Running Water?

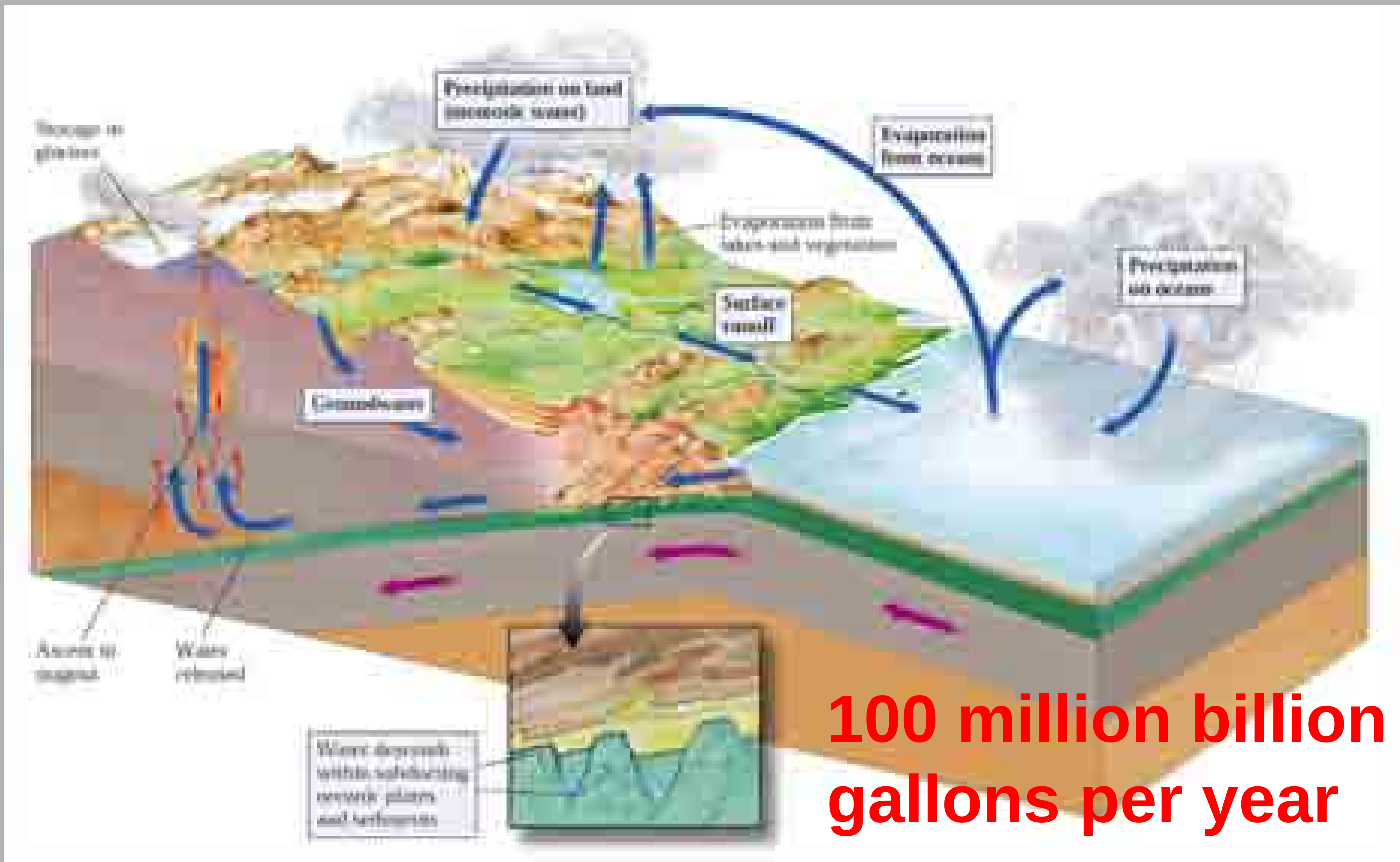
- Running water is the single most important geologic agent modifying Earth's land surface.
- Rivers and streams are sources of fresh water for industry, agriculture, and domestic use. They generate 8% of all electricity used in North America and are important avenues for trade. Much rich agricultural land owes its fertility to annual flooding.

Flood waters from a breached levee, Hermann, Missouri, June-July, 1993 Source: National Geographic, v 185, No 1

Streams and Flooding

- Flooding is probably the most widely experienced catastrophic hazard.
- In the US alone floods kill an average of 85 people a year and cause $1 billion in property damage. The loss of life in developing countries is typically higher
- Because water play such an important role in sculpting the earth's surface by eroding mountains, carving valleys and depositing sediment it is necessary to understand the basic characteristics of streams and water movement.
- Water is basically a renewable resource as a result of the hydrologic cycle, which accounts for the movement of water in the hydrosphere.
- Except for small gains as a result of volcanism and losses through subduction the amount of water in the hydrosphere is constant

Hydrologic cycle

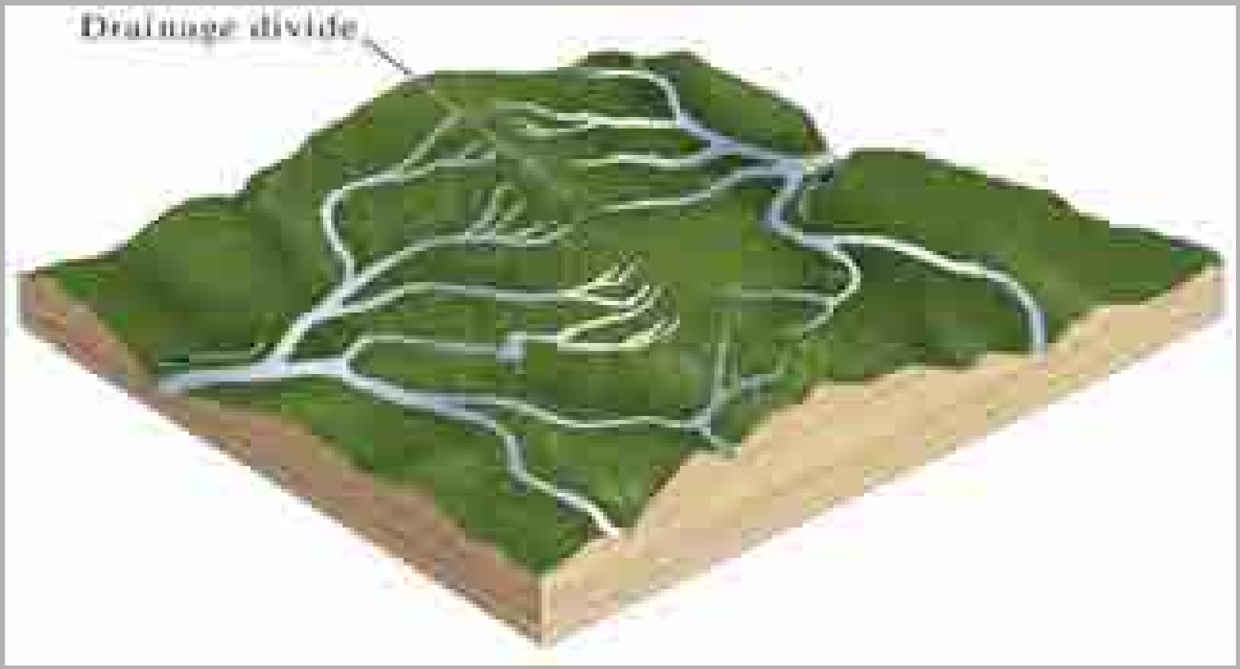


100 million billion gallons per year

Chernicoff & Whitney (2002)

Streams

- In geological terms a stream is any body of flowing water confined within a channel
- The drainage basin is the area from which a stream draws its water. The larger the drainage basin the larger the stream, although climate, vegetation and geology can all influence this

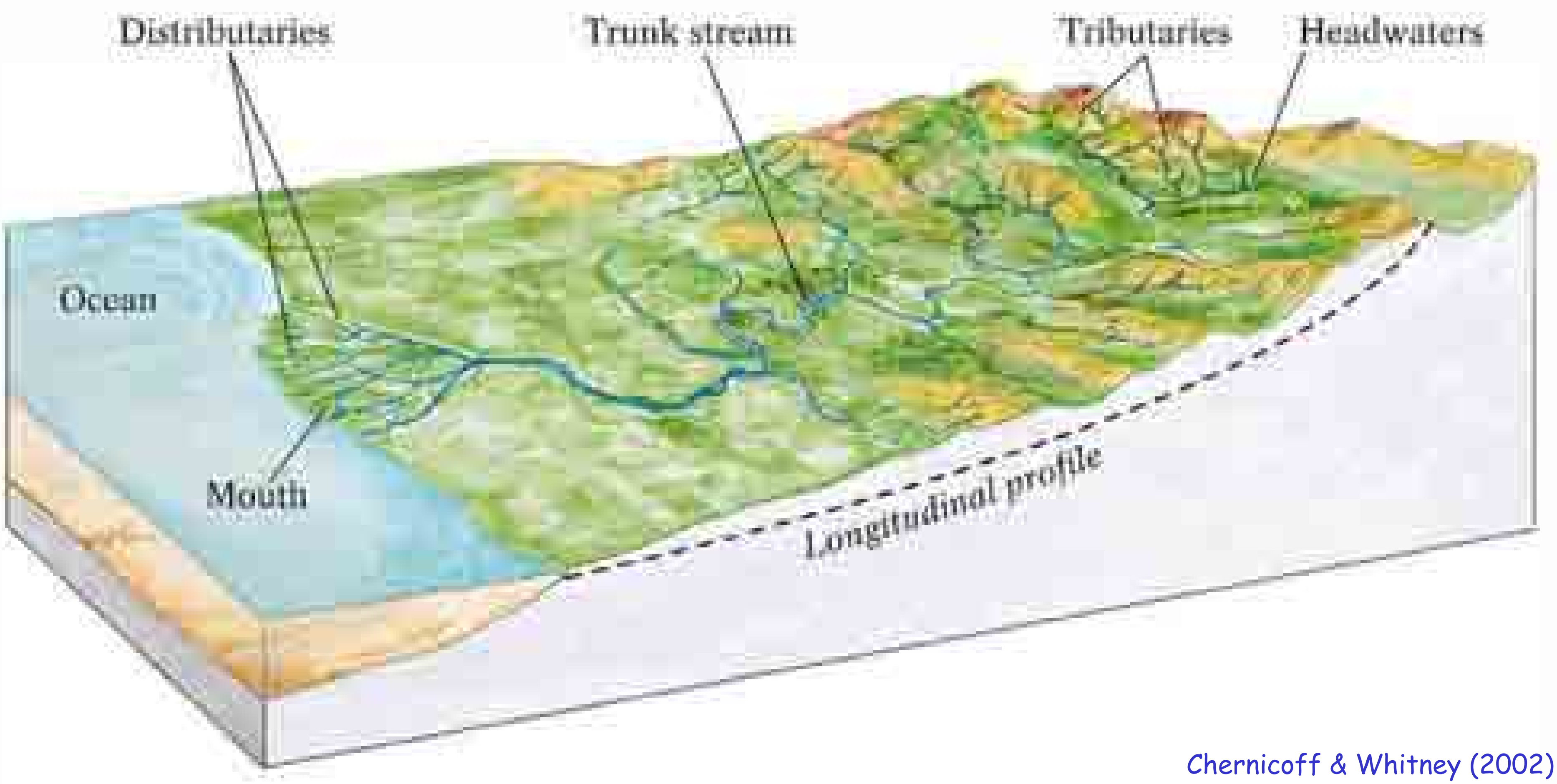


Marshak (2002)

N American drainage basins

Marshak (2002)
Modified from Chernikoff, 1999

A stream system network.



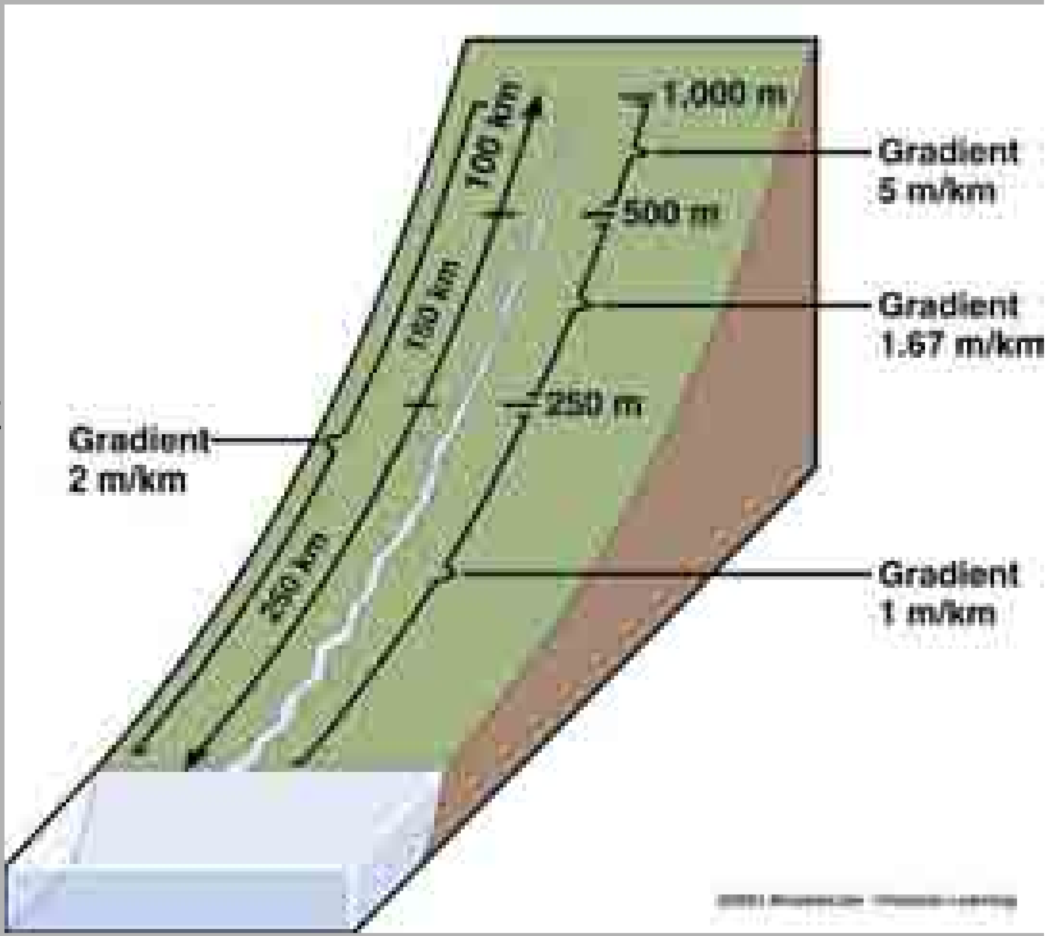
Chernicoff & Whitney (2002)

Running Water

- Runoff, gravity-driven flow across Earth's surface, depends on infiltration capacity of the surface material.
- Infiltration capacity is the rate at which surface materials can absorb water, which depends on duration and intensity of rainfall, permeability of the surface material, and saturation state of surface material.
- Runoff moves downhill as either sheet flow or channel flow.
  - Sheet flow occurs when a more-or-less continuous sheet of shallow water moves over the surface.
  - Channel flow is confined to long, trough-like depressions ranging in size from tiny rills to huge rivers.
- Rivers and streams receive their water from: rain falling within the channel, sheet flow, and most importantly, groundwater flow into the bottom and sides of the channel.

Gradient, Velocity & Discharge

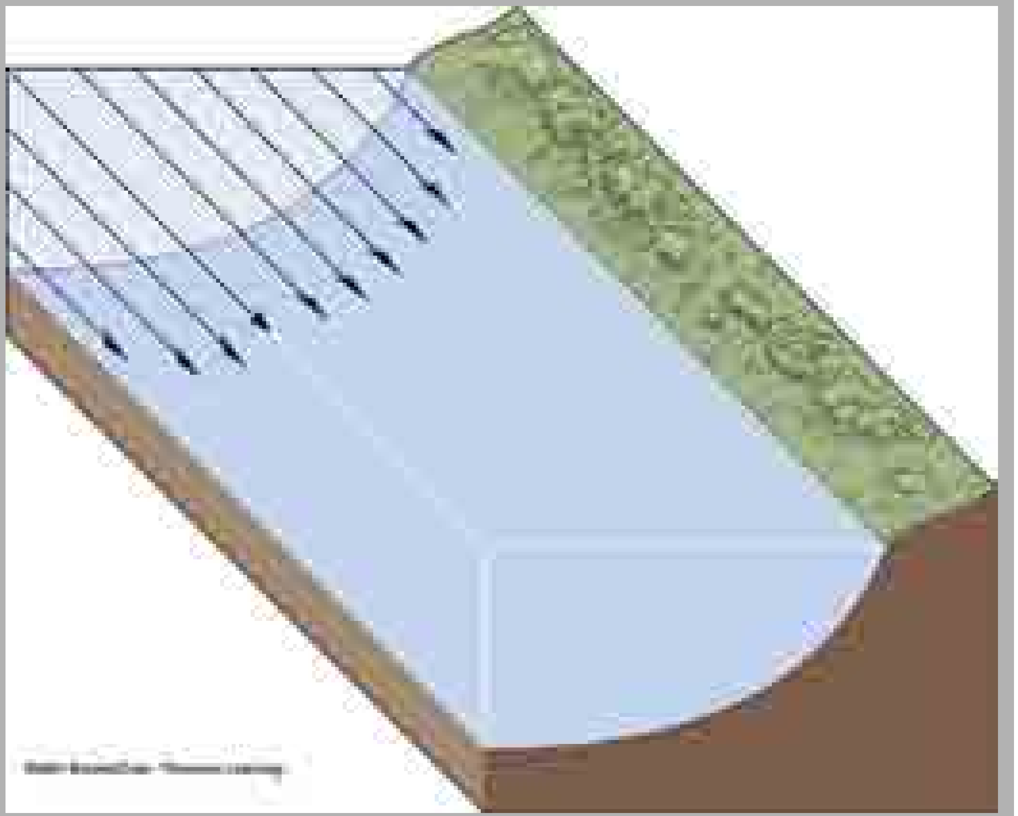
- Water in a channel flows downhill over a slope known as the gradient. Gradient is the vertical drop divided by the horizontal distance along the stream.
- Gradient is not uniform over the full course of a stream. Rather, it varies from steeper in the headwater area to low gradient in downstream reaches.



Monroe & Wicander 2002

Gradient, Velocity & Discharge

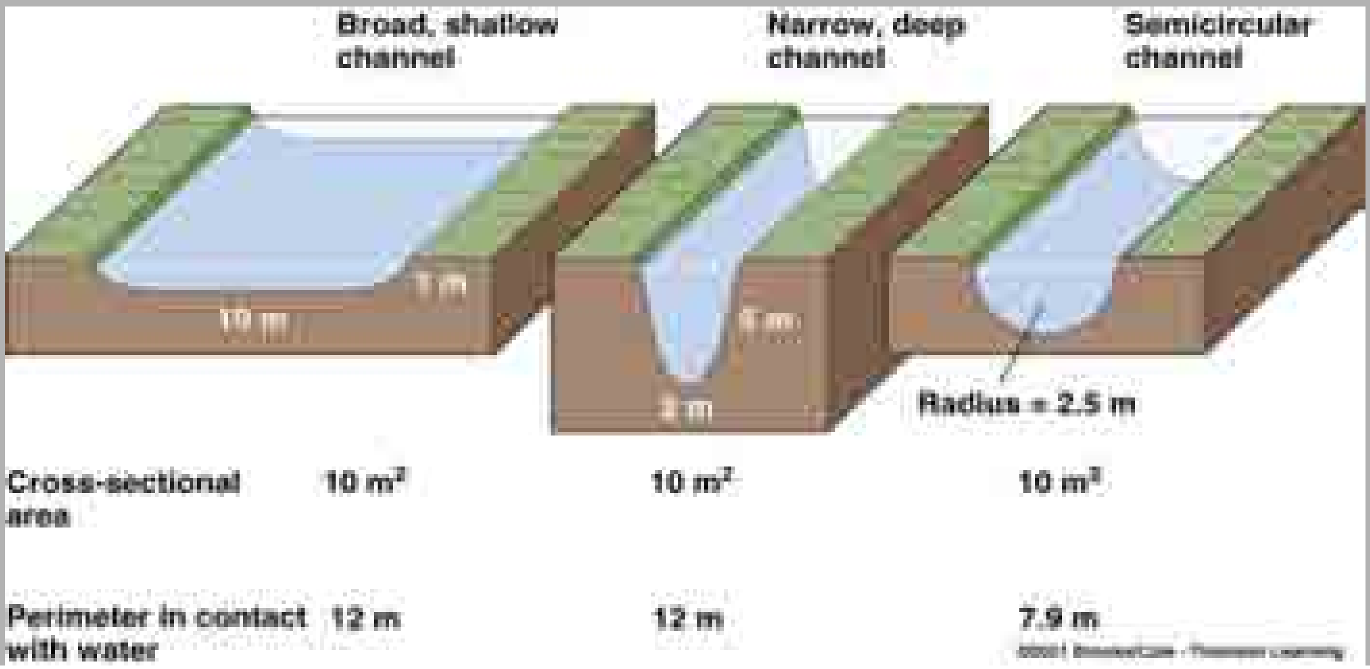
- Stream velocity measures the distance water travels in a given time. Velocity varies across a channel. Flow is slowest along the sides and bottom of the channel where flow is impeded by turbulence.
- Velocity is generally greatest near the middle of the stream, just below the surface. Velocity is commonly measured in ft/sec or m/sec.



Monroe & Wicander 2002

Gradient, Velocity & Discharge

- **Channel shape and roughness influence flow velocity. All other things equal, semi-circular channels permit higher velocity because less water is in contact with channel margins where friction acts to impede flow. Rough channels strewn with boulders offer more resistance to flow than do smooth channels in sand or mud**



Monroe & Wicander 2002

Gradient, Velocity & Discharge

- Stream discharge is the volume of water passing a particular point in a given period of time. Discharge is measured in ft3/sec or m3/sec. Discharge can be calculated using the following formula:

  (Q) discharge = (V) velocity x (A) cross-sectional area of channel

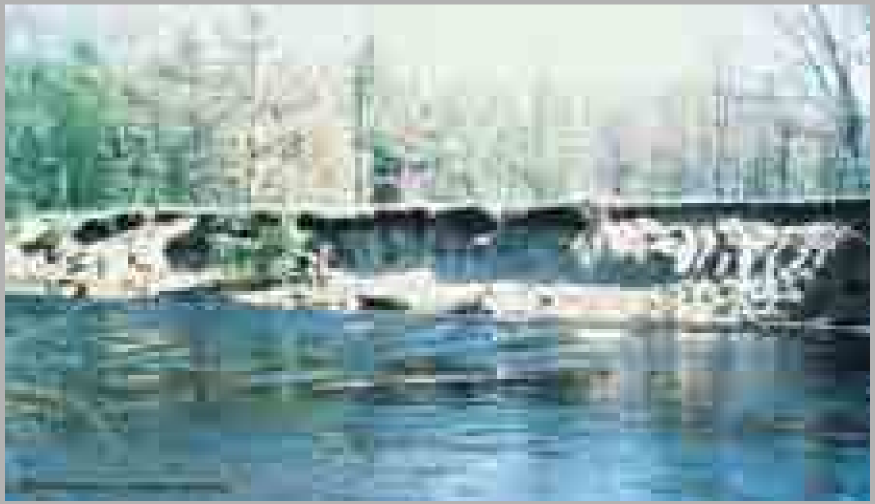
- Discharge increases downstream, unless evaporation or infiltration through the stream bottom significantly reduces the water volume.

Velocity and gradient

- In addition to the discharge the velocity of a stream is dependant on the gradient.
- Higher gradient = higher velocity
- While the gradient will tend to decrease downstream the velocity may not because of increases in discharge or changes in channel width and depth

Erosion and transport

- Erosion involves removal, from a source area, of dissolved substances as well as loose particles of soil, minerals, and rock. Solid particles from channel margins are eroded by hydraulic action, the direct impact of flowing water on loose material. Running water carrying sand and gravel also erodes by abrasion, involving the direct impact of solid particles on exposed rock surfaces.

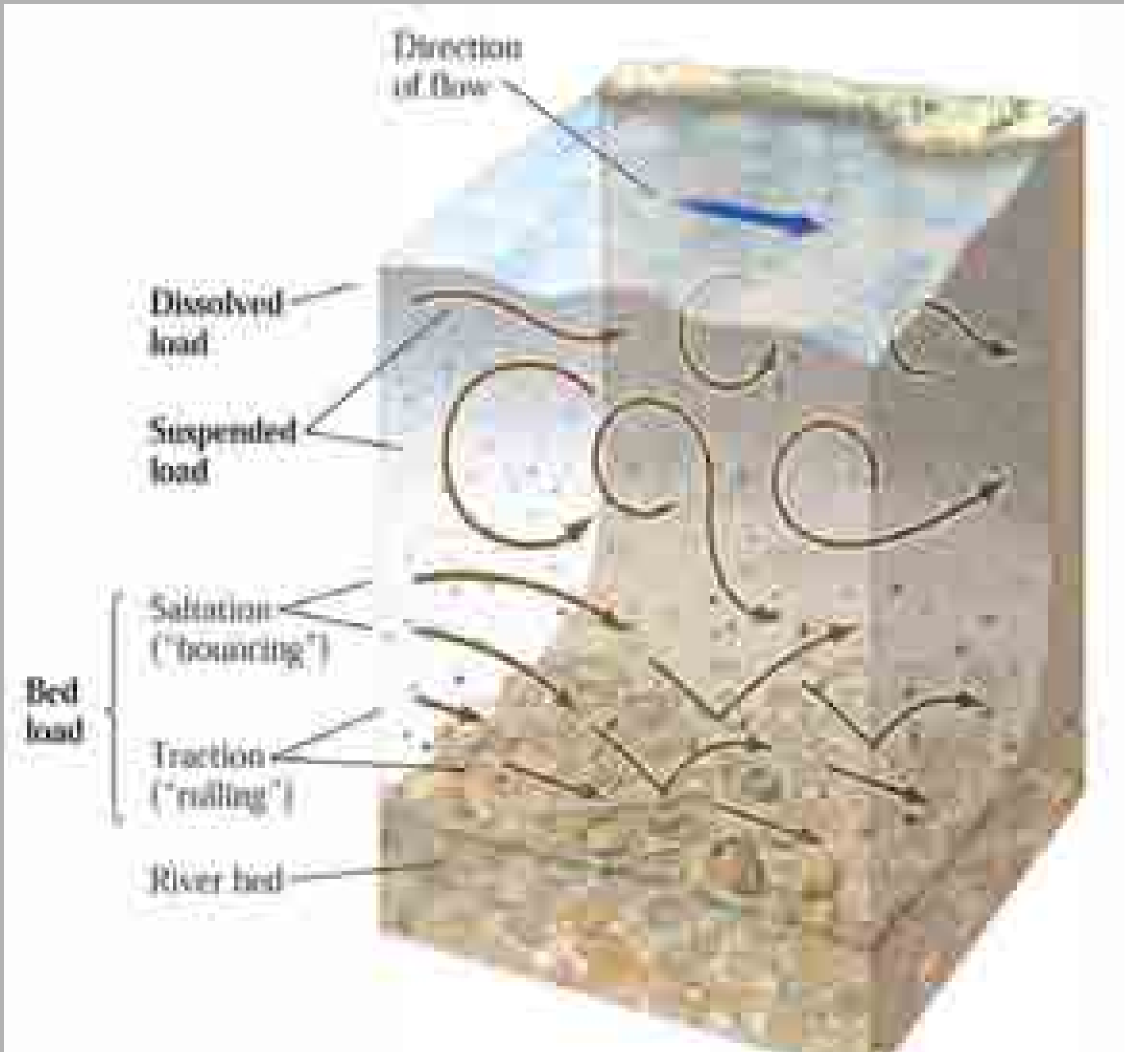


Erosion & transport

- With equal discharge a fast flowing stream will erode and carry more material than a slow moving one. Streams move material in a variety of ways
  - Bed load
  - Suspended load
  - Saltation
  - Dissolved load

Erosion and transport

- The dissolved load is invisible & consists of ions taken into solution during chemical weathering.
- Suspended load consists of mud kept in suspension above the channel bed by turbulence.
- Bed load consists of sand and gravel too large for turbulence to suspend.



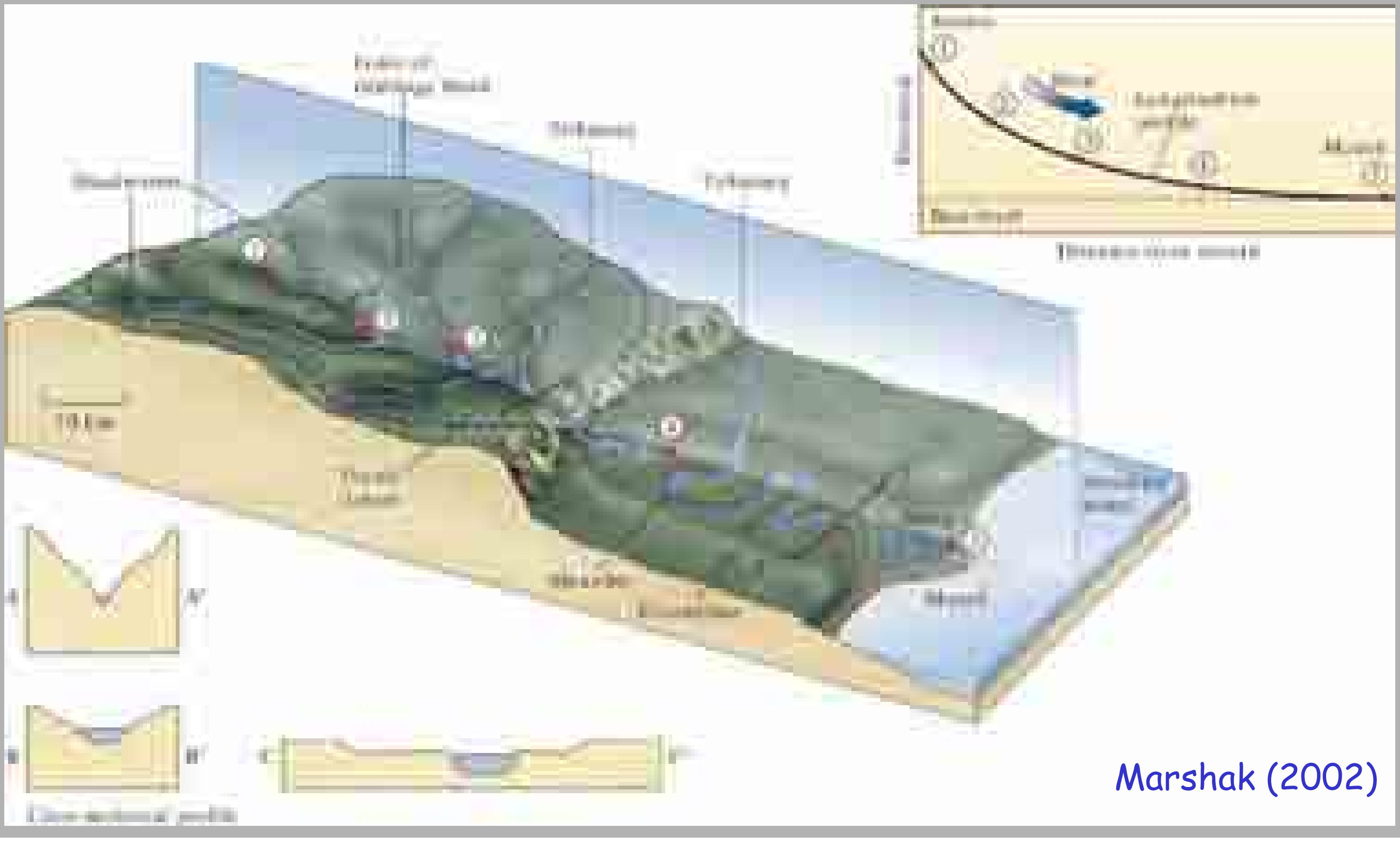
Chernicoff & Whitney (2002)

Deposition By Running Water

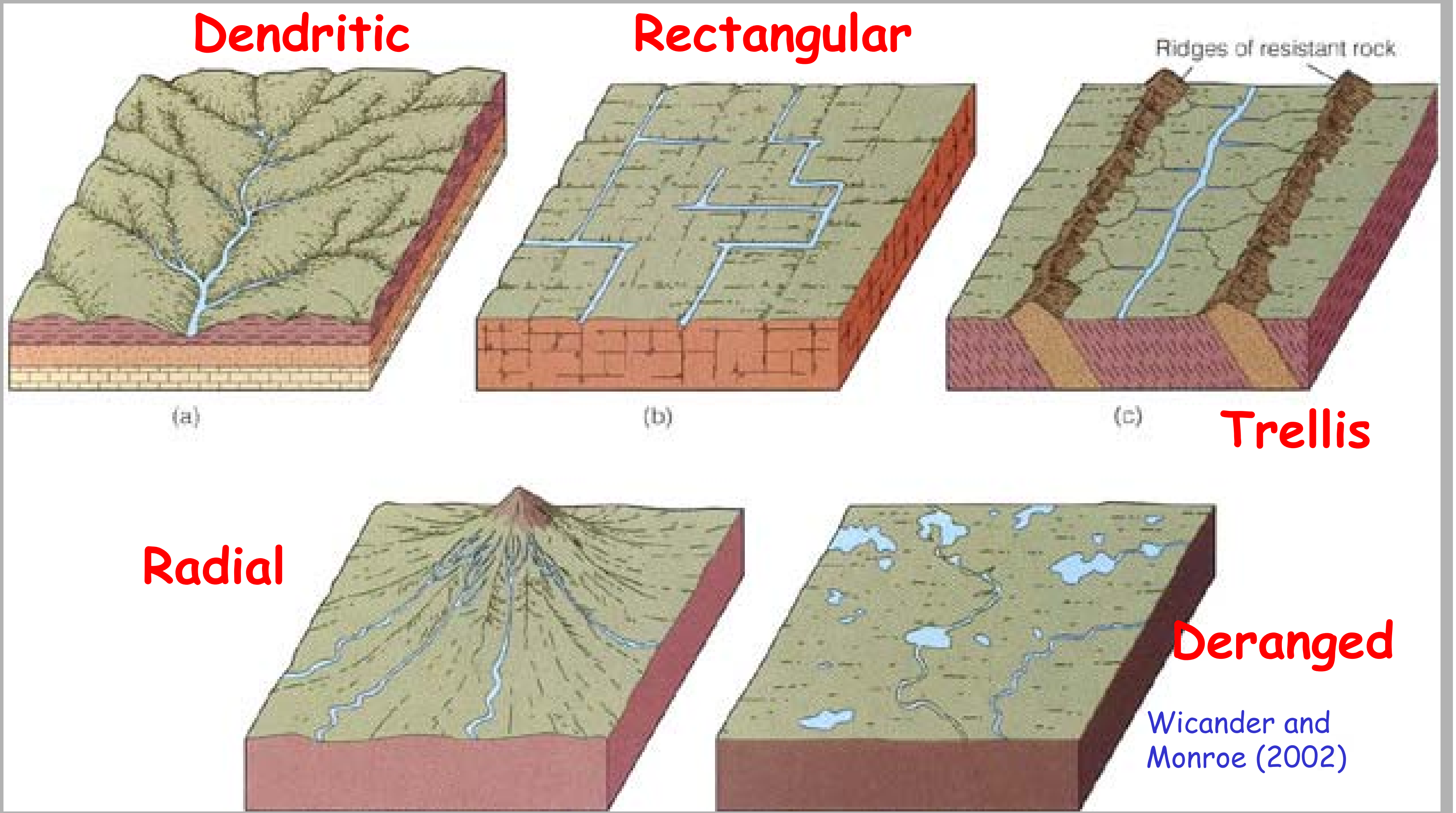
- Sediment can be transported great distances by rivers, but it is eventually deposited.
- Deposition may take place within the channel, on the floodplain, at the mouth of the river where it enters a lake or the sea, or where the river flows from the mountains on to a flat valley floor.
- Most of the geologic work (erosion, transport, and deposition) done by running water takes place during periodic flooding.
- Some sediment carried by rivers and streams makes its way to the ocean where it can be distributed and deposited by currents and tides.

Stream Features

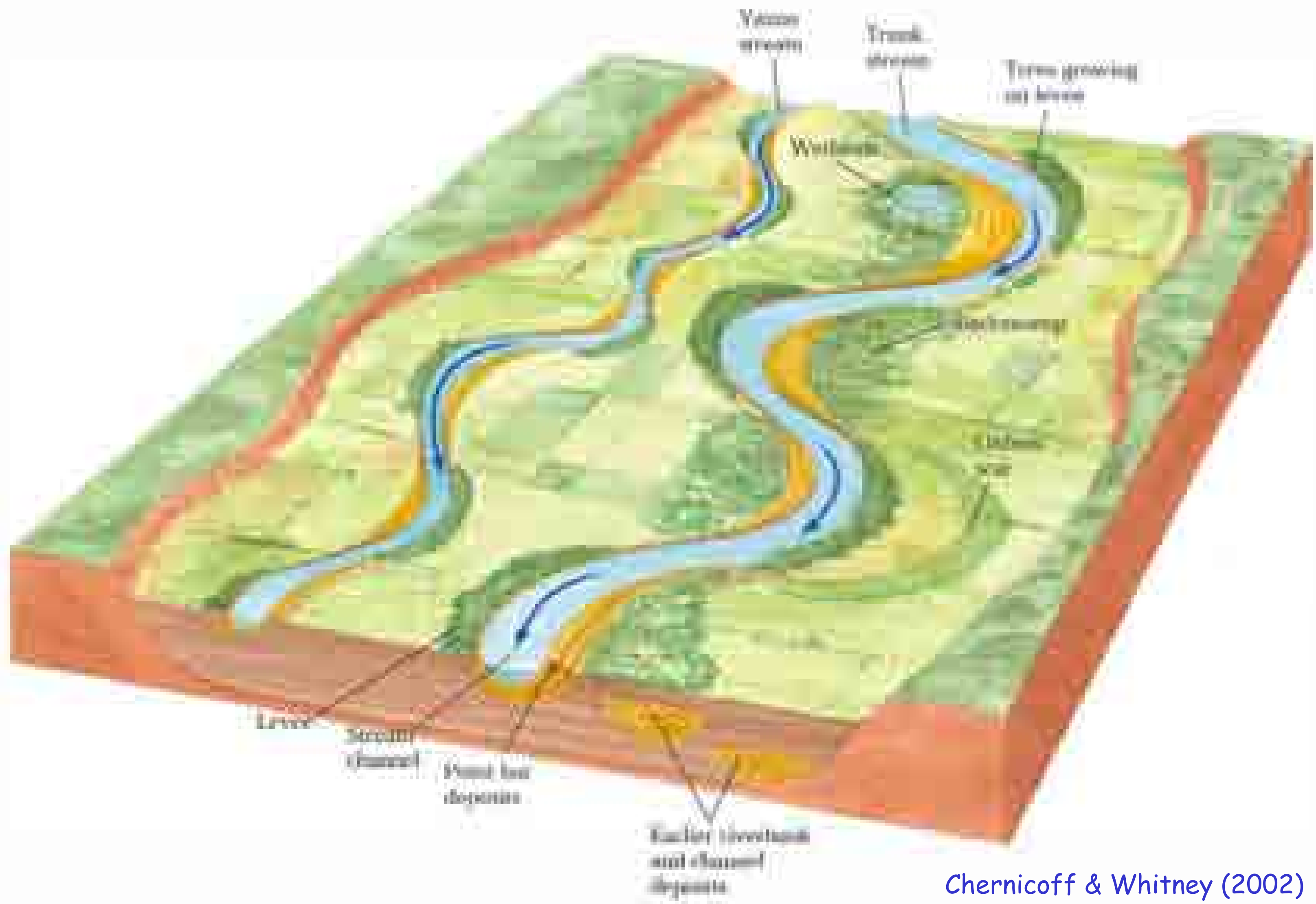
Streams and rivers with low gradients develop floodplains with a number of characteristic features



Types of drainage



Floodplain features.



Chernicoff & Whitney (2002)

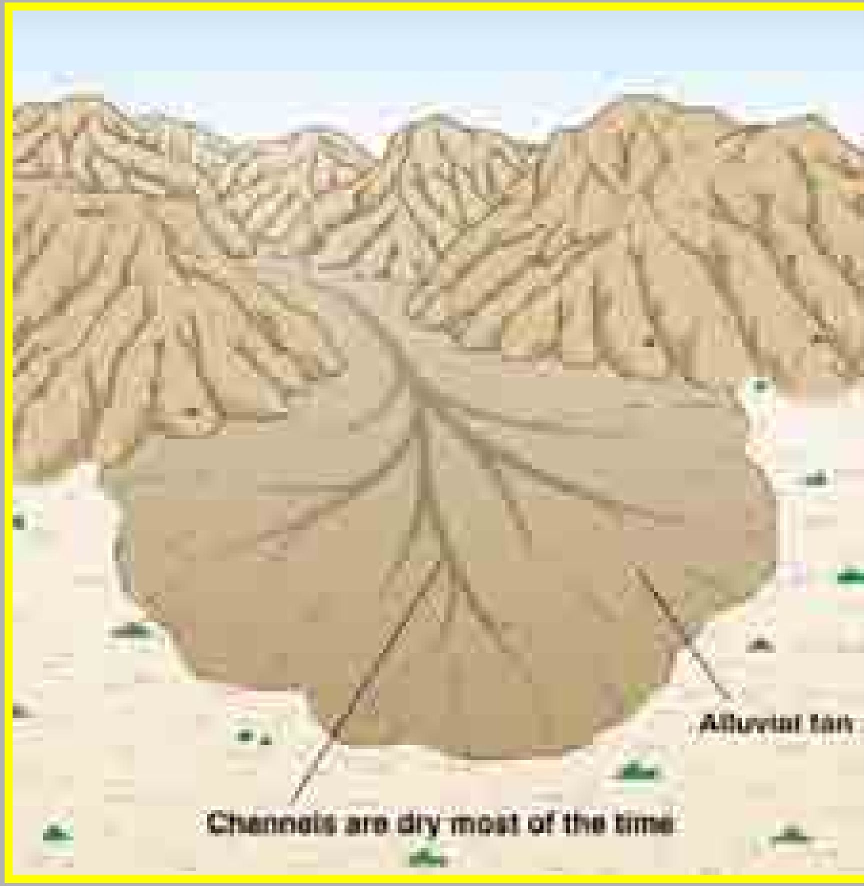
Alluvial fans

- Form where mountain streams flow into flat valleys. The change in stream velocity causes the stream to deposit it's sediment load. Can be subject to flash floods and debris flows as a result of intense seasonal storms

Montgomery (2000)

Alluvial Fans

- Alluvial fans are lobate deposits formed along the boundary between lowlands and mountains. They form in arid and semiarid areas where infrequent runoff is funneled into fast flowing streams in mountain canyons. When such a stream exits its canyon, flow spreads outward from the canyon mouth across the adjacent flats depositing an apron of sediment.



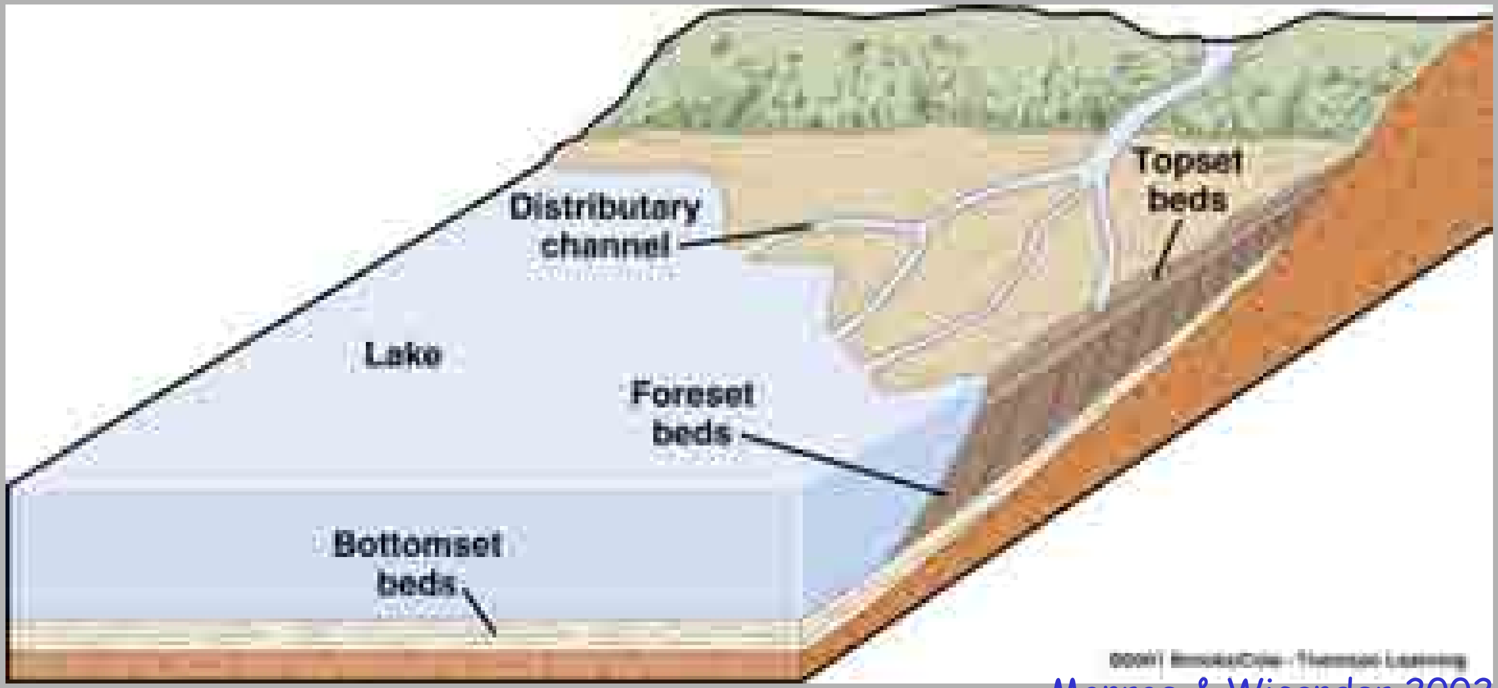
Monroe & Wicander 2002

Deltas

- Form where running water moves into standing water (lakes or oceans), typically have low stream gradients and changing channel systems
  - Stream dominated (Mississippi)
  - Wave dominated (Nile)
  - Tide dominated (Ganges)
  - Deltas at or near sea level are subject to flooding by tropical storms.
- Coastal flooding is the deadliest of natural disasters 500,000 people were drowned in Bangladesh in 1970

Deltas

•Sediment accumulates such that the shoreline gradually builds outward by a process called progradation. The simplest deltas have a characteristic vertical sequence of beds: bottomset, foreset, and topset beds. The river divides into a network of channels called distributary channels as it crosses the delta.



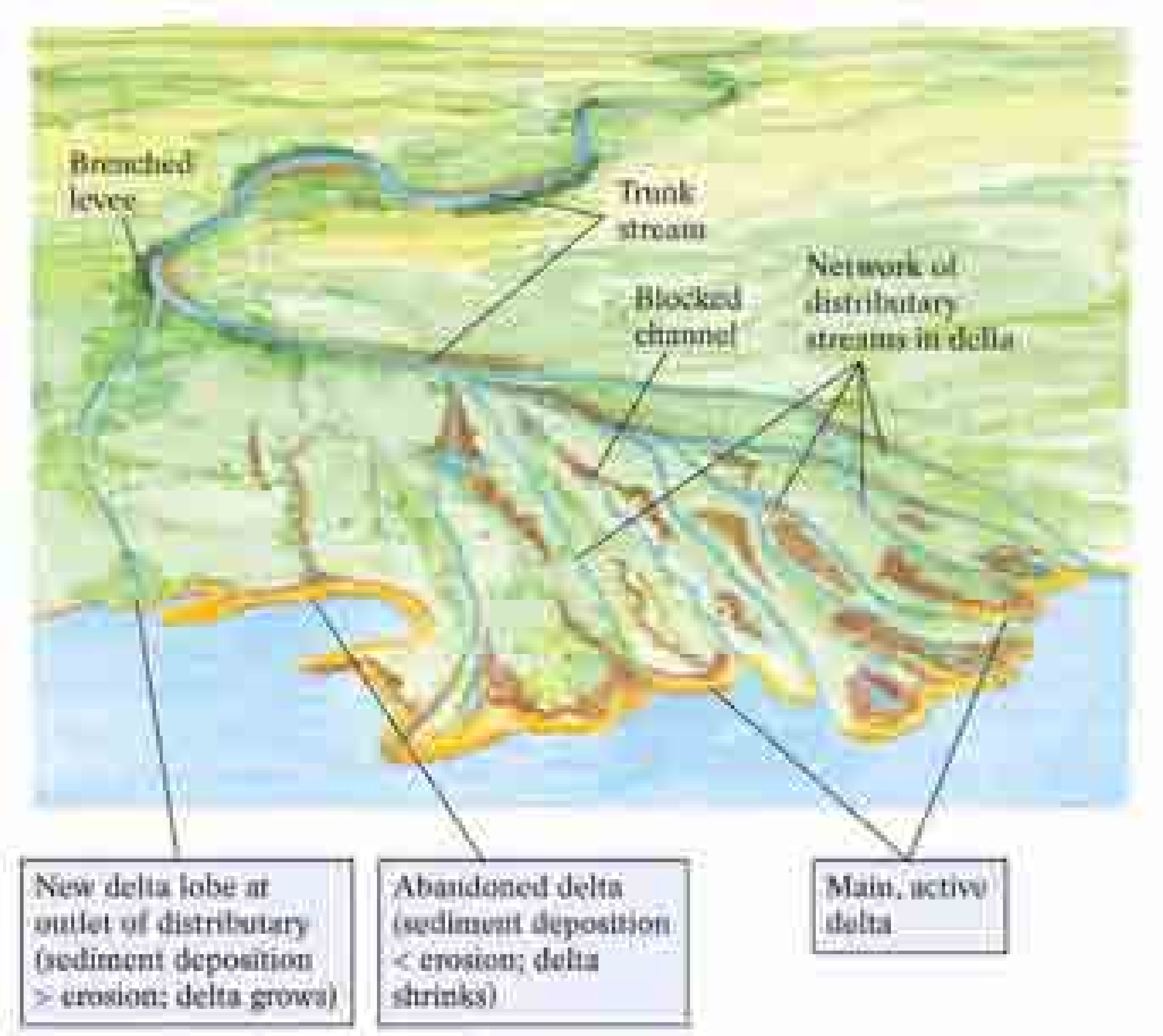
Monroe & Wicander 2002

Deltas

- Deltas forming along sea coasts are often large, complex, and sometimes economically important.
- The Mississippi delta is a bird's-foot delta, the classic shape of river-dominated deltas.
- Much of the oil and gas produced in the Gulf of Mexico comes from buried delta deposits.
- The swampy areas typical of most deltas are potential areas of coal formation.

Monroe & Wicander 2002

Deltas



Chernicoff & Whitney (2002)

Braided Channels

- Braided streams possess multiple channels that divide and rejoin, separated by bars of sand and gravel. They are bed-load dominated, sediment-choked streams with broad shallow channels. Such streams are especially common in arid and semiarid regions where surface material is easily eroded due to sparse vegetation. Because of the great volume of sediment dumped by melting ice, streams flowing from glaciers are braided.

Meandering Channels

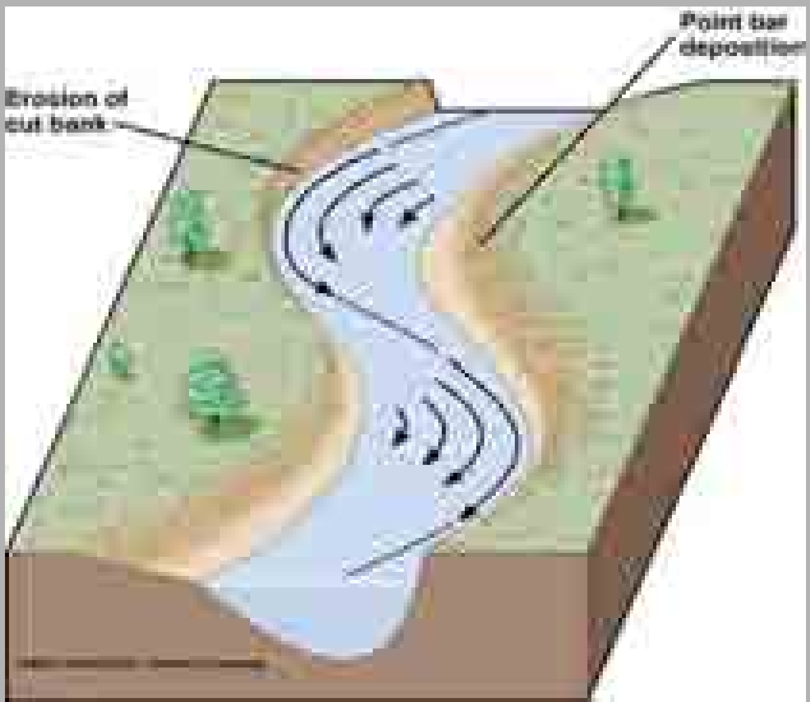
- Meandering streams have single, winding channels that form broad looping curves known as meanders. Oxbow lakes are common along meandering streams. They form when individual meanders are abandoned by the stream.

Monroe & Wicander 2002

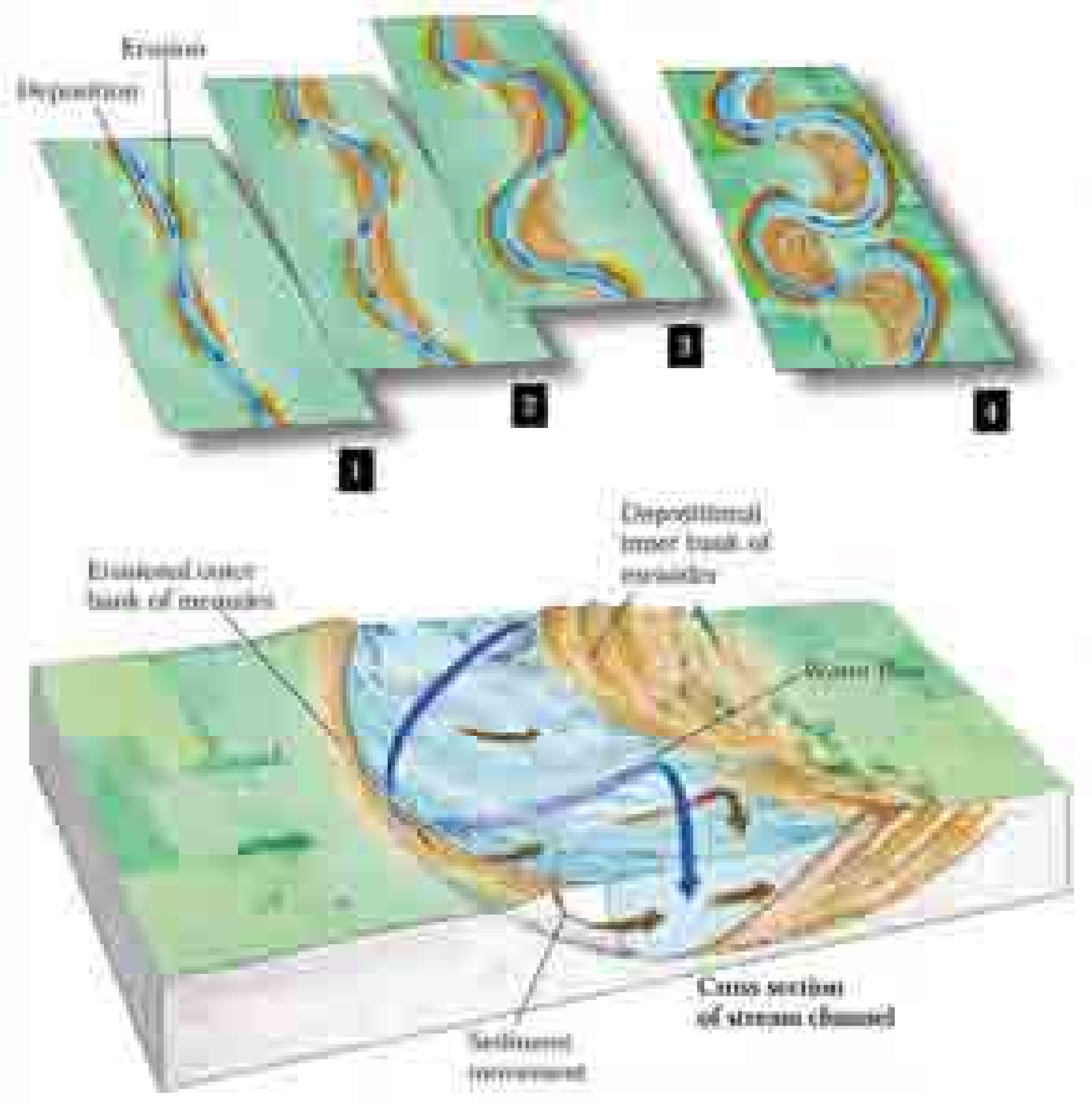
Meandering Channels

- The channel cross-section is asymmetric. The bank on the outside is actively eroding and known as the cut bank. Flow velocity is lower along the inside of the meander so along this bank, sediment is deposited to form a point bar.

Monroe & Wicander 2002



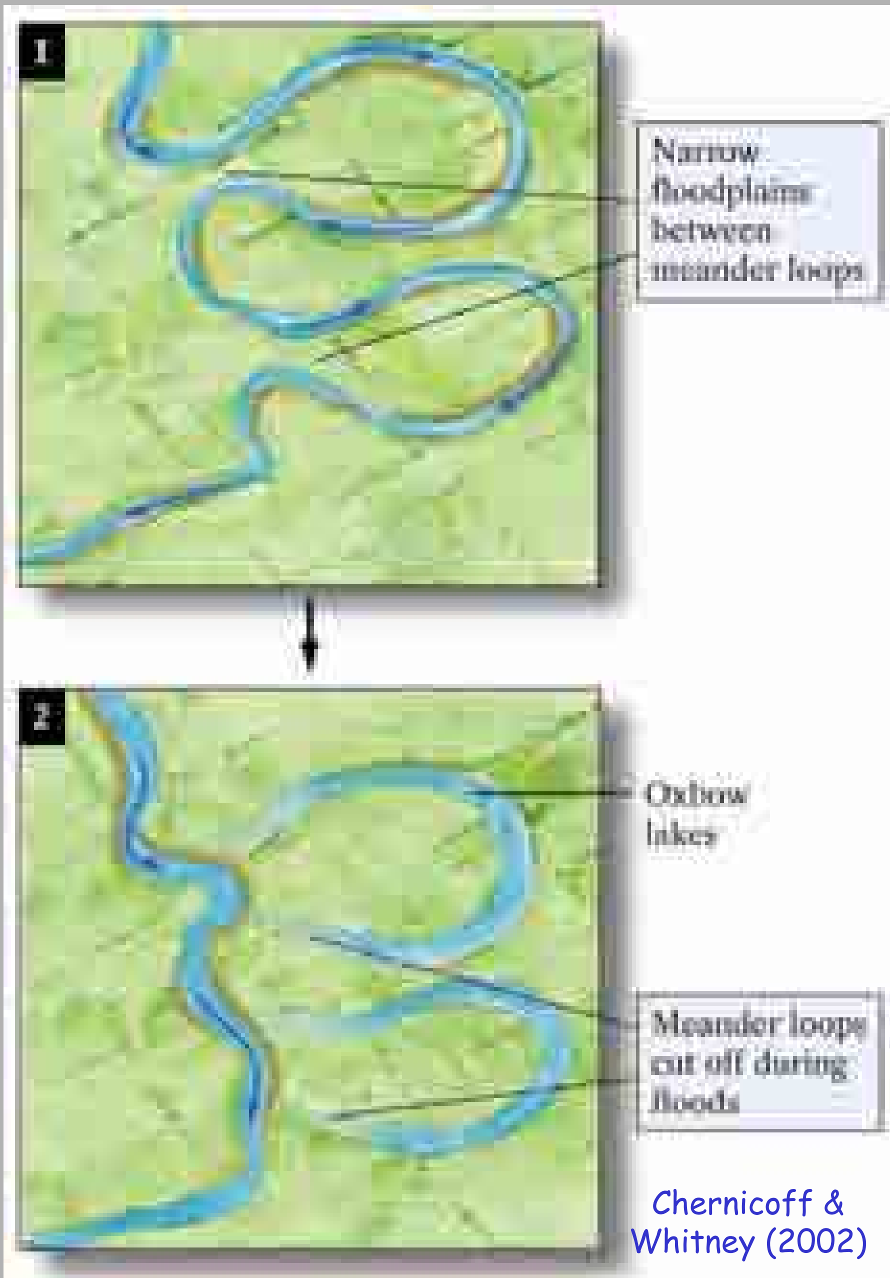
Evolution of meanders



Chernicoff & Whitney (2002)

Oxbows

Meanders sometimes become so sinuous that the neck of land between them can be eroded away during flooding. As a result, the flow will follow a new, straighter course, and the meander will be cut-off or abandoned by the stream. The abandoned meanders are referred to as oxbow lakes. Oxbow lakes may persist for some time, but are eventually filled with organic matter and mud carried in during flooding of the active stream.



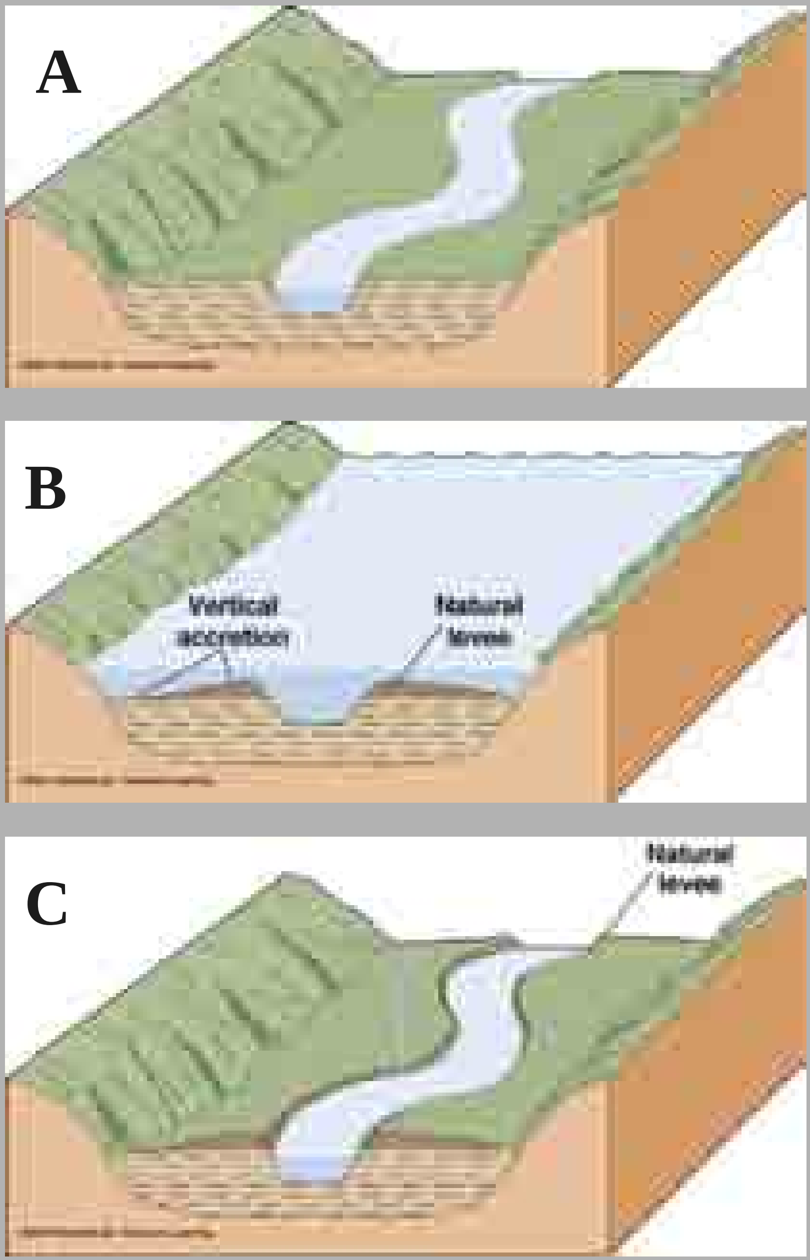
Chernicoff & Whitney (2002)

Oxbows

Montgomery (2000)

Levees

Floodplains are low-lying, flat areas adjacent to channels (A). When streams overtop their banks, water carrying mud and fine-grained sand spreads across the floodplain (B). As flood water flows from the channel, its velocity and depth rapidly decrease. As a result, the coarser floodplain sediment, fine-grained sand, is deposited along the channel margin to form a ridge, a natural levee (C).

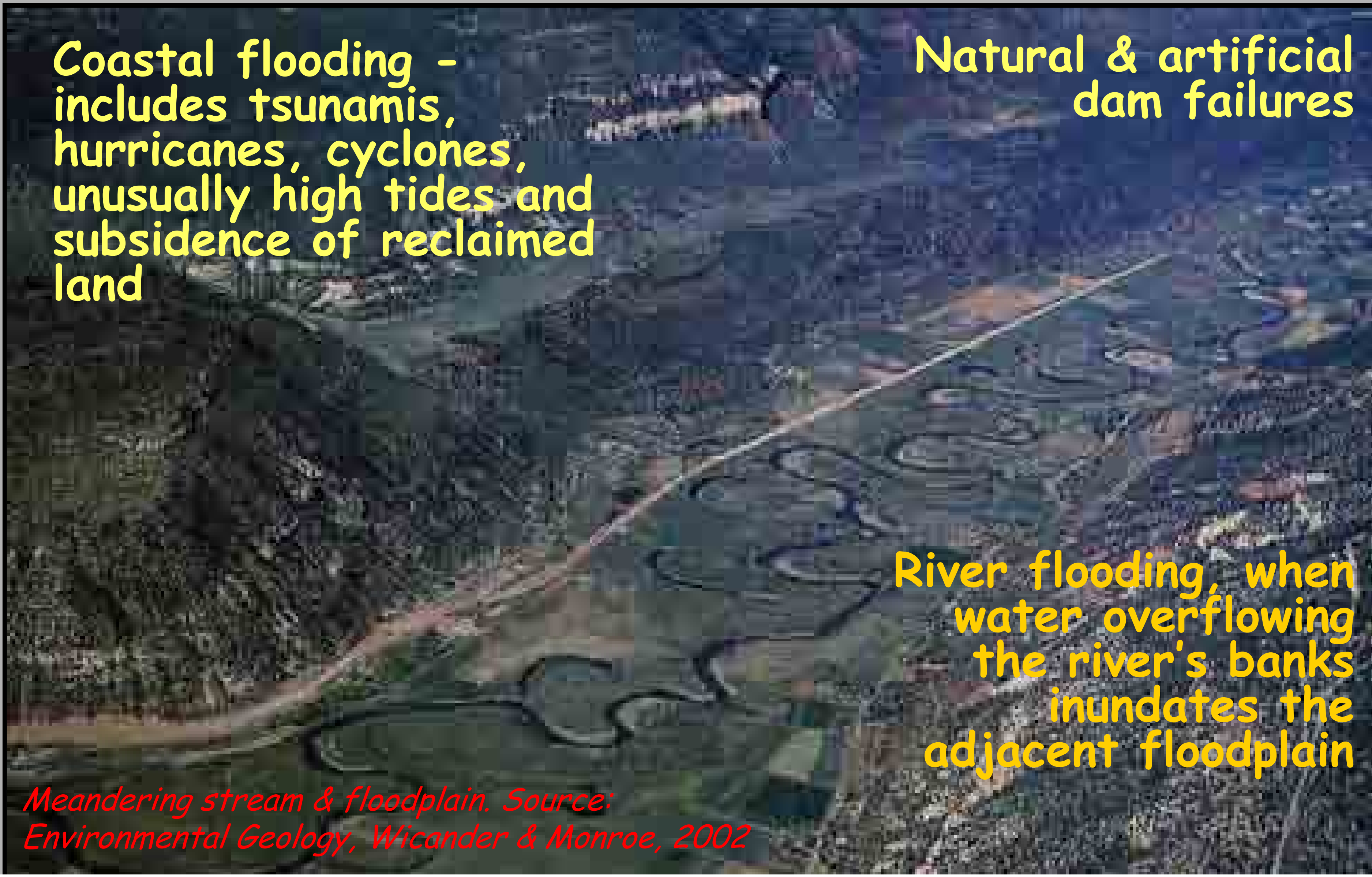


Monroe & Wicander 2002

Levees

- Natural levees build up when a river floods and overflows it's banks. At the point of overflow the velocity drops and sediment is deposited. These levees will tend to channelise the flow of future flood. Artificial levees are constructed to mimic this process
- When levees do breach then the flooding is often on a large scale and because of levees downstream may take longer to recede

Types of Flooding



Flooding

Natural river channels are typically of sufficient volume to carry the average maximum discharge each year. When this is exceeded and the water overflows the banks the stream is in flood

Salvaging property from a flooded caravan, Missouri, July, 1993 Source: National Geographic, v 185, No 1

Primary Effects

- Water damage to household items
- Structural damage to buildings
- Destruction of roads, rail lines, bridges, levees, boats, barges & moorings
- Historical sites destroyed
- Crop loss
- Cemeteries damaged
- Loss of life

Missouri, July, 1993 Source: National Geographic, v 185, No 1

Secondary & Tertiary Impacts

- Destruction of farmlands
- Destruction of parks & wildlife habitat
- Disruption of electrical services
- Lack of clean water
- Impacts on crop prices
- Food shortages
- Job loss & worker displacement
- Gas leaks

Source: National Geographic, v 185, No 1

Secondary & Tertiary Impacts

- Disease related to pollution
- Injuries (back, electric shock, etc.)
- Fatigue
- Stress
- Depression
- Economic impact:
  - Construction (beneficial)
  - Insurance (negative)
  - Legal (beneficial)
  - Farming (negative)

Source: National Geographic, v 185, No 1

Secondary & Tertiary Effects

- Misuse of government relief funds
- Changes in river channels
- Collapse of whole community structures

Source: National Geographic, v 185, No 1

Flooding

- The severity of a flood event is dependent on a number of factors
  - Rainfall intensity or rapidity of snowmelt
  - Amount of previous rainfall (saturation)
  - Topography
  - Vegetation
  - Soil type (porosity & permeability)

Flooding

- These same factors affect the crest of the flood. The crest is the maximum stage (highest water level) is reached. Downstream the crest may not occur for several days after the flood episode
- Upstream (flash) floods tend to only affect small localised areas and are generally caused by intense storms or dam failures. The localised nature of the floods means they are easily absorbed downstream but their high energy causes considerable damage
- Downstream (riverine) floods affect large stream systems in large drainage basins as a result of prolonged rain or snowmelt events. Buildings tend to get wet and muddy rather than being destroyed

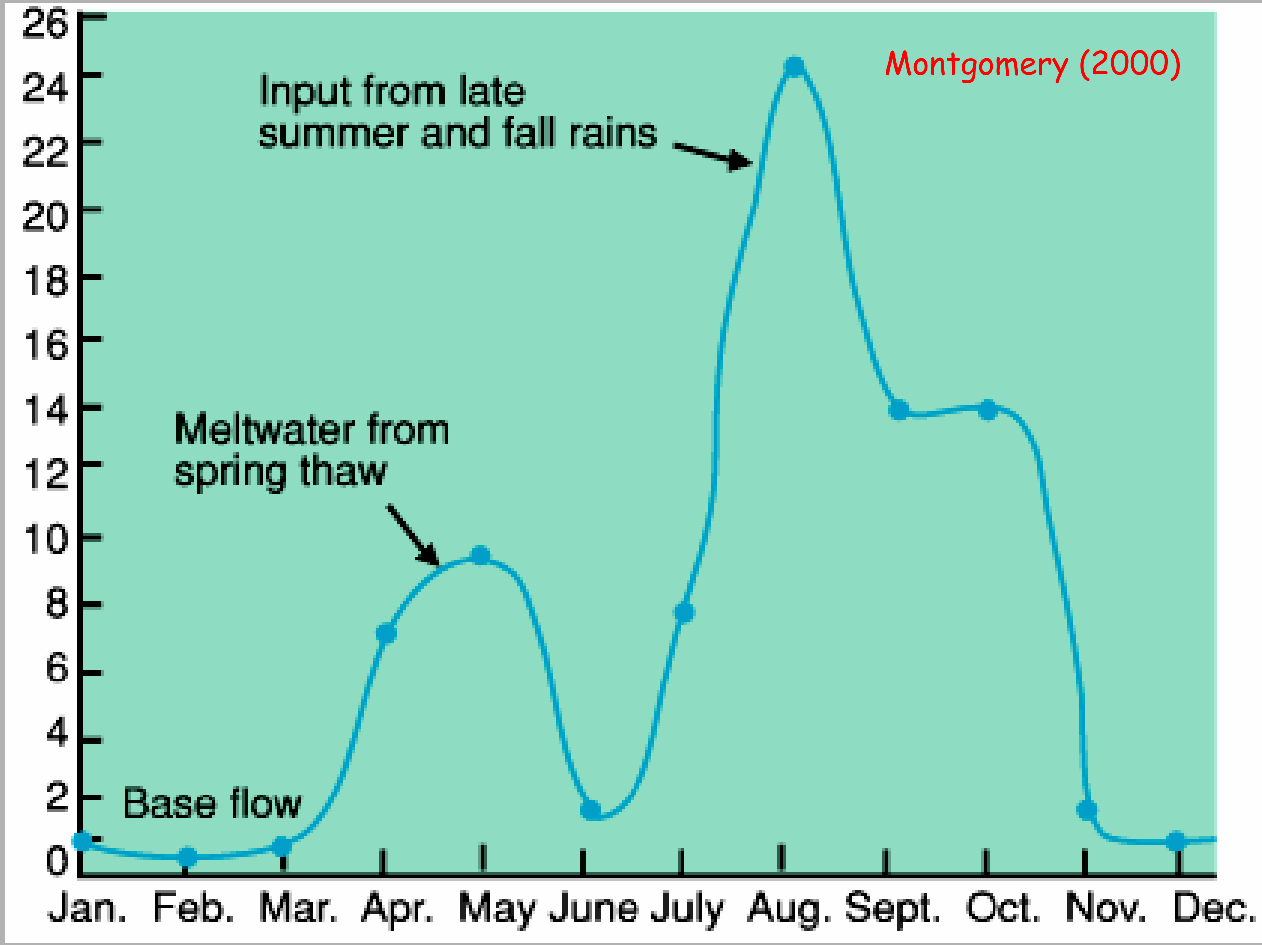
Upstream flooding

Montgomery (2000)

Measuring stream flow

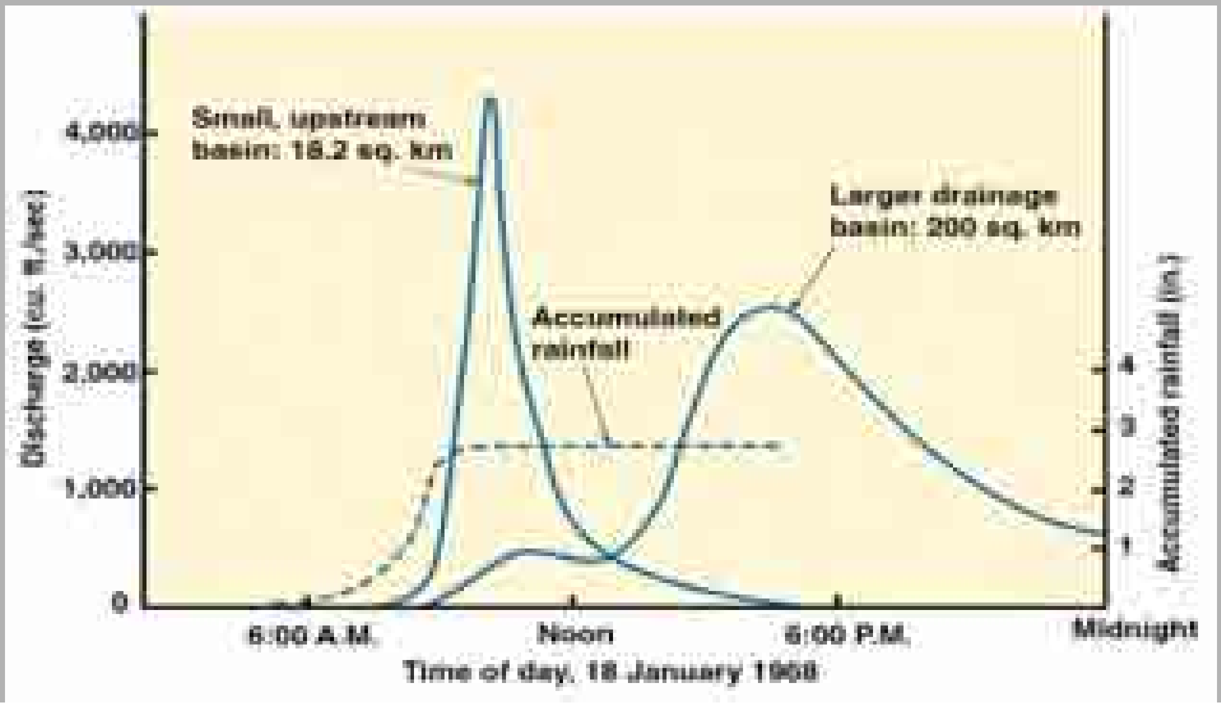
Stream discharge and velocity can be described using a hydrograph.

By measuring discharges over a long period it is possible to determine the 'normal' behaviour of the stream. Floods can then be identified as peaks



Hydrographs

Upstream floods will result in narrower crests but with a higher peak, whereas downstream floods will result in broader, lower peaks. This reflects the fact that the inputs downstream will come from a greater range of sources over a longer time period



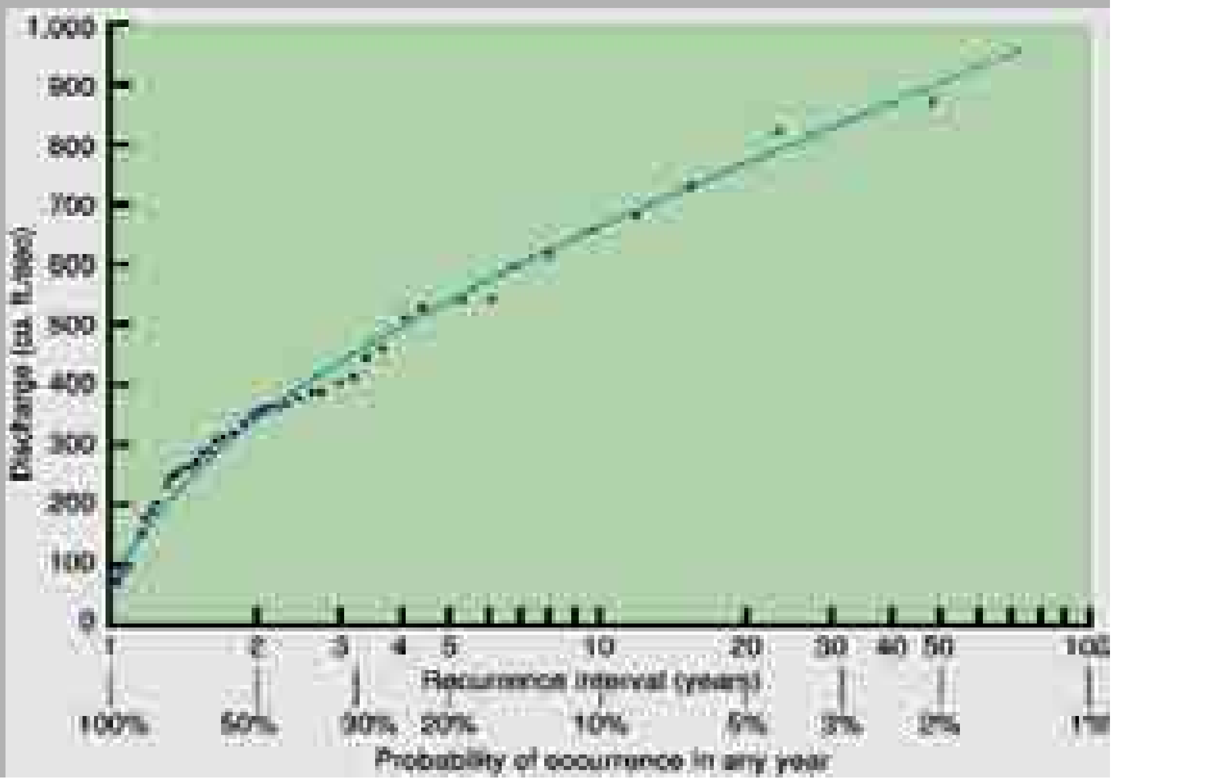
Montgomery (2000)

Flood frequency curves

- Streams can be expected to overflow their banks every two or three years, larger flood events tend to occur at less frequent intervals. Long term records make it possible to show this as function of recurrence interval

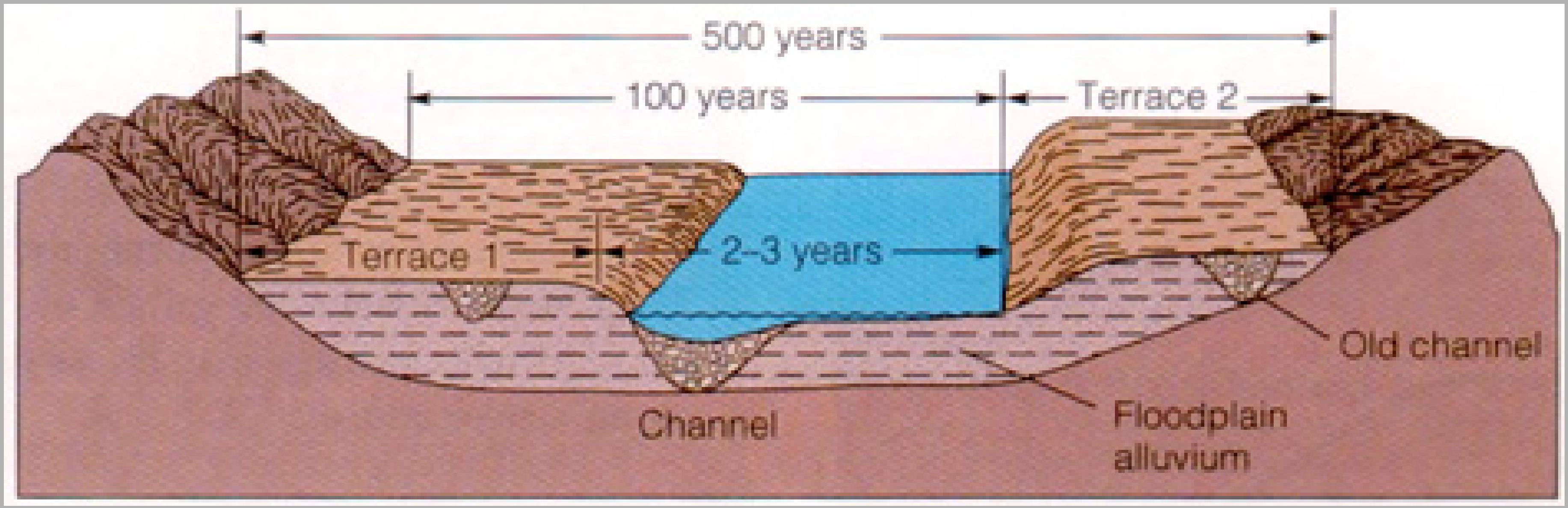
Flood frequency curves

- **There are different ways of reading flood frequency curves:**
- **Recurrence interval – from the graph it can be seen that a ~600 cu ft/sec flood occurs once every 10 years**
- **Probability – this is the inverse of the recurrence interval. The ~600 cu ft/sec flood is a "ten year" flood. It has a probability of occurring once every 10 years or a 10% chance in any one year**



Montgomery (2000)

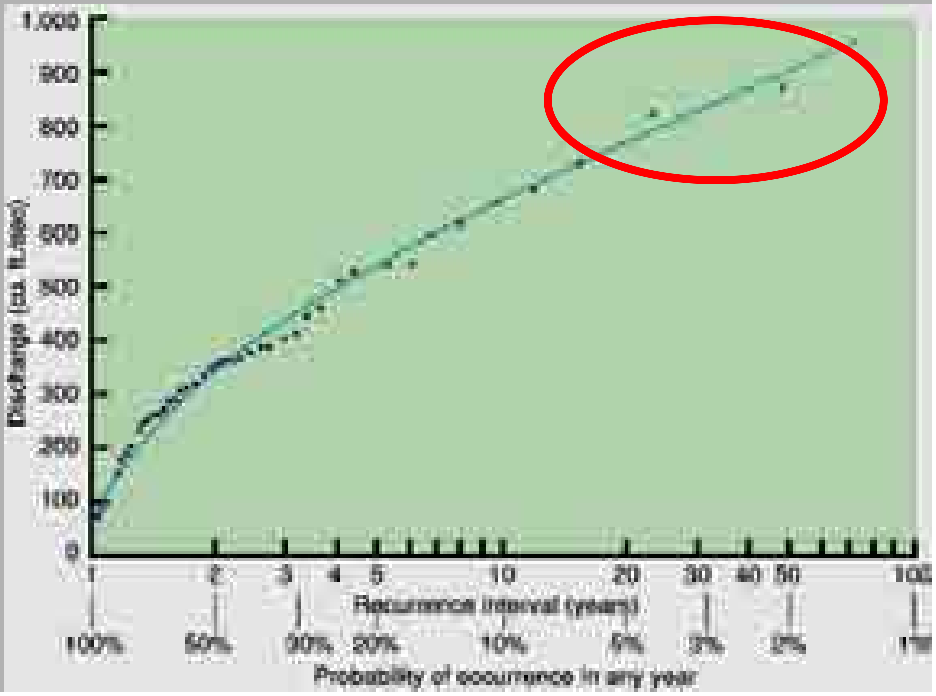
Defining the floodplain



Pipkin and Trent (2000)

Flood frequency curves

- These curves are useful for assessing the regional flood hazard. By estimating the discharge of the 100 or 200 year floods it is possible to map out the equivalent floodplain.
- But the higher end of the curve is the least constrained. Parts of the US have been settled for < 100 years so there is no record of a 100 year flood

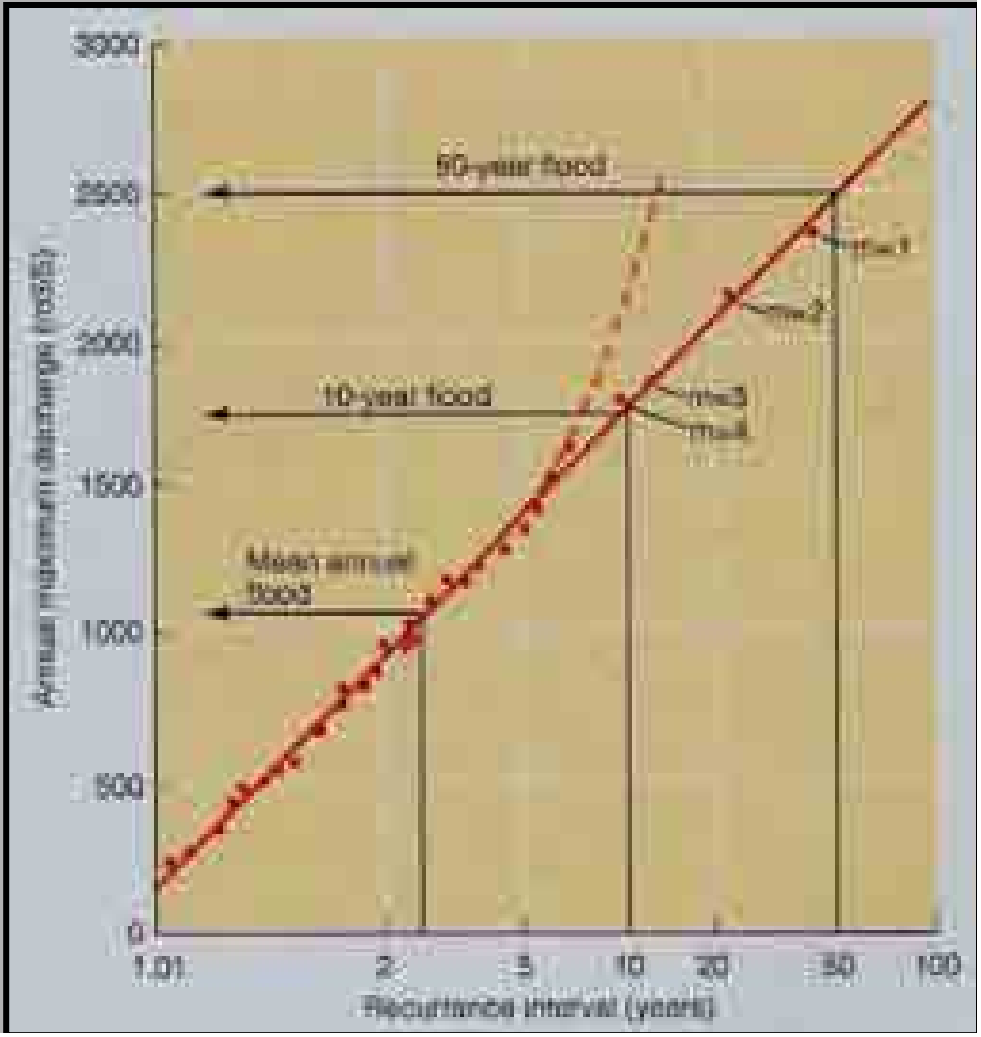


Montgomery (2000)

Flood frequency curves

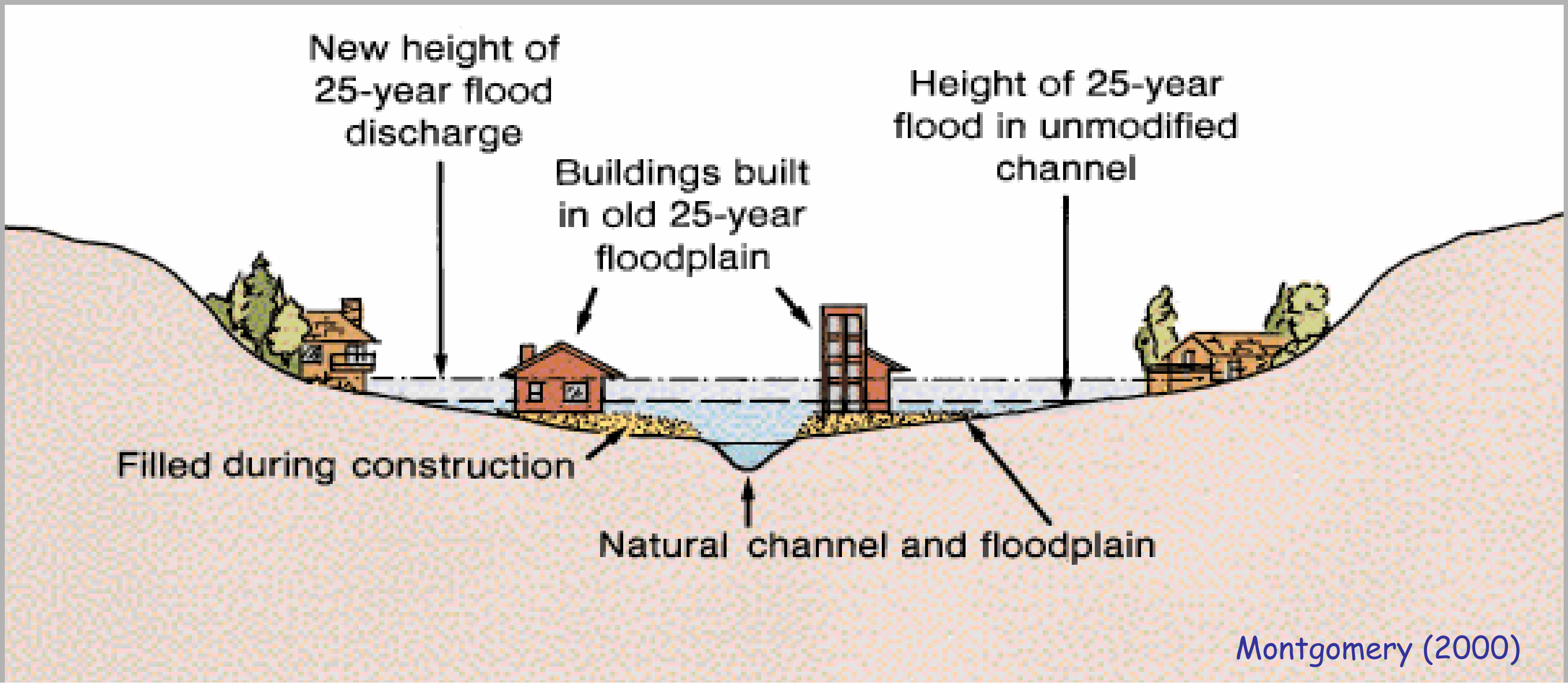
- **Flood frequency curves and estimates are only average values.**
- **Over many centuries a 50-year flood should occur on average once every fifty years. However, there is nothing to stop two such floods occurring within a single decade**
- **For example in 1986-1987 the Chicago area experienced two 100 year floods in a ten month period**

Skykomish River flood frequency curve. Source: Dangerous Earth - Murck, Skinner & Porter, 1997



Flood frequency curves

Human activity can also impact on recurrence rates. Land use has changed over the last 100 years. So a rainfall event that caused only minor flooding 100 years ago could cause a more significant flood today. Flood frequency curves are changing with time



Why live on a floodplain?

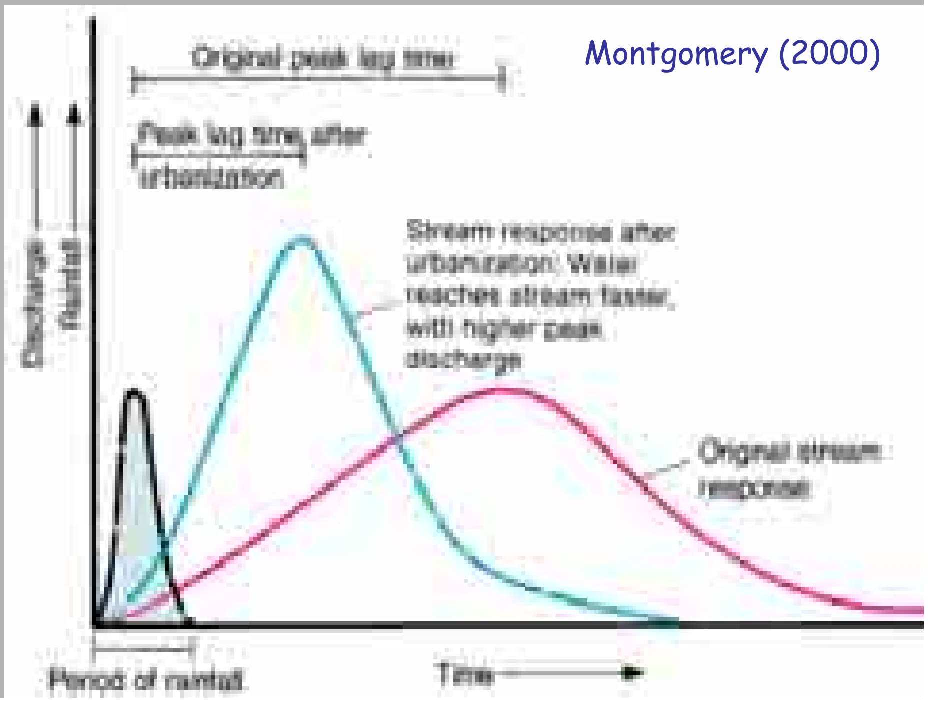
- Ignorance – someone on a 200 year floodplain my not be aware of the risk
- Convenience – easier to build on flat level land and proximity to historical transport routes
- Agriculture – the fine sediments in a floodplain makes for extremely fertile soil

Urbanisation

- **The nature of occupation can have a significant impact on flooding. In the majority of cases agricultural use does not increase the risk of flooding and any flooding that does occur will have relatively little impact**
- **In contrast urbanisation not only increases the risk of flooding but increases the ultimate cost**

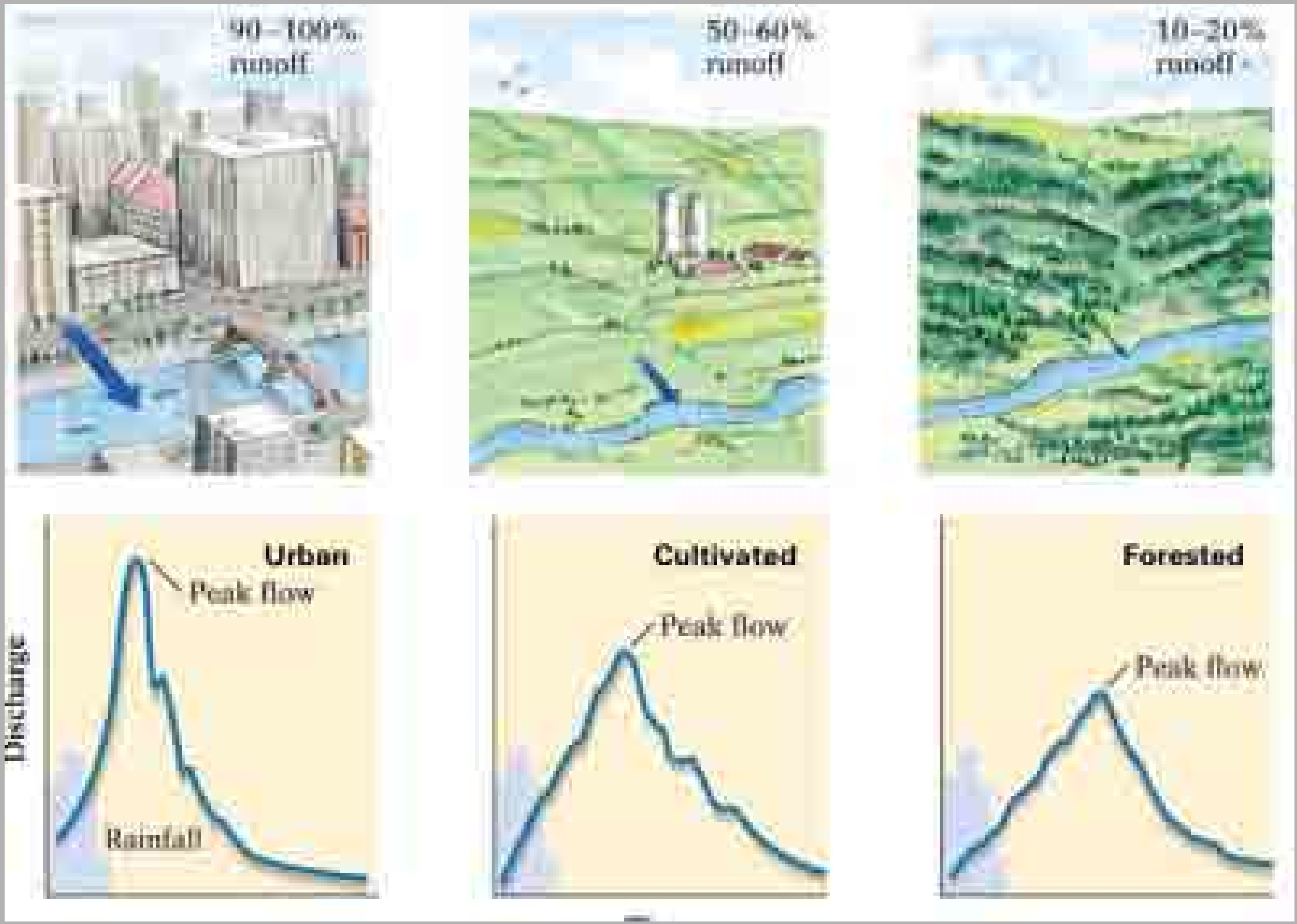
Urbanisation

- Buildings decrease lag time (quicker run off)
- Buildings increase flood heights (decreases the space available for streams)
- When 50% of a drainage basin is urbanised the frequency of flooding increases by a factor of 4



Montgomery (2000)

Urbanisation



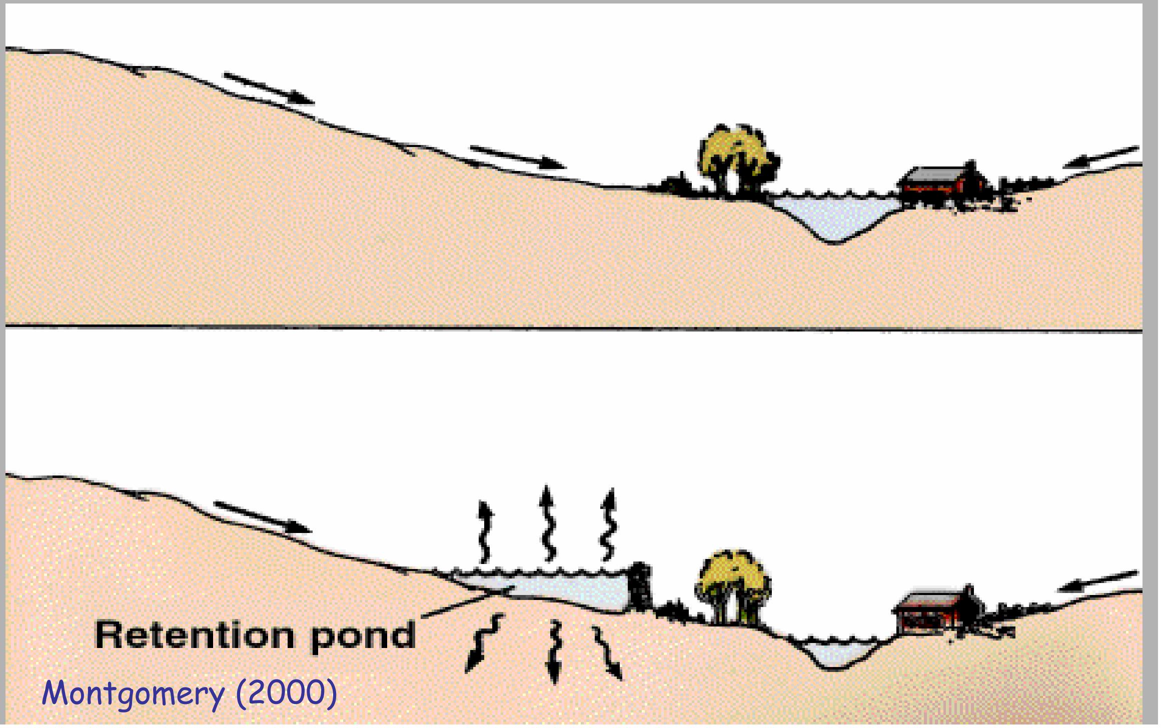
Chernicoff & Whitney (2002)

Mitigation

- A variety of techniques can be applied to reduce the risks of flooding
  - Restrictive zoning
  - Dam construction
  - Retaining basins
  - Artificial levees
  - Building design
- A number of factors limit the value of all these techniques.

Retention ponds

- These are simply areas set aside to trap surface run off and prevent it flowing immediately into the stream. They can be quarries or fields dammed with dykes. They are cheap, the land can still be used and they don't affect the characteristics of the stream



Diversion channels & channelisation

- Diversion channels simply divert excess water out of the stream into areas where the damage from flooding will be minimal
- Channelisation - generic term for modifications to the stream intended to increase the velocity of volume of the channel. In areas where sediment has infilled the channel it can be widened or deepened or alternatively the stream channel can be straightened, decreasing the flood hazard upstream
- This is an expensive option that needs constant modification and tends to increase the risk of flooding downstream

Levees

- These are simply raised banks built along the stream bank in order to protect the adjacent land from flooding, however it simply moves the water downstream putting those areas at greater risk
- Levees can encourage development in an area that is not really suitable. In the ’93 Mississippi flood 80% of privately built levees failed. Once breached the presence of levees prevents the flood subsiding

Saguenay, Quebec 1996

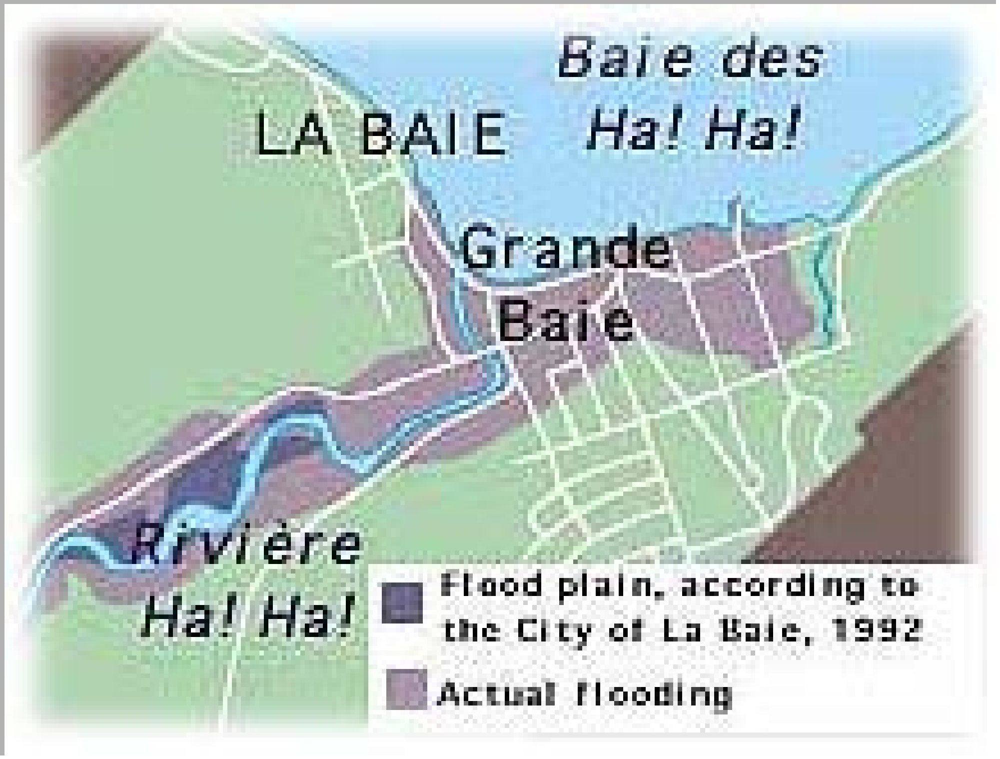
- The most devastating floods in Canadian history, 10 deaths, $800 million in damages and more than 2,500 buildings damaged or destroyed. 16,000 people were evacuated
- 45 major watercourses feed into the Saguenay and Lac Saint-Jean. The region's hydrological network is made up of 2,000 structures - mostly dikes and embankments - owned by 25 public and private organizations, most of which were built before the 1960s, with minimal environmental and technological controls

Saguenay, Quebec 1996

- Having endured three dry summers that left water levels low at Lac Kénogami, vacationers successfully lobbied for the Quebec government to keep the water level high after heavy spring rains in 1996. There was only 160 centimetres left between the water and the crest of the dams before the flooding.
- Over a period of 50 hours, starting at 1 AM on July 19, 155 millimetres fell on the region - the average rainfall for the entire month of July

Saguenay, Quebec 1996

- On the morning of July 20, 1996, the rainwater that had been collecting in Lac Ha! Ha! for 28 hours started flowing over a wall of earth and tree trunks.
- Thirty million cubic metres of water ruptured the earthen dike, digging a 20-metre-deep trench through the forest before joining Rivière Ha! Ha! and swamping the hamlet of Boilleau with churning mud and uprooted trees, and later hitting La Baie with the force of a bomb.



Saguenay, Quebec 1996

- Floodwaters deposited 25 to 50 centimeters of sediment in Baie des Ha! Ha! - 75 to 150 years worth.
- The Nicolet Commission, created to look into the Saguenay floods, recommended that:
  - dam owners, when warned of heavy rain, should rush competent employees to their dams
  - the level of Lac Kénogami should be kept lower in the summer;
  - a moratorium should be declared on construction within 20-year flood zones
  - that dams should be re-evaluated at least every 20 years "to take account of climatic changes that might have taken place in the interim."

The Red River, Manitoba

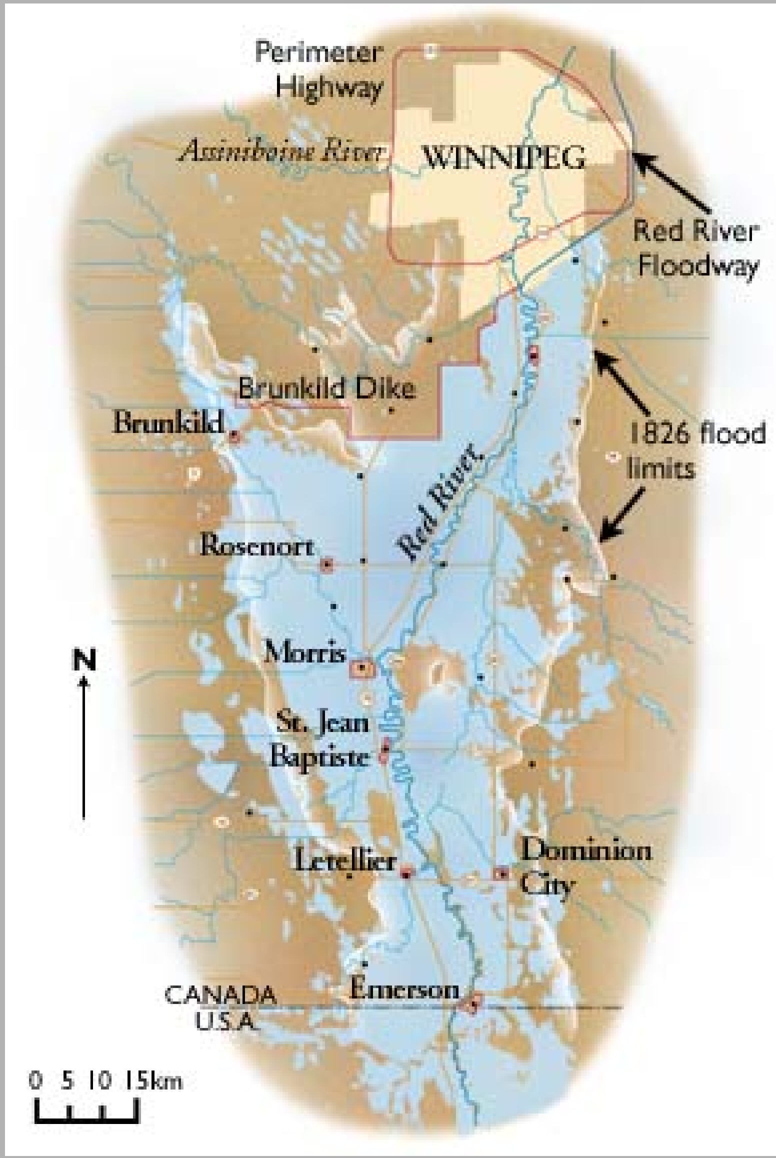
- 877 km in length, the Red is prone to floods in part because its headwaters, located in the south, thaw in the spring before its northern Manitoba reaches are free from ice
- The 1997 floods have been described as the “flood of the century”. The numbers vary but the discharge levels in Winnipeg were statistically those of a 110 year flood.

The Red River, Manitoba

- Unregulated discharge rates were some of the highest on record
  - 162,000 cfs on May 4, 1997
  - 108,000 cfs in 1996
  - 107,000 cfs in 1979
  - 108,000 cfs in 1950
  - 165,000 cfs in 1852
  - 225,000 cfs in 1826
- The flood covered 202,500 hectares, or about five percent of Manitoba's farmland. 28,000 people were evacuated and damage costs estimated at $150 million

The Red River, Manitoba

- But the social & economic costs were lower than those of the 1950 floods when 100,000 people were evacuated and the bill was $606 million.
- Probably the main reason for this is the Red River Floodway built in response to the 1950 flood
- A total of 47 km long.
- Work was completed on the dike in 1968.
- Total cost for construction was $63-million.



The Red River, Manitoba

- The floodway serves to divert the Red River around the eastern edge of the city where it continues on to its final destination, Lake Winnipeg.
- The floodway has saved the city from flooding 18 times.
- Without the floodway in ‘97, 80% of Winnipeg would have been underwater and 500,000 city dwellers evacuated.

Conclusions

- Flooding is a natural process and the only way to limit the damage is to limit the amount of development. The bill from flood damage in the US has tripled between 1950 and the mid ‘90s to ~$3 billion per year
- A US congressional report summed the situation up saying - “floods are an act of God. Flood damages result from acts of men”
- Developed counties have more resources and better infrastructure, people choose to live with the hazard. In developed countries people don’t have a choice and there aren’t the resources to cope with flooding