

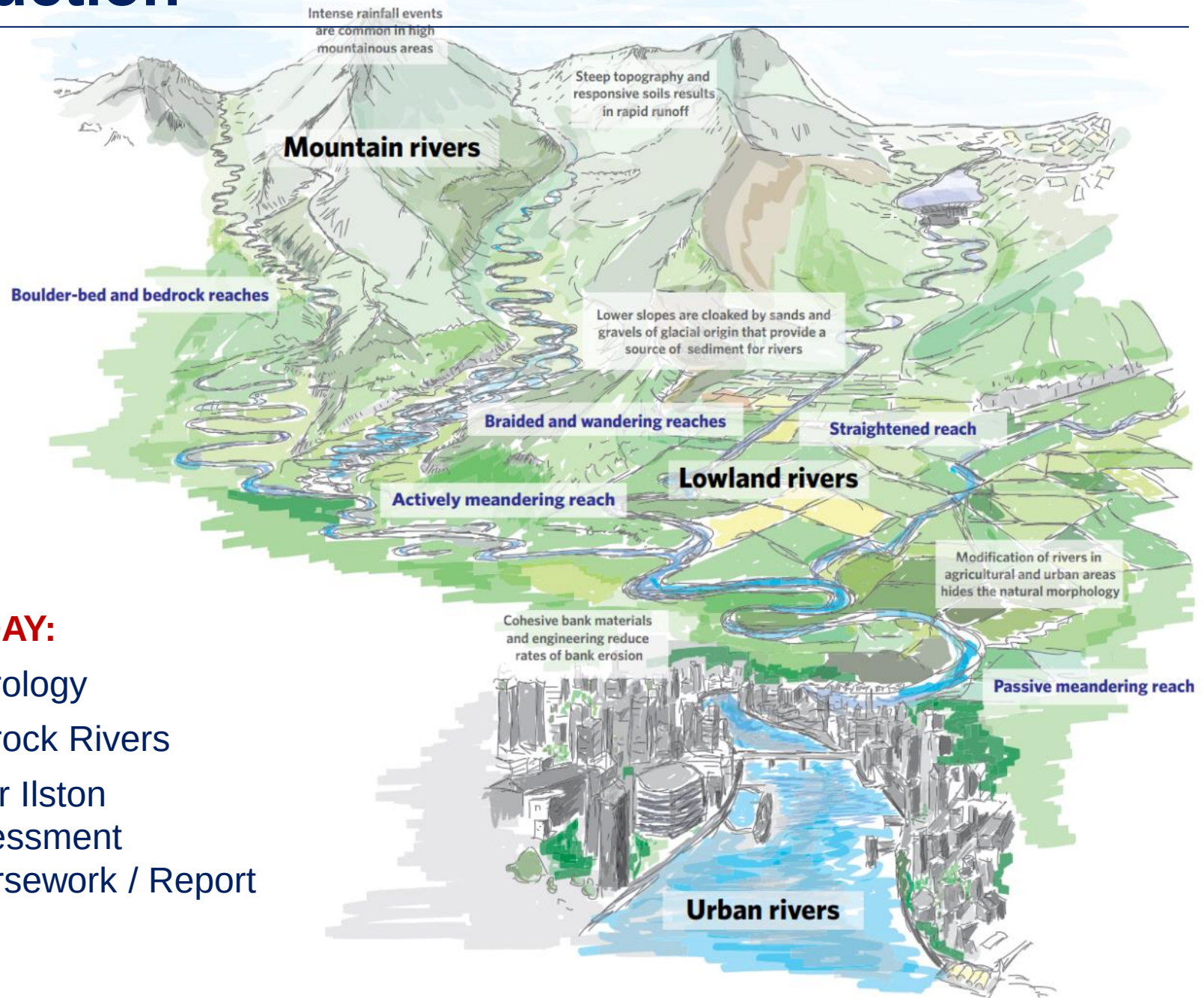


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Y Drindod Dewi Sant
University of Wales
Trinity Saint David

Hydrology

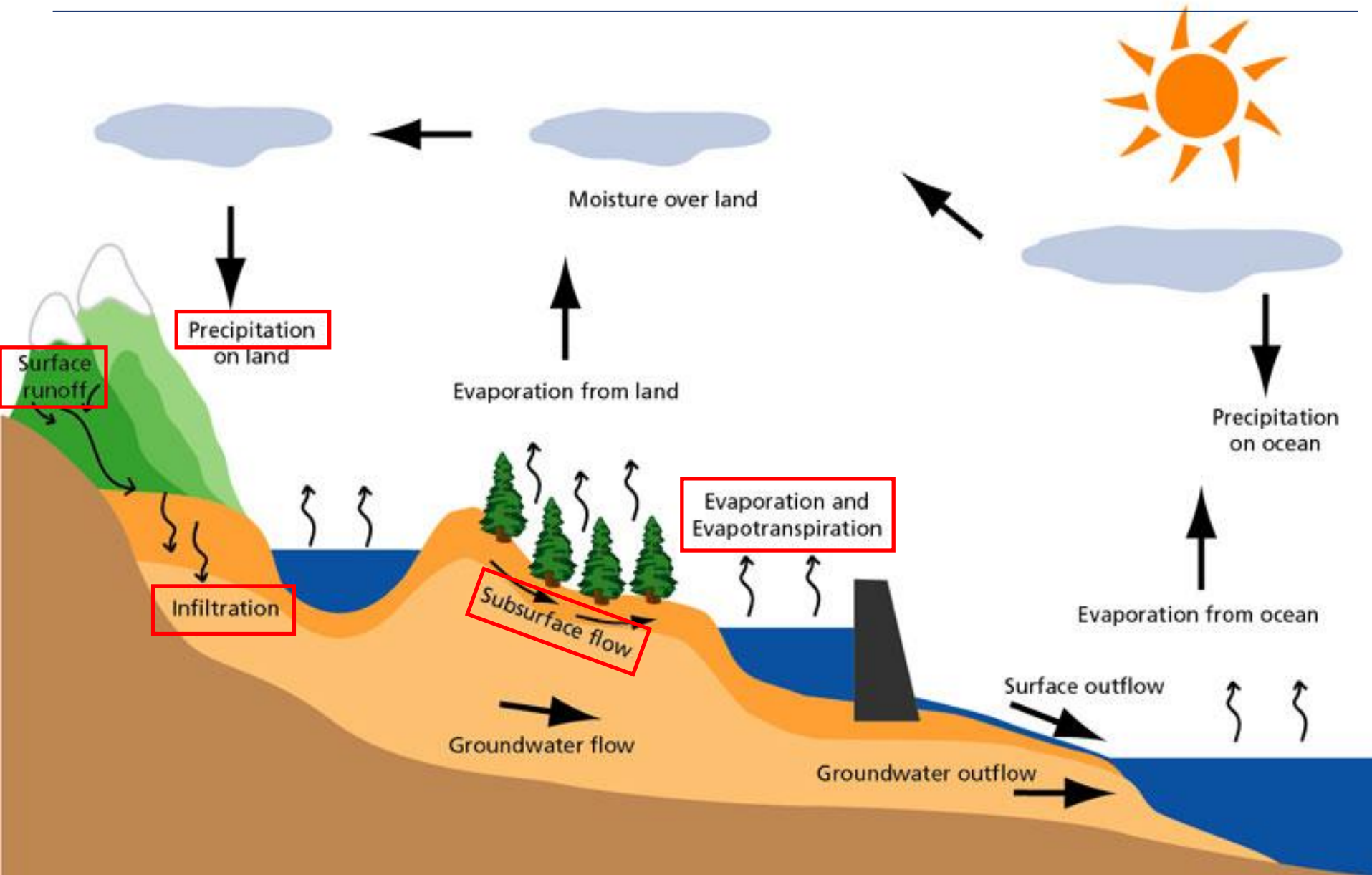
Dr Alissa Flatley
ACNA4007 – Physical Landscape and the Geosphere

Introduction



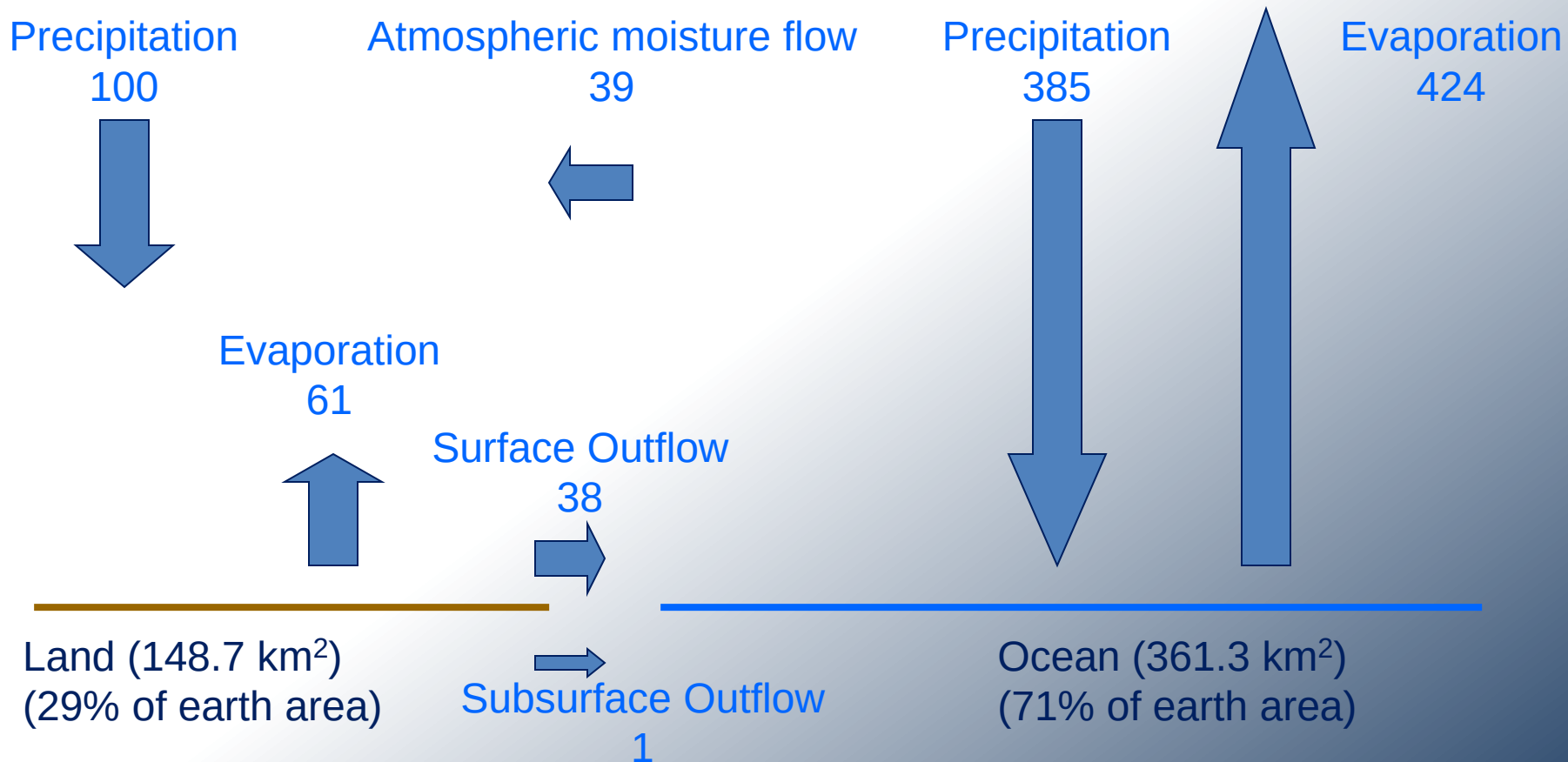
- **TODAY:**
- Hydrology
- Bedrock Rivers
- River Ilston Assessment Coursework / Report

Hydrologic Cycle



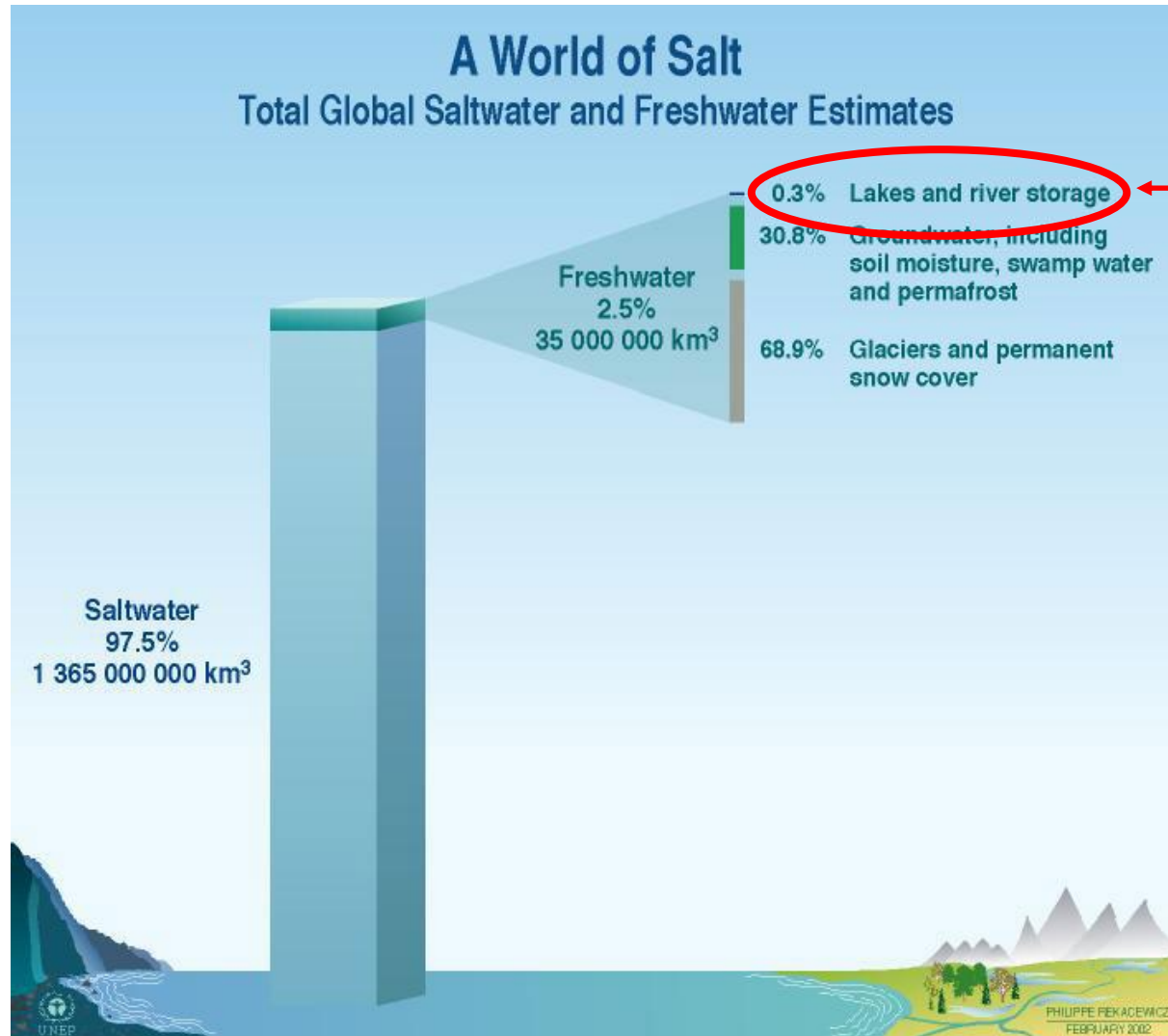
Global water balance (volumetric)

Units are in volume per year relative to precipitation on land (119,000 km³/yr) which is 100 units



What conclusions can we draw from these data?

Global water resources

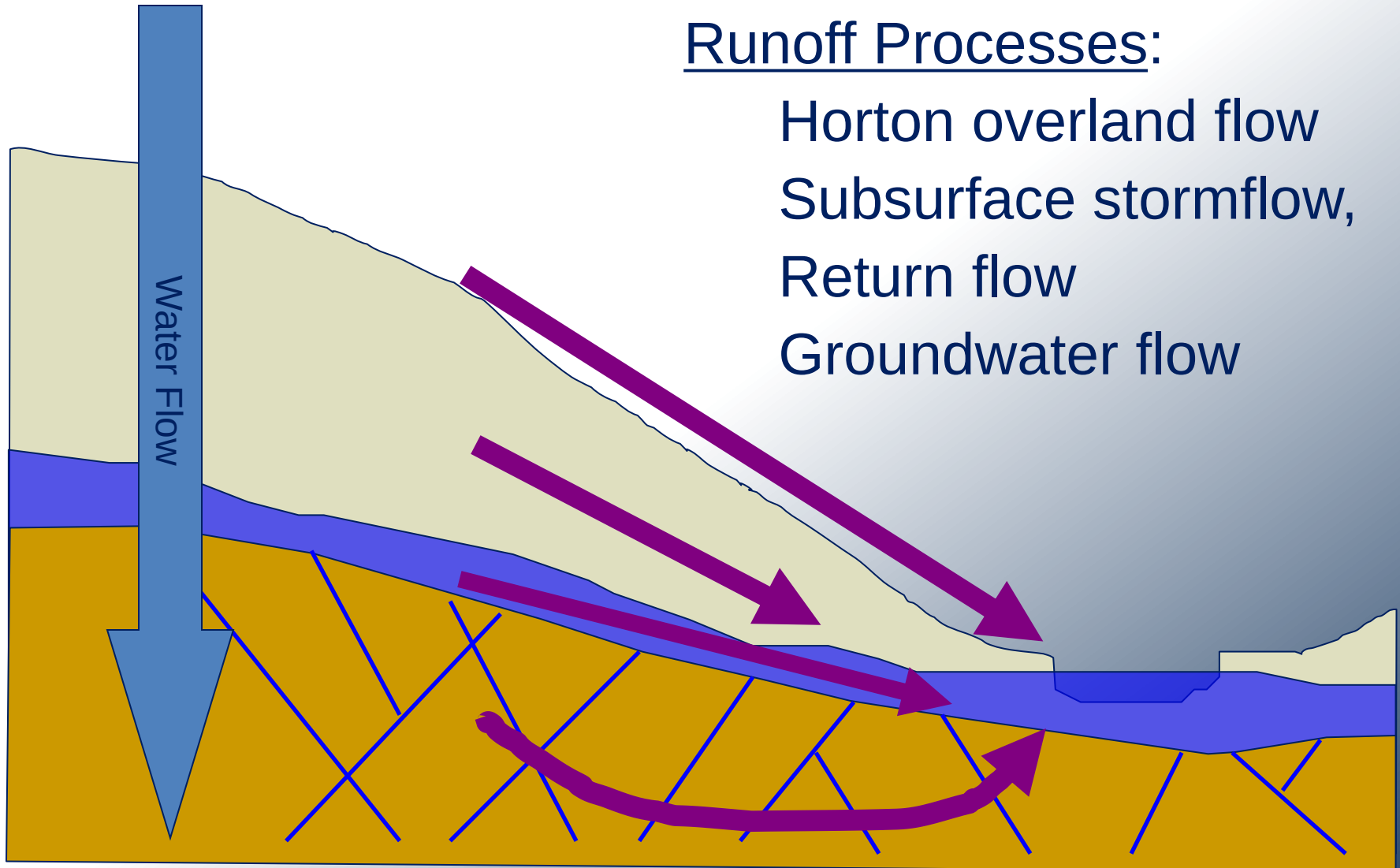


105,000 km³ or
0.0076% of total
water

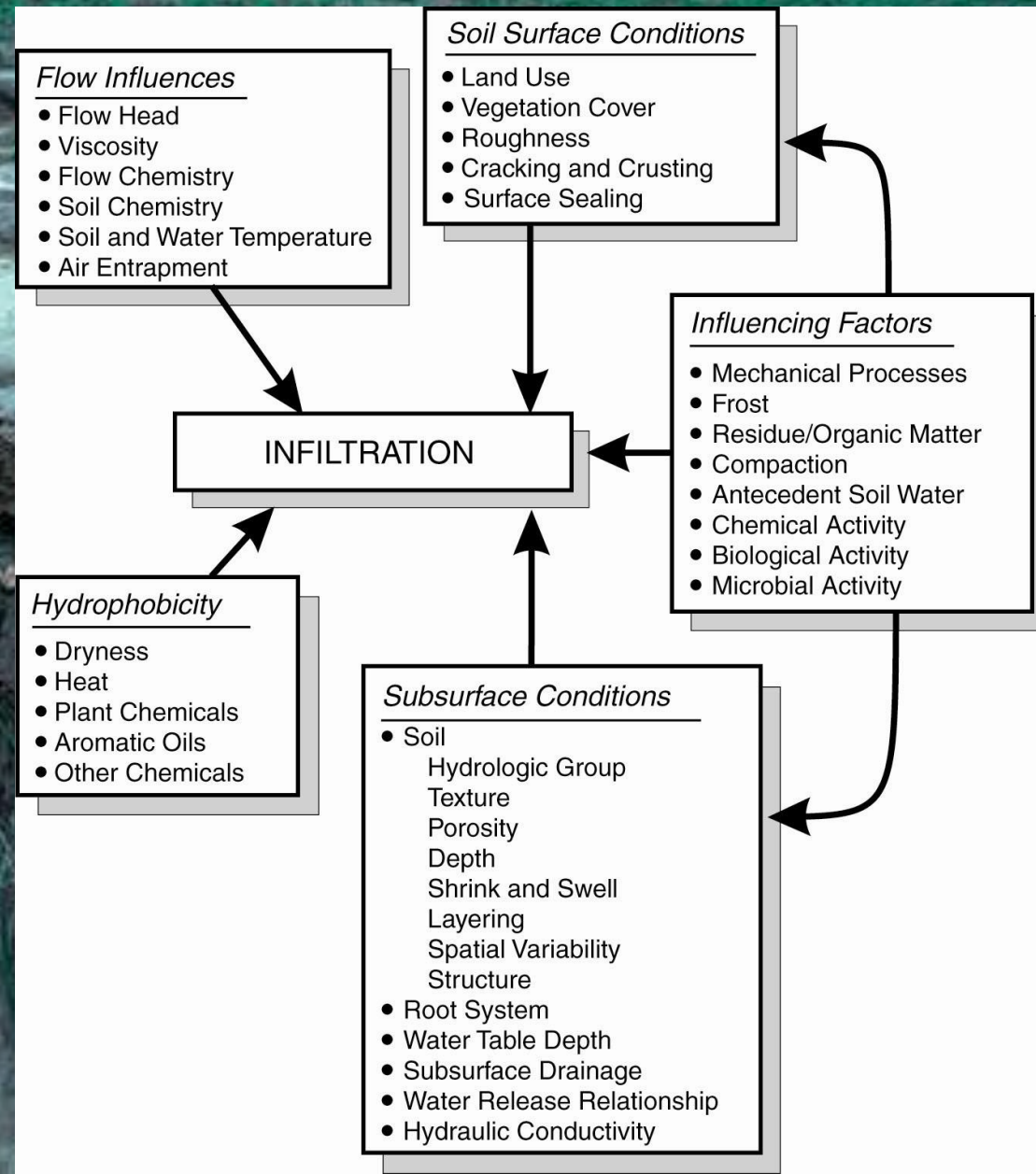
Hillslope hydrology

Runoff Processes:

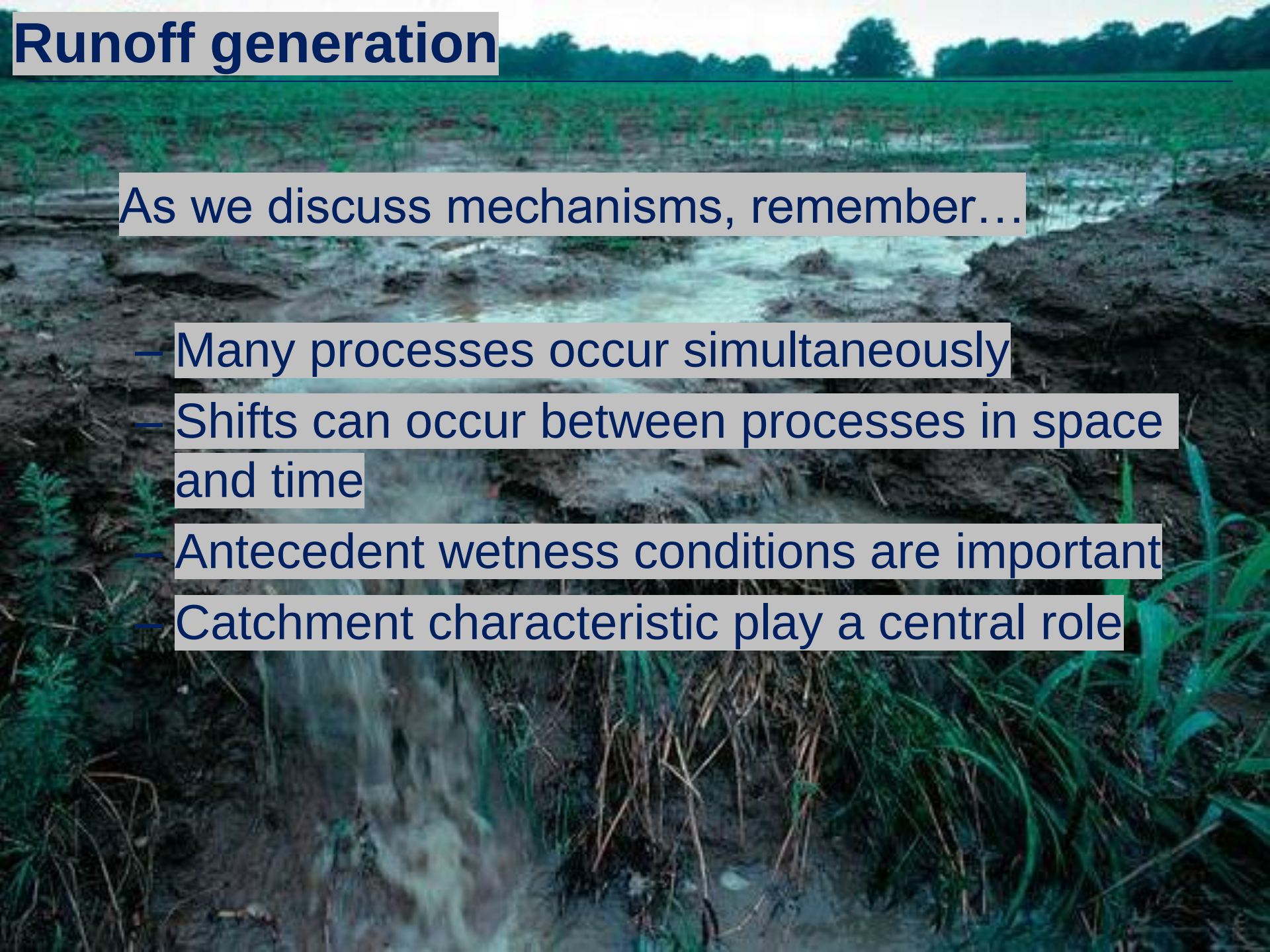
Horton overland flow
Subsurface stormflow,
Return flow
Groundwater flow



Factors Affecting Water Movement in Soils



Runoff generation



As we discuss mechanisms, remember...

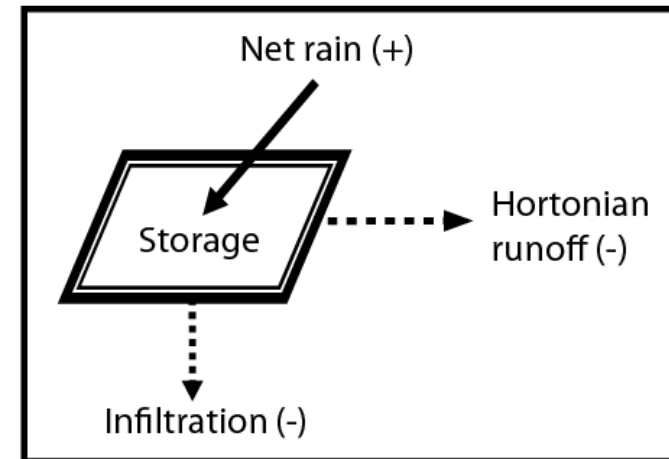
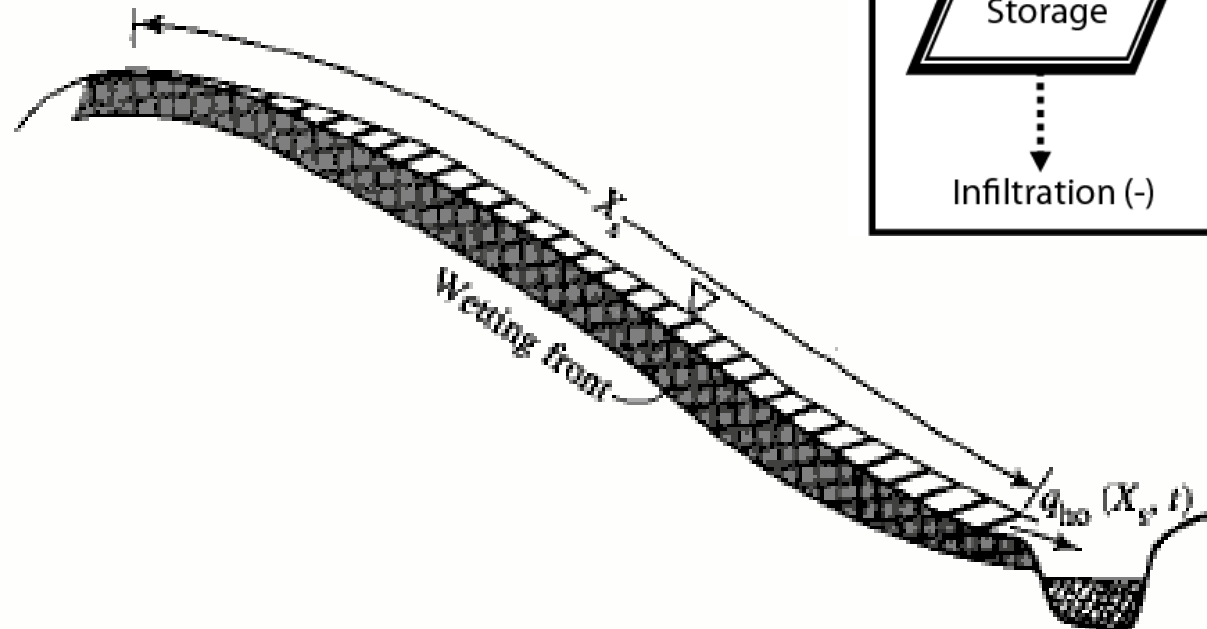
- Many processes occur simultaneously
- Shifts can occur between processes in space and time
- Antecedent wetness conditions are important
- Catchment characteristics play a central role

Overland Flow

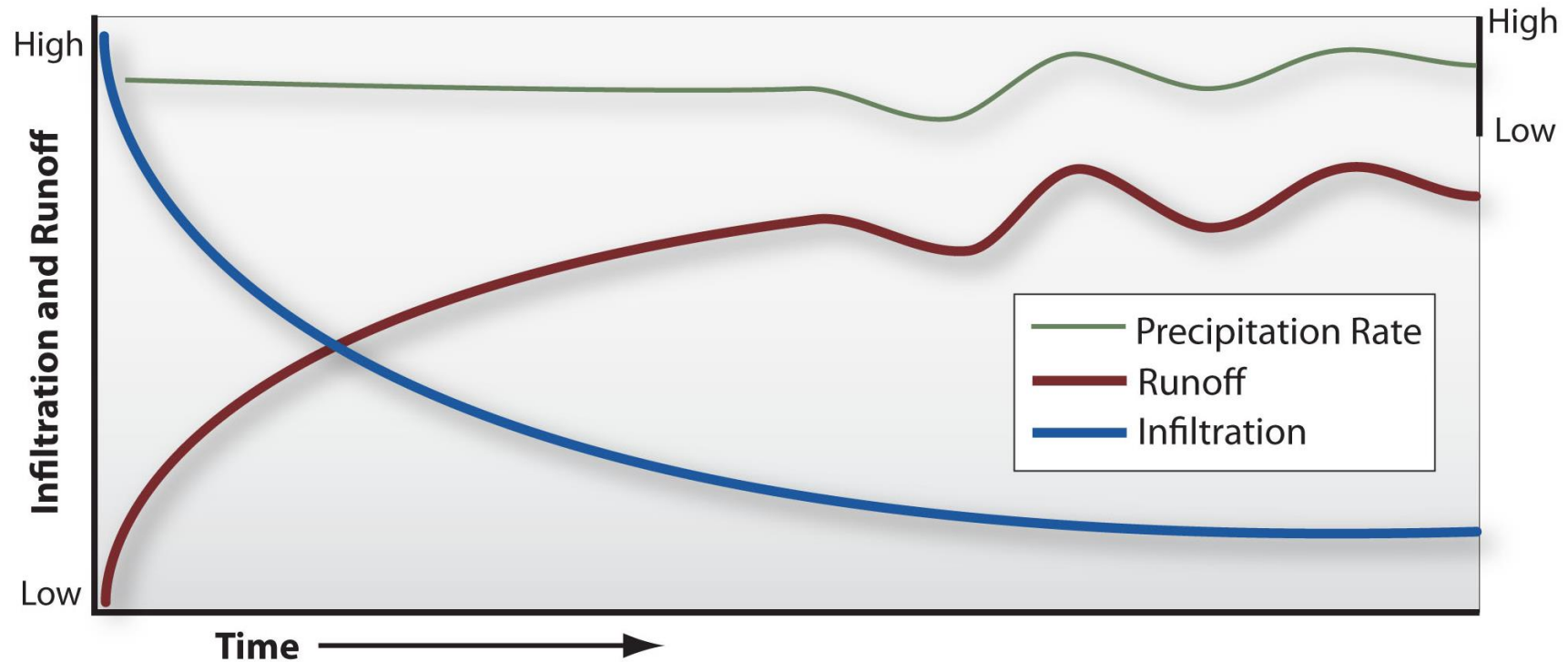
- Overland flow is the term used to describe surface flow that is outside the confines of a stream channel.
- The generation of overland flow is traditionally divided into **two primary mechanisms**, **infiltration excess** (Horton; after Horton (1945)) and **saturation excess** (Dunne; after Dunne and Black (1970a, 1970b)).

Horton Overland Flow (HOF)

Horton overland flow occurs when the rainfall intensity exceeds the infiltration capacity



Infiltration and runoff over time



Infiltration
Trends

Infiltration rate decreases over time as dry pore spaces between soil particles fill with water. Rates of infiltration drop and become steady as the soil saturates. After saturation, the infiltration rate is a function of soil hydraulic conductivity.

Runoff
Trends

Runoff increases over time because soil pores are filling with water, allowing less of the rainfall to soak into the ground. Once the soil is saturated, runoff varies with the precipitation intensity.

Horton Overland Flow (HOF)

- Once thought to be the **ONLY** mechanism of runoff generation
- Became coded into hydrologic models still in use today
- Subsequent work showed role of partial source area where Saturation overland flow is produced

Horton Overland Flow (HOF)

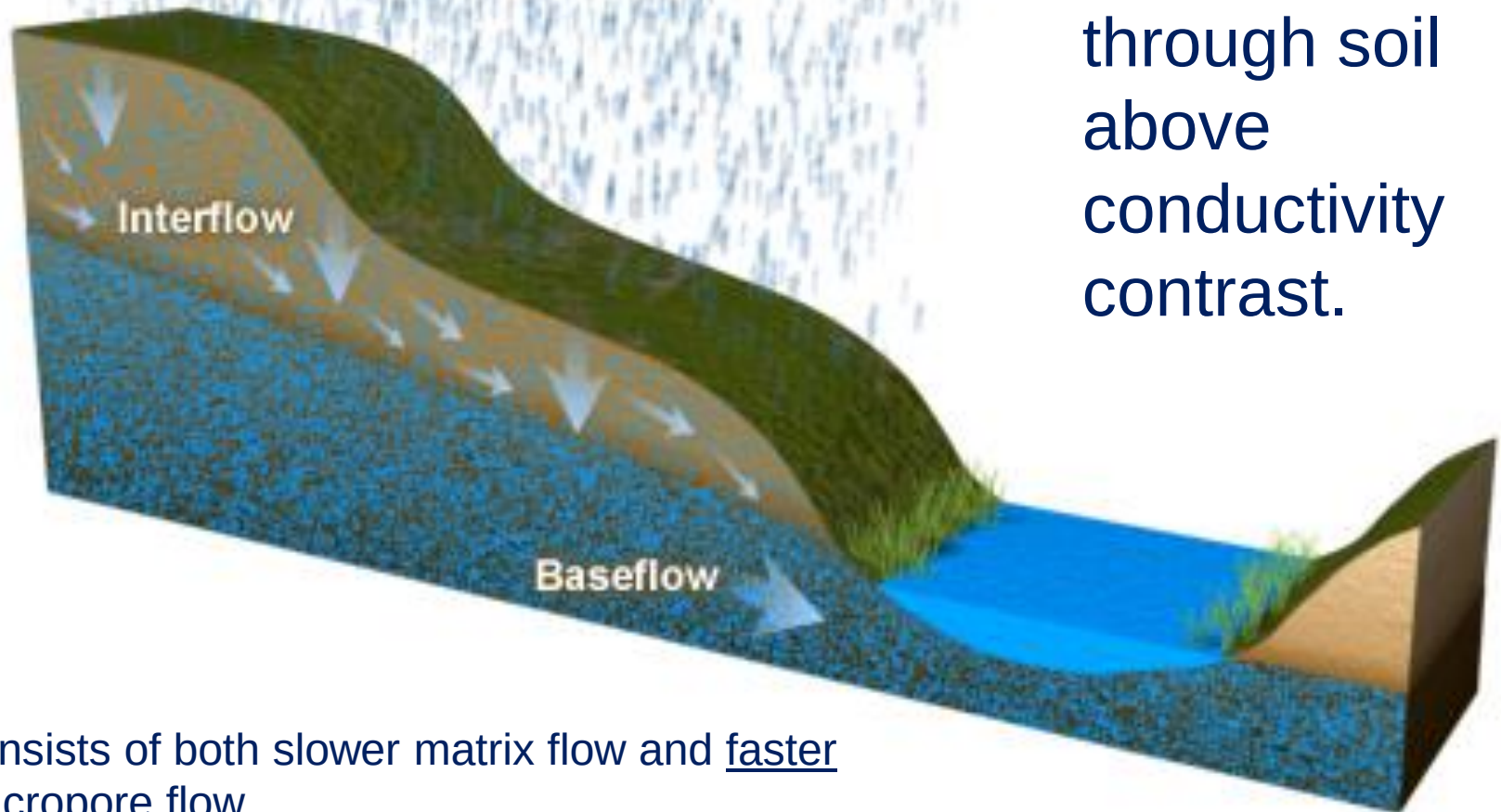
If rainfall exceeds soil infiltration capacity:

- Water fills surface depression then
- Water spills over downslope as overland flow and
- Eventually to the stream

Subsurface stormflow

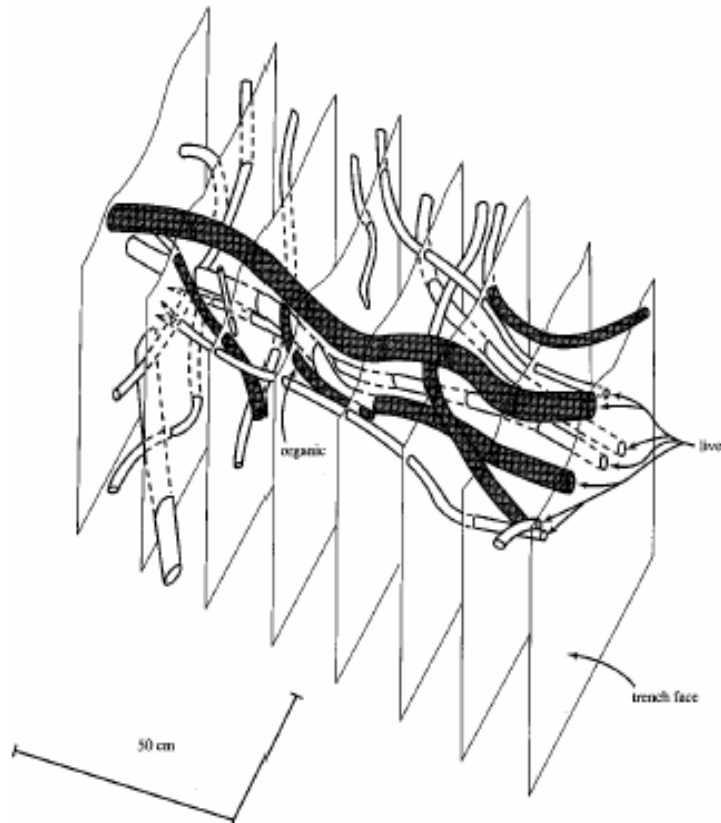
Interflow / Subsurface Stormflow

Lateral flow through soil above conductivity contrast.



Consists of both slower matrix flow and faster macropore flow

Macropore flow, Tennessee Valley, California



Complex Macropore Network within a Soil Matrix



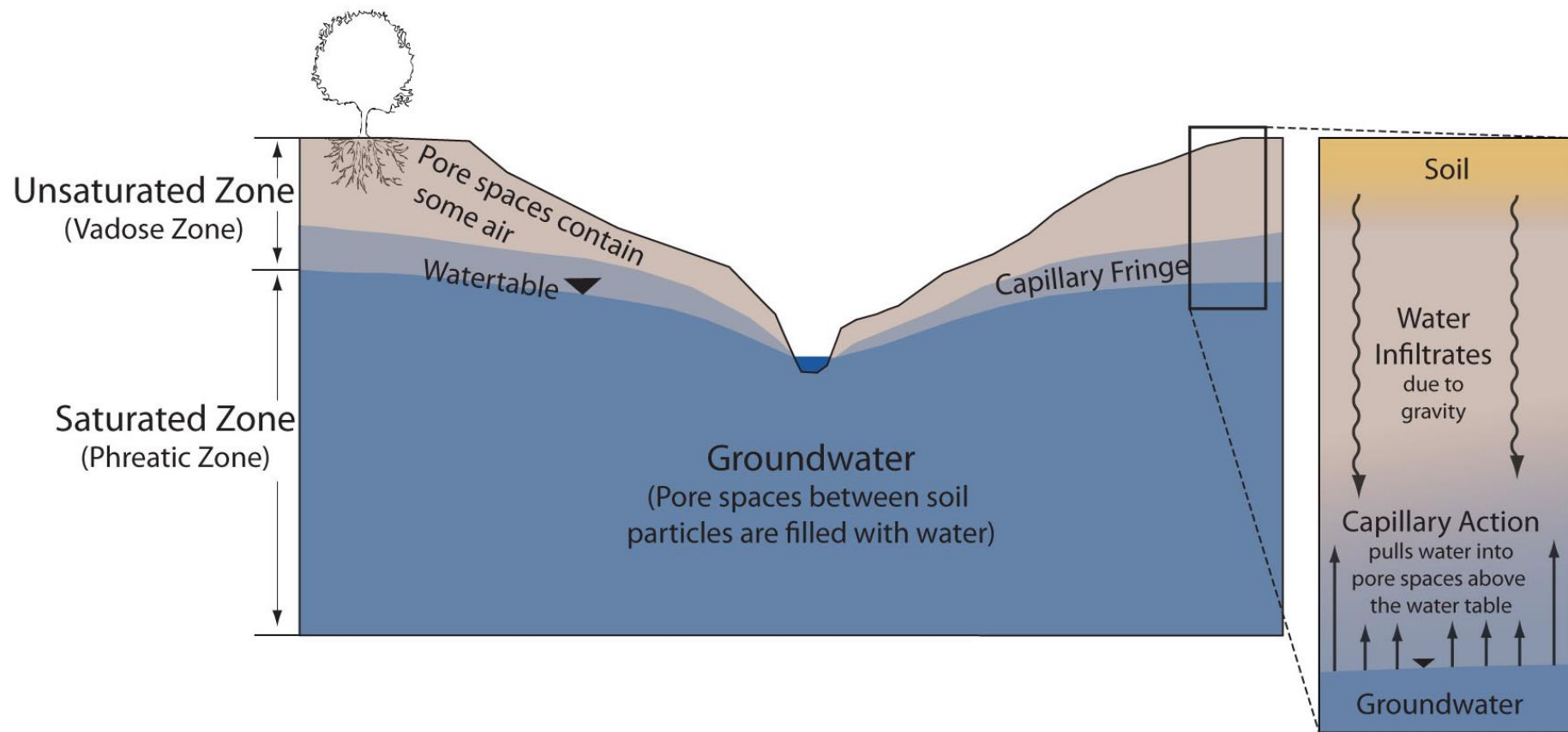
Saturation Overland Flow

[Runoff Processes - Section Two: Paths to Runoff \(luther.edu\)](#)

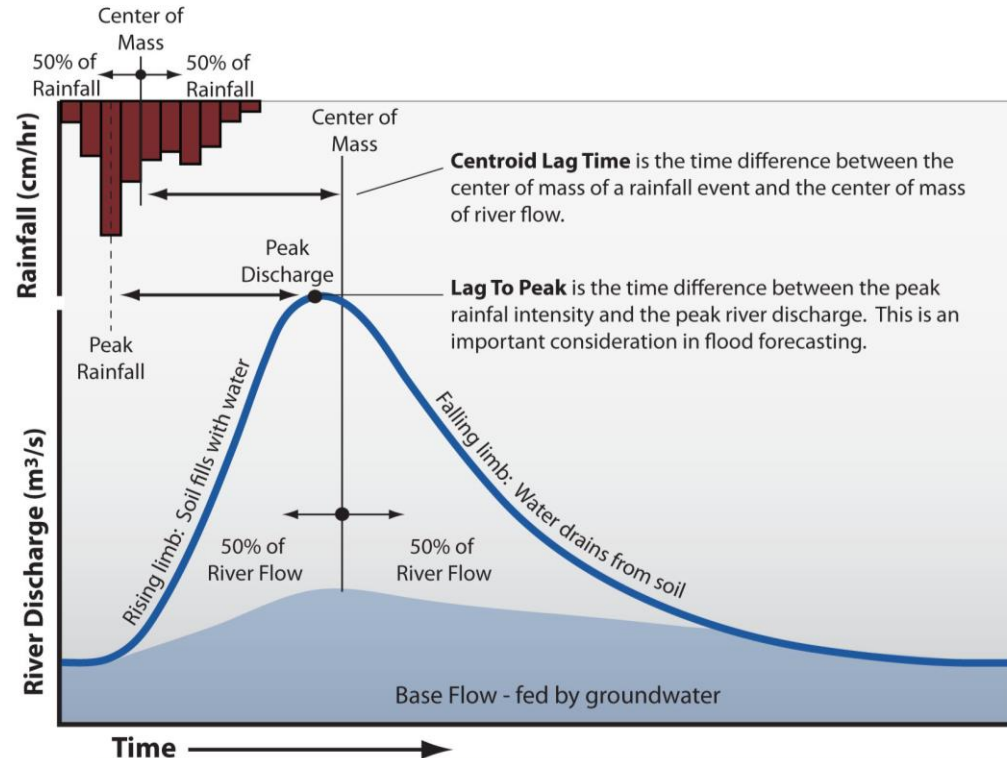
Direct rainfall onto saturated areas.

Return flow from saturated soils in topographic lows and along valley bottoms where water table rises to intersect the surface.

Groundwater and the vadose zone



Hydrograph Definitions



Rainfall

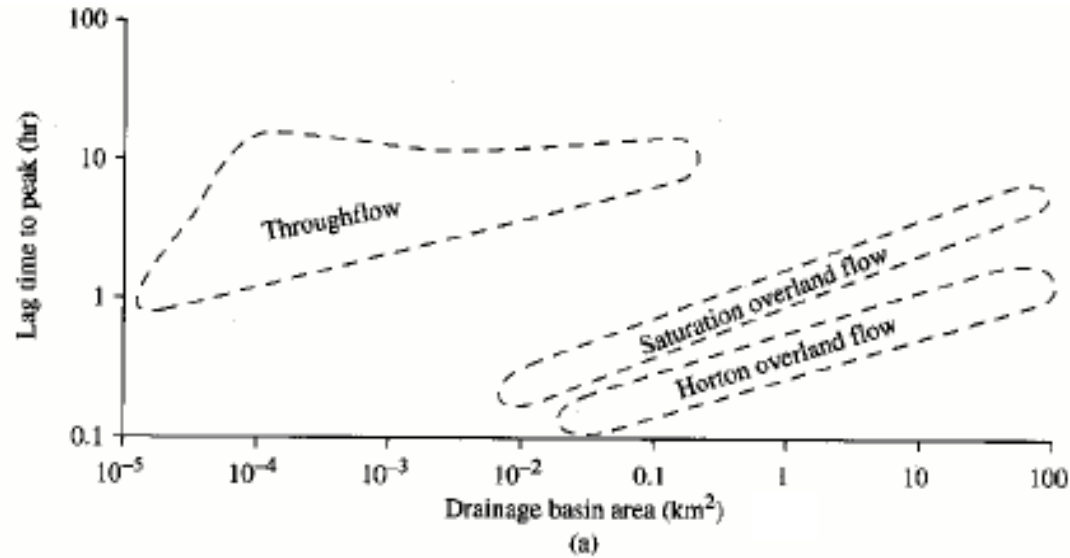
During a **rainfall event**, the intensity at which precipitation falls on a landscape is often variable. The **peak rainfall**, a measure of the greatest intensity of rainfall, does not necessarily occur in the middle of a rainfall event. Therefore, the peak and the **center of mass** of rainfall (the point at which half of the total rainfall has fallen) often do not correspond.

Discharge

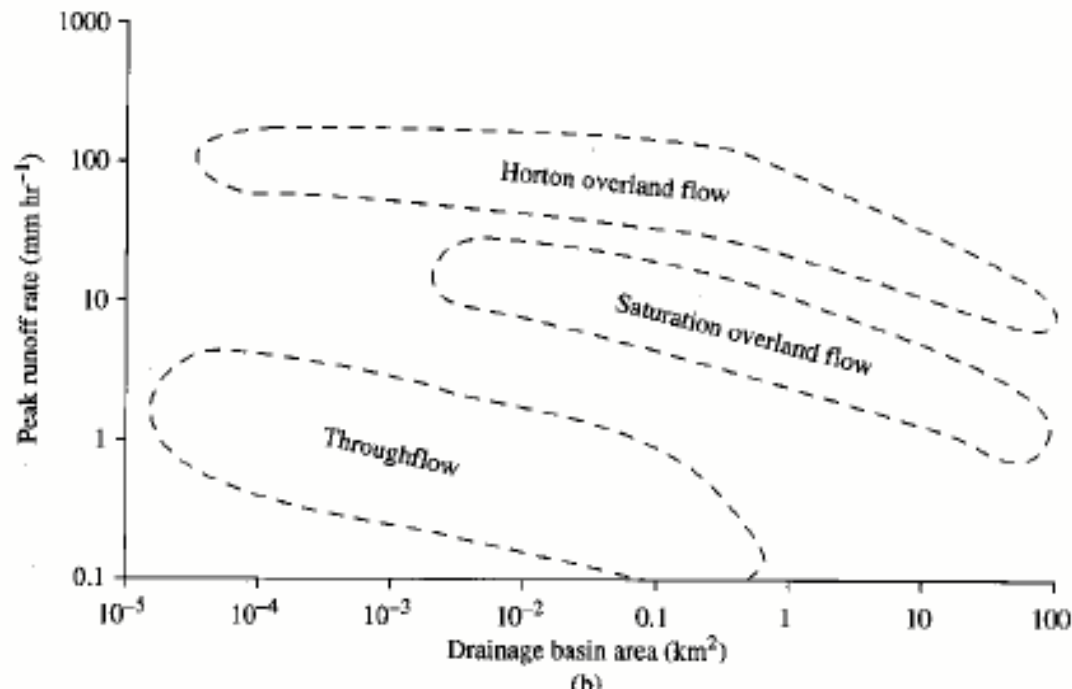
As precipitation falls across a landscape, some **infiltrates** the soil and some **runs off** and enters river channels causing discharge and river stage to rise. As the soil fills with water, more precipitation enters river channels as runoff, groundwater flow and subsurface stormflow. Stage rises until reaching the **peak**, or maximum discharge resulting from a rainfall event. As water drains from soils and from the landscape, the river stage begins to fall, eventually returning to **base flow**, which reflects normal groundwater discharge to rivers in humid regions.

Hydrographs by runoff mechanism

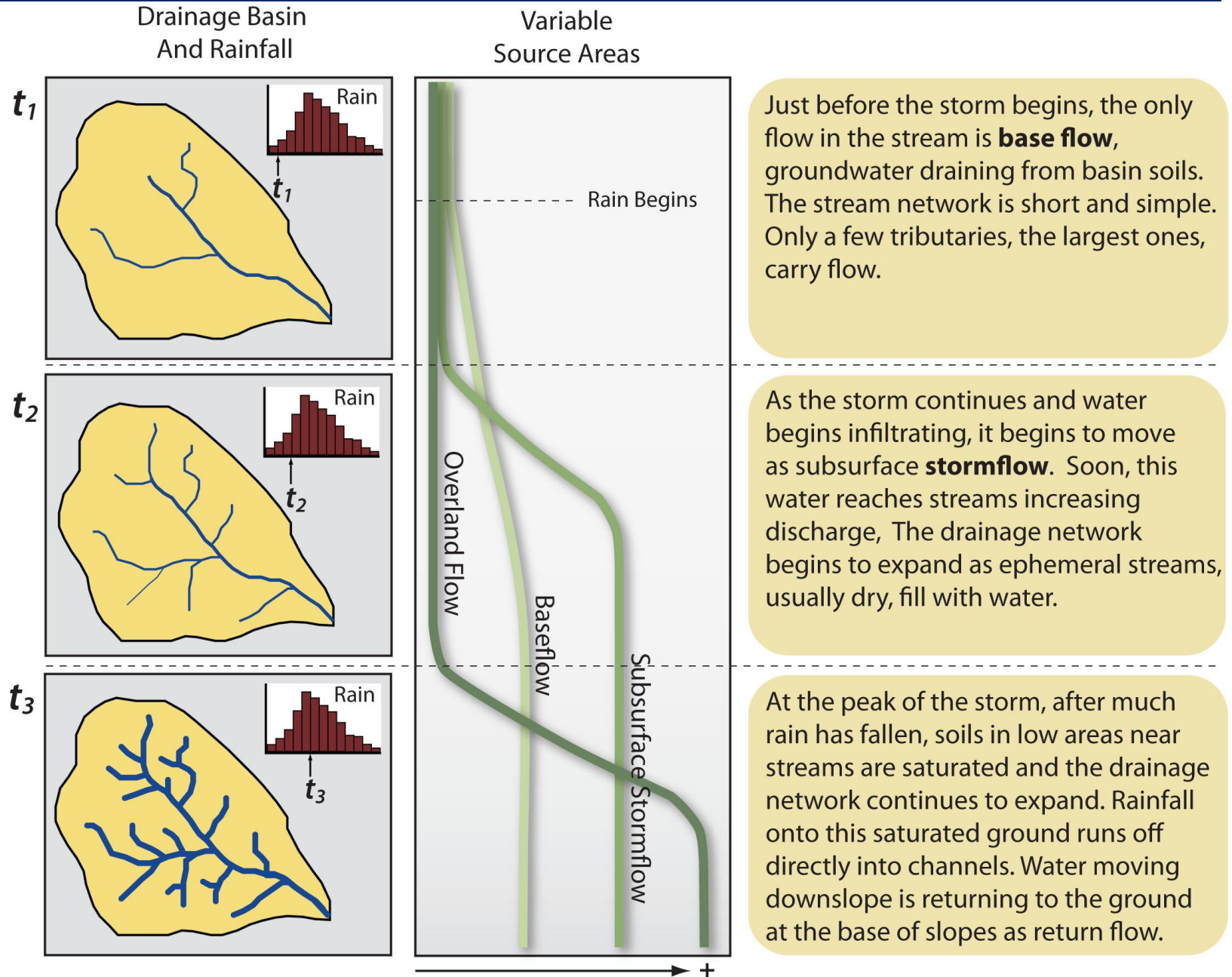
Lag to peak
Throughflow
SOF
HOF



Peak Runoff
HOF
SOF
Throughflow

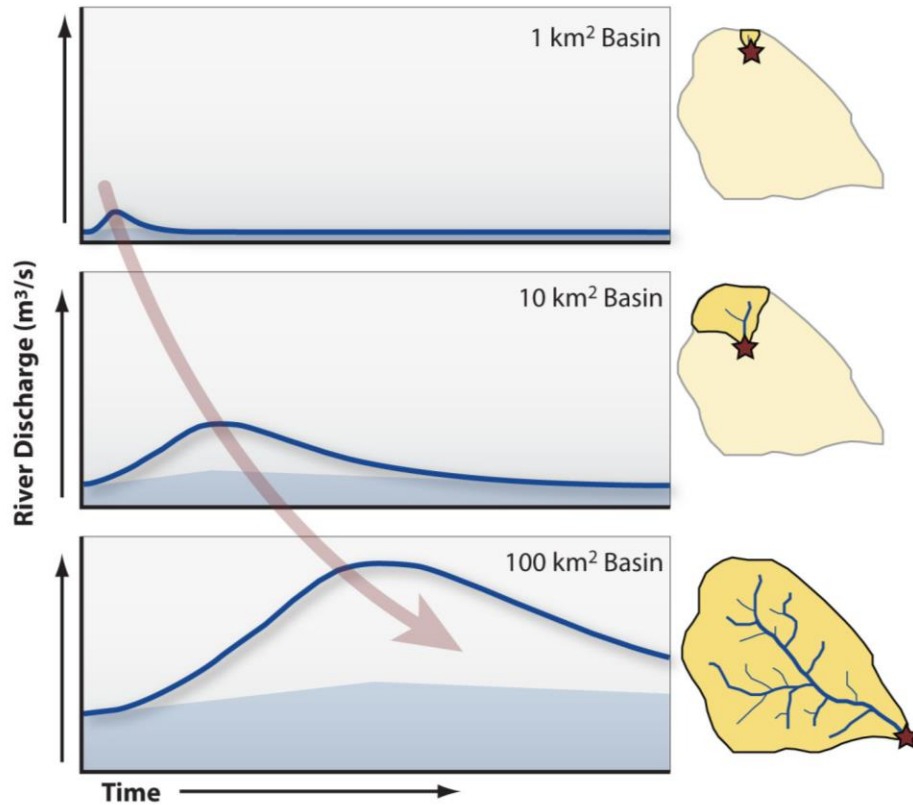


Variable source area



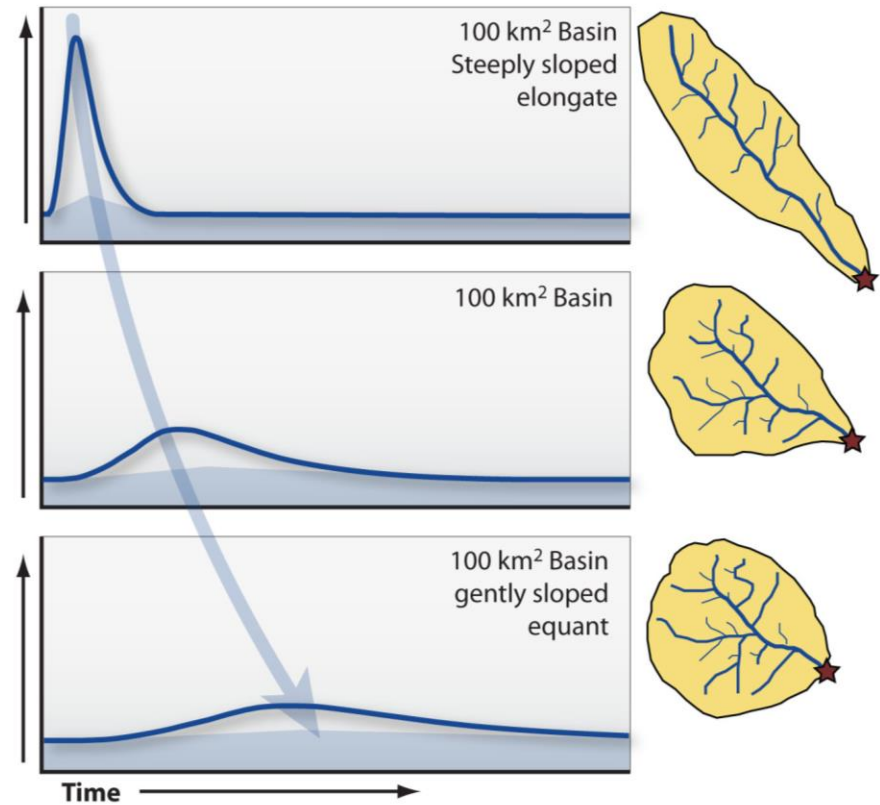
Basin scale and shape

Effects Of Basin **Scale** On The Hydrograph:



River discharge increases with basin area. Rivers rise and fall more slowly in large basins than in small basins.

Effects Of Basin **Slope** and **Shape** On The Hydrograph:



Hydrographs are more peaked and floods more abrupt in narrow, steep basins than in equant, gently sloping basins.

Water balance of catchment

Net difference between precipitation and evaporation yields streamflow or groundwater recharge

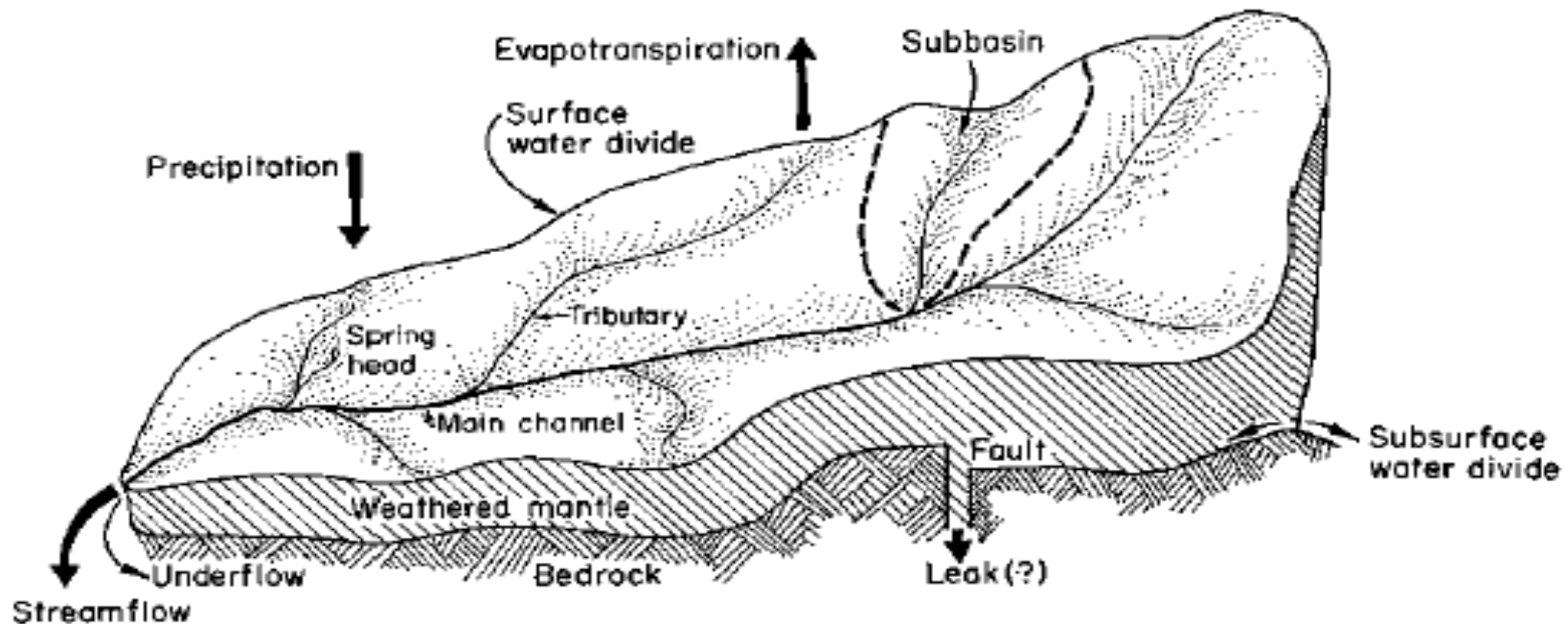
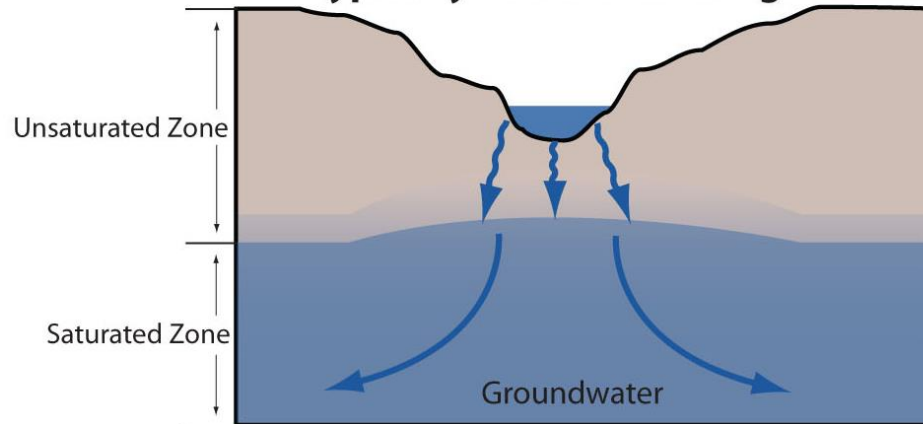


Fig 2-3. Diagram showing terms essential to describe the drainage basin and its water balance. Underflow is unmeasured streamflow in sands, gravels and rocks beneath the channel bed.

Gaining v losing streams

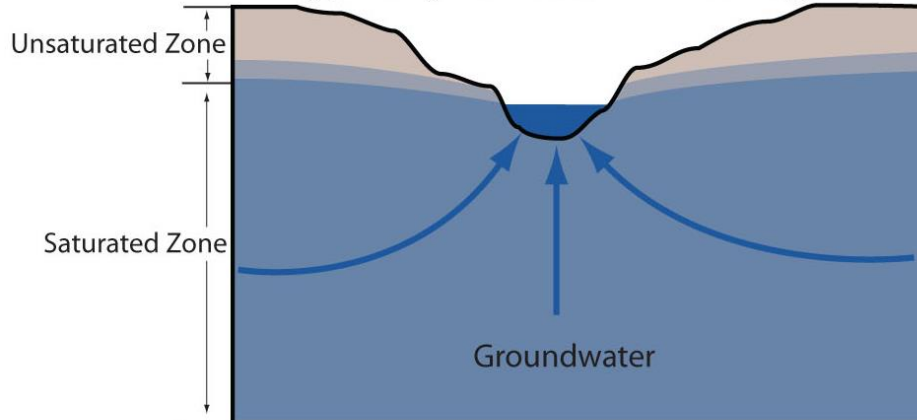
Typically found in arid regions



Losing Stream:

In arid regions, streambeds are usually dry. When storm flows fill the channel, water infiltrates through the bed recharging the aquifer below.

Typically found in Humid regions



Gaining Stream:

In humid regions, streambeds are usually wet. Groundwater, recharged by frequent rainfall, flows into the stream maintaining baseflow.

Catchment urbanisation

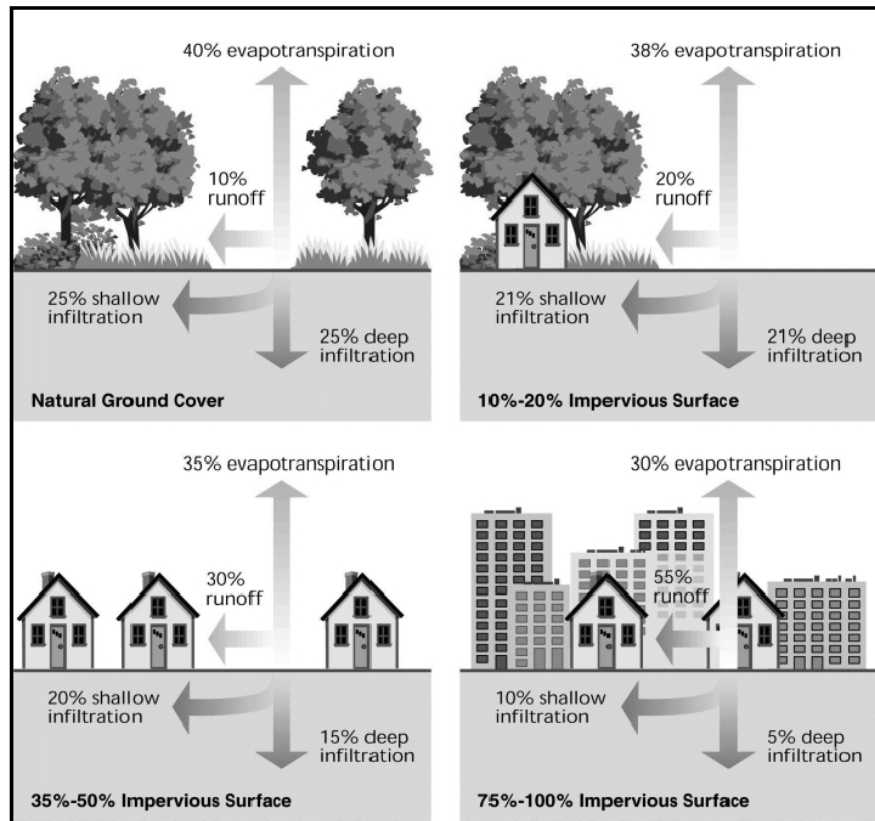
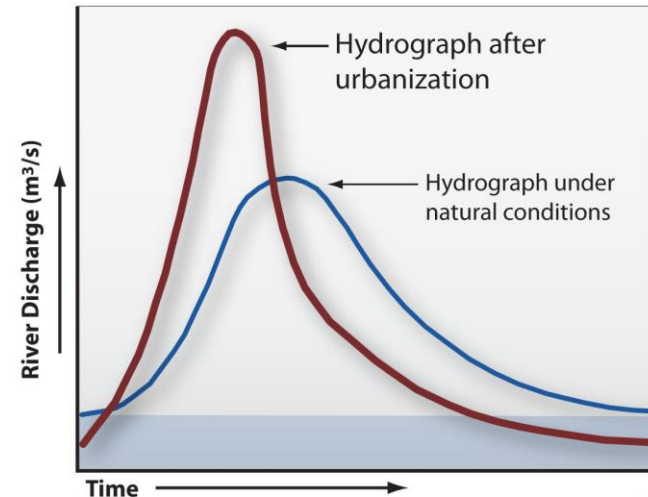


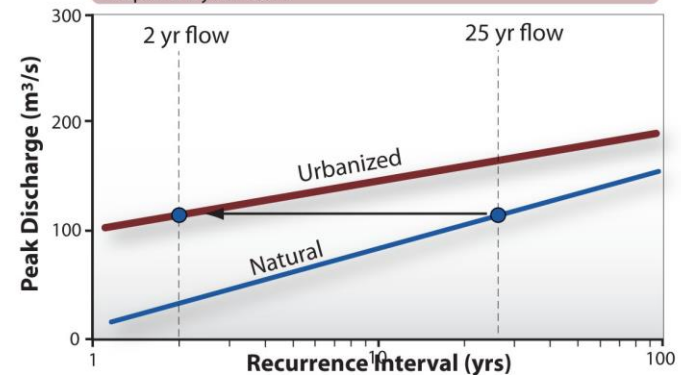
Figure 1.2: Relationship Between Impervious Cover and Surface Runoff

Source: Federal Interagency SRWG, 2000



Before development, rainfall followed a more convoluted path through the landscape - held in detention storage by pit and mound topography, infiltrating into organic-rich forest soil and moving slowly to the channel. The infiltrating water fed baseflow during times when it was not raining. Flood peaks were lower and came later.

After urbanization, rainfall moves rapidly to the channel with little chance to infiltrate during storms, thus baseflow is reduced. Flowing directly off impervious surfaces such as parking lots, runoff enters streams quickly raising their level. Flood peaks now come sooner and are higher, increasing flood hazards and the tempo of geomorphic change. For example, the natural 25 yr flow becomes the much more frequent 2 year flow.



3 minutes...



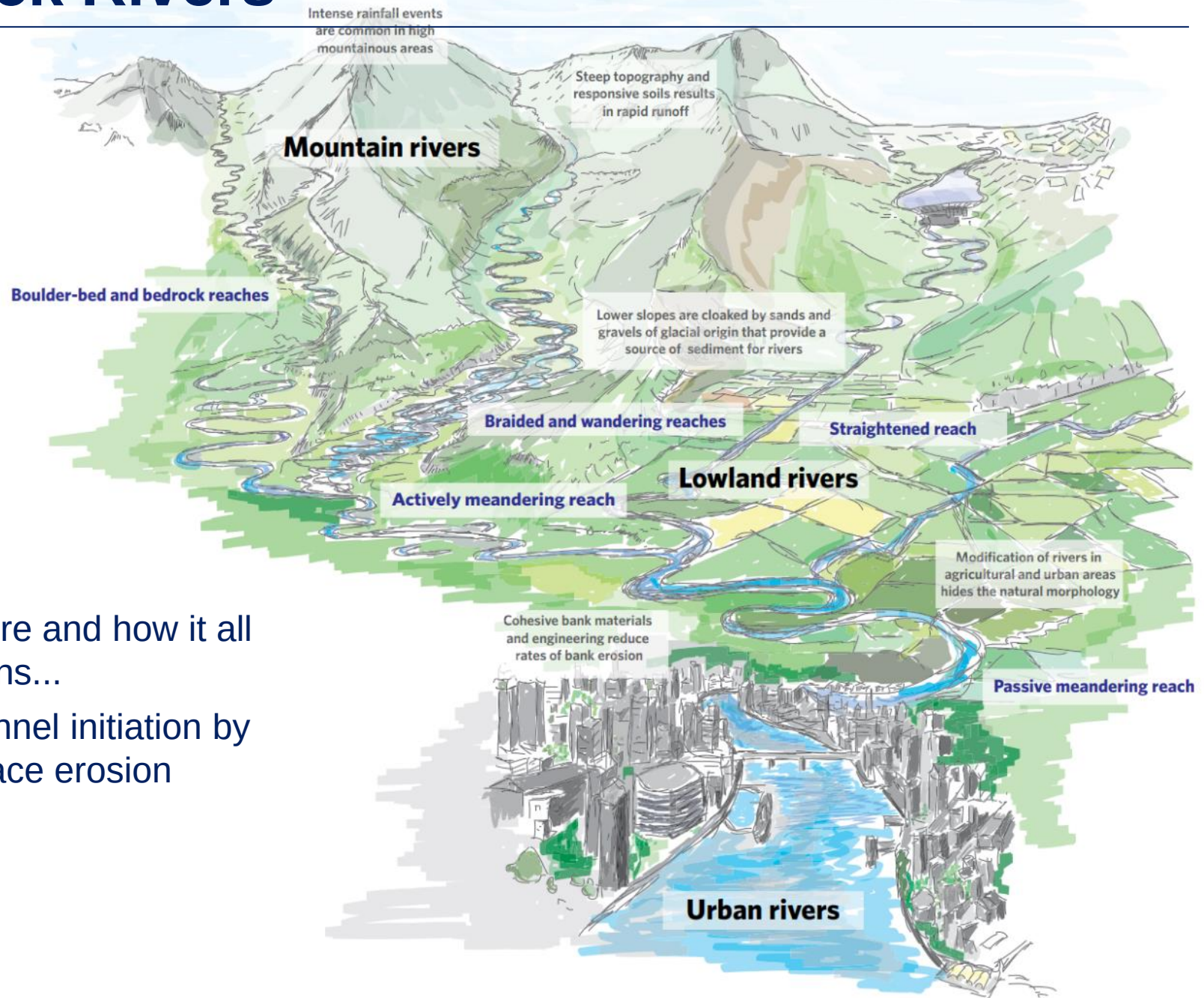


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Bedrock Rivers Form, process and evolution

Dr Alissa Flatley
ACNA4007 – Physical Landscape and the Geosphere

Bedrock Rivers



- Where and how it all begins...
- Channel initiation by surface erosion

Bedrock Rivers

Mountain or bedrock rivers: $Q_c > Q_s$ (i.e. excess power), steep headwaters



River Nevis, Highland



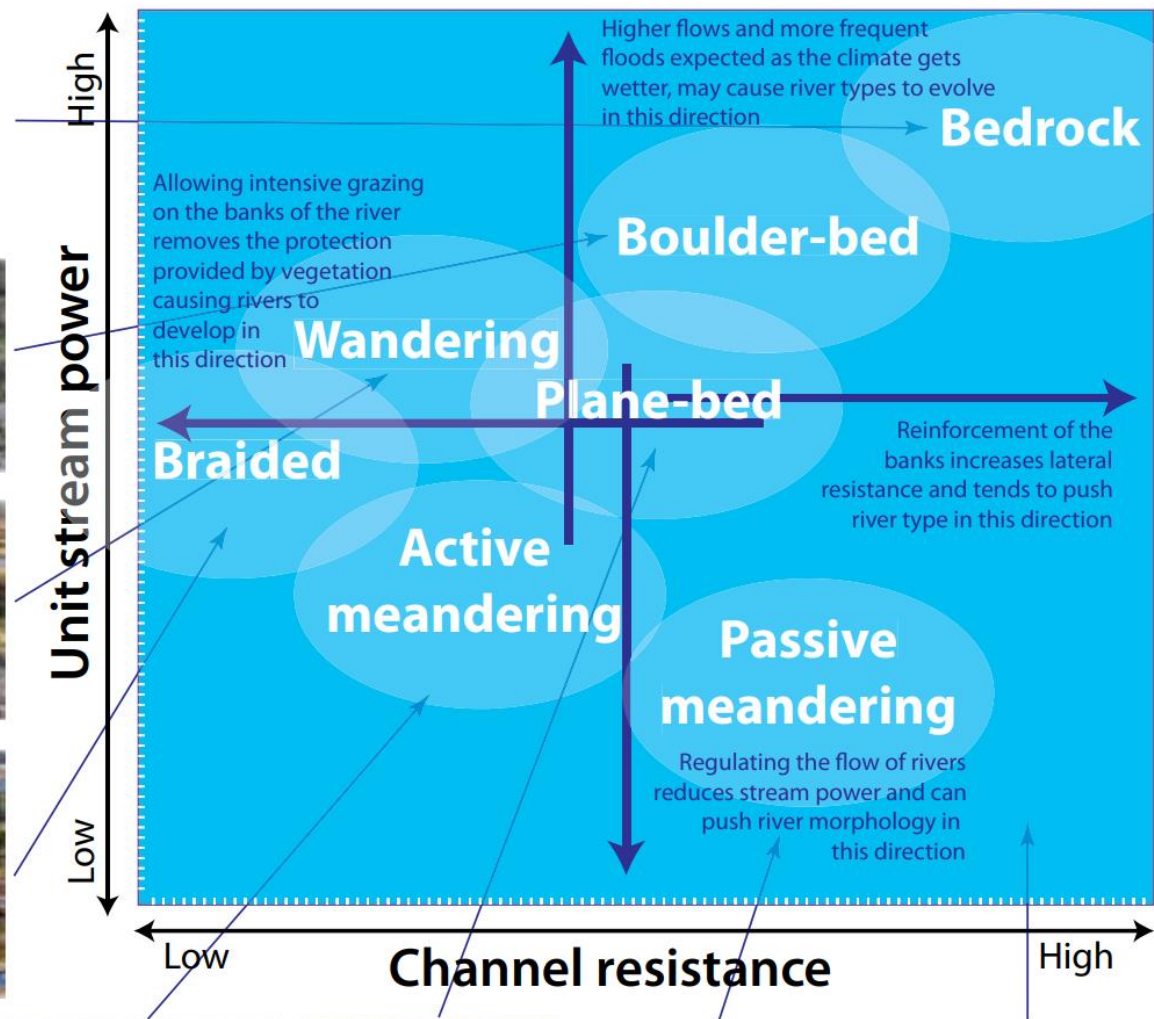
Black Burn, Aberdeenshire



Allt Bhran, Highland



River Feshie, Highland



River Brora, Highland



River Blackwater, Perthshire



River Devon, Stirlingshire

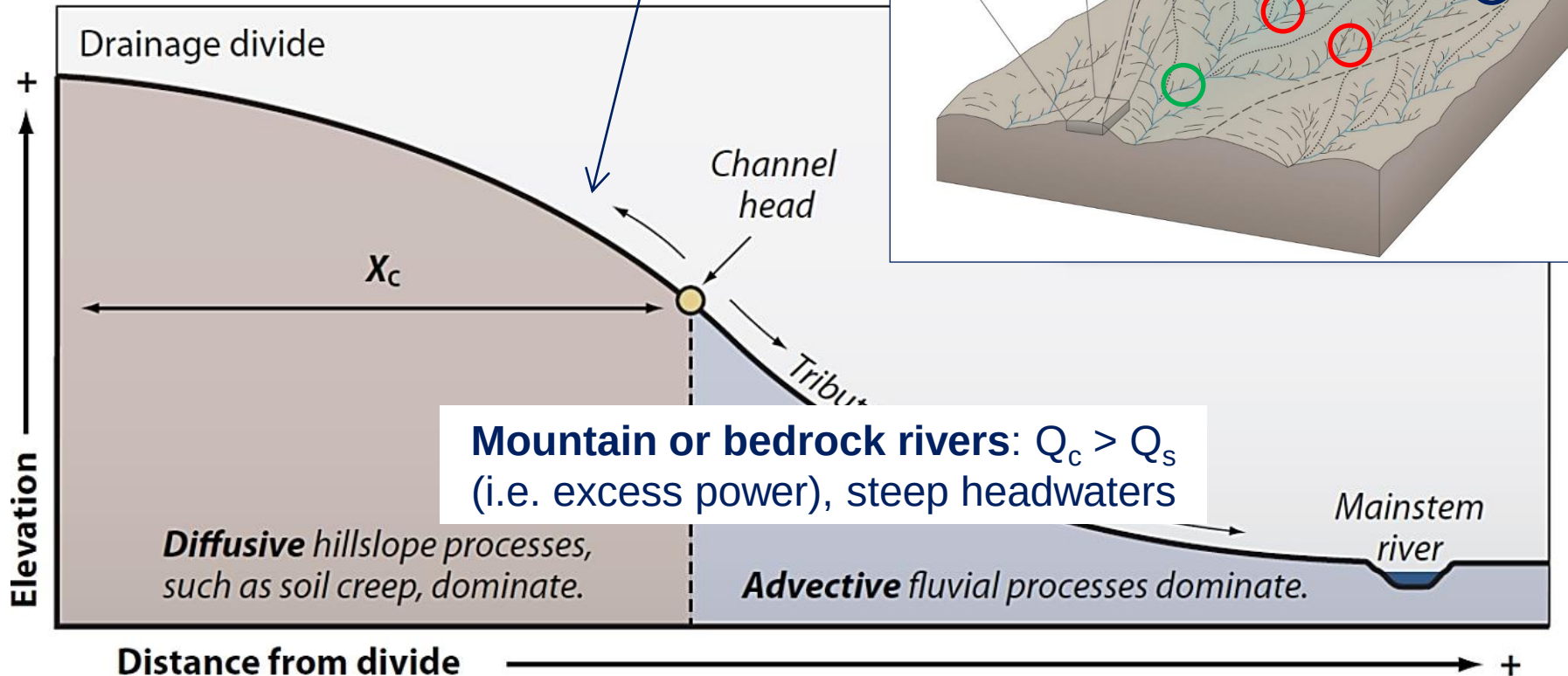
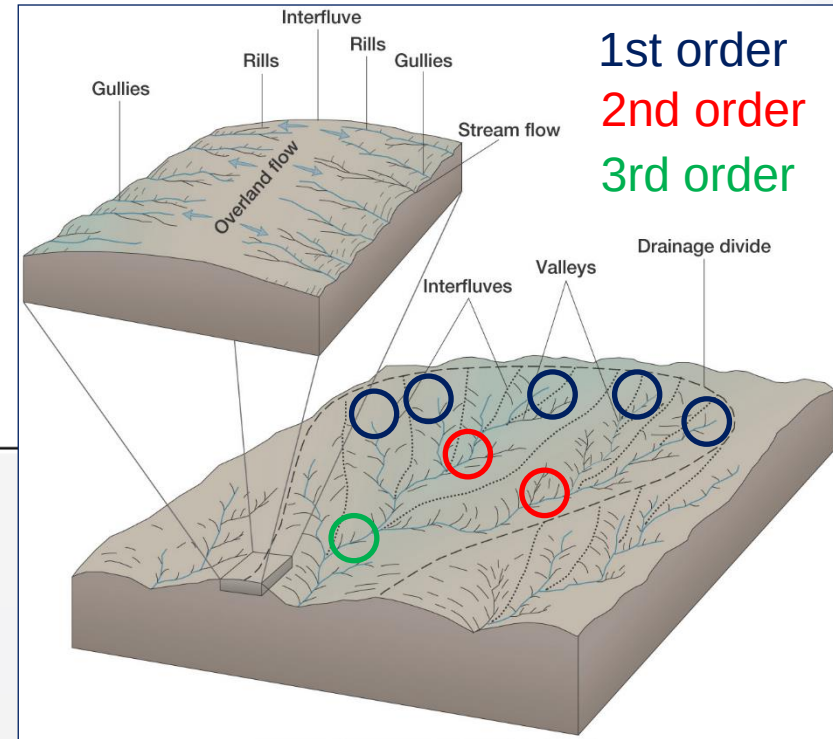


Whitecart tributary, South Lanarkshire

Hillslope – channel transition...

- Where and how it all begins...
- Channel initiation by surface erosion
- Stream Order systems

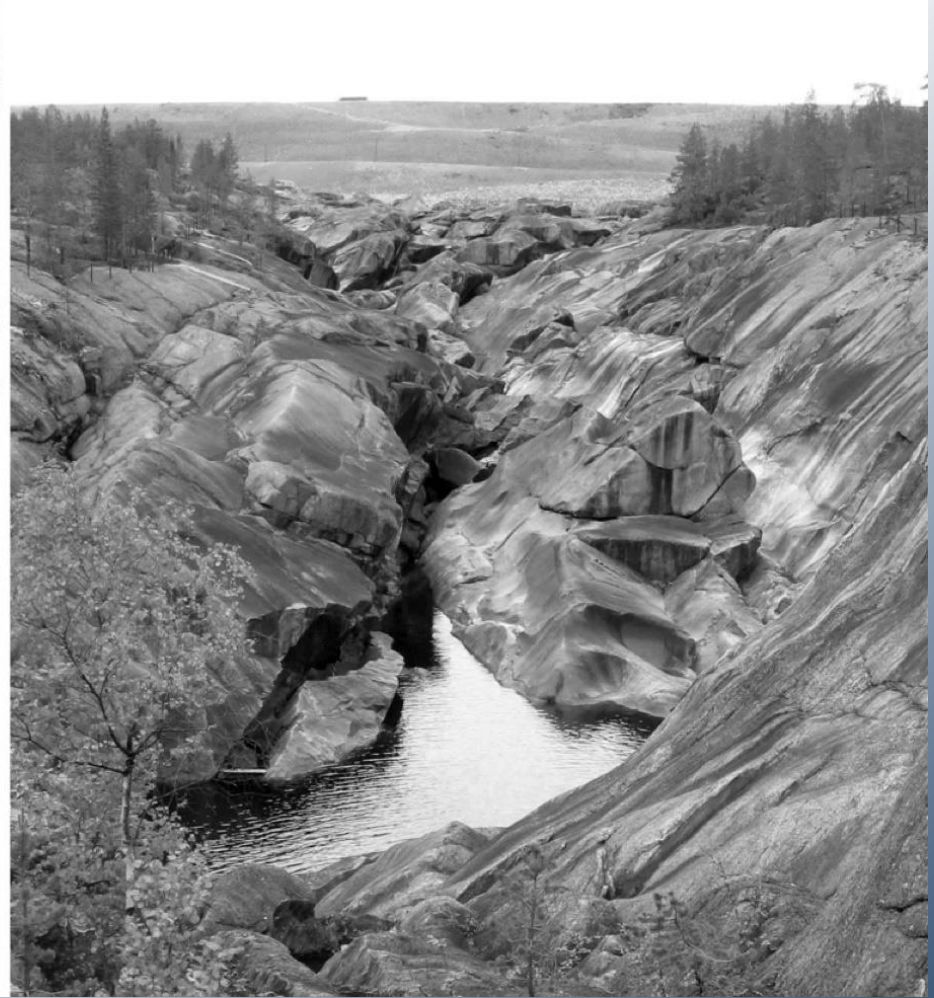
distance → depth, velocity & turbulence → shear stress...



Mountain Rivers...

1. What are bedrock (and mountain) rivers and what are the mechanisms of **bedrock erosion**?
2. Which role does **sediment** play in bedrock erosion?
3. How does **climate and environmental change** influence erosion and the evolution of valley form?
4. How does the river longprofile (i.e. the entire river system) **adjust to change**?

Stream Power



Harsprångsfallet (Sweden) before and after hydro-electric dam construction in the 50s

Bedrock Erosion

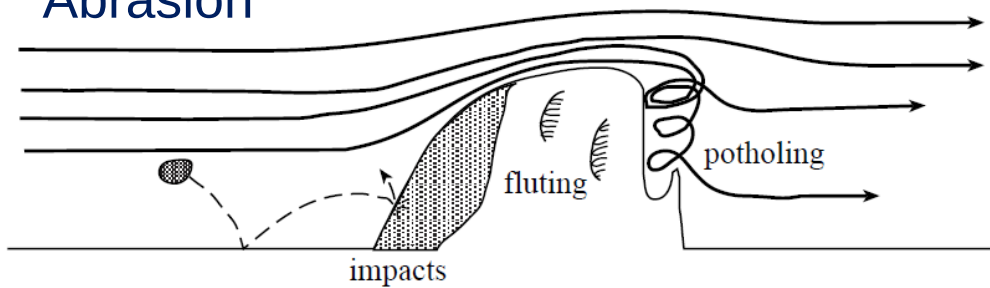


Bedrock Erosion

Sculptured bedrock

Polishing...

Abrasion

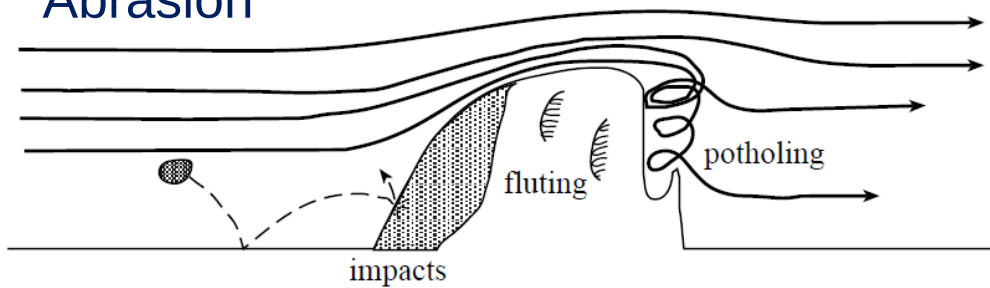


Bedrock Erosion

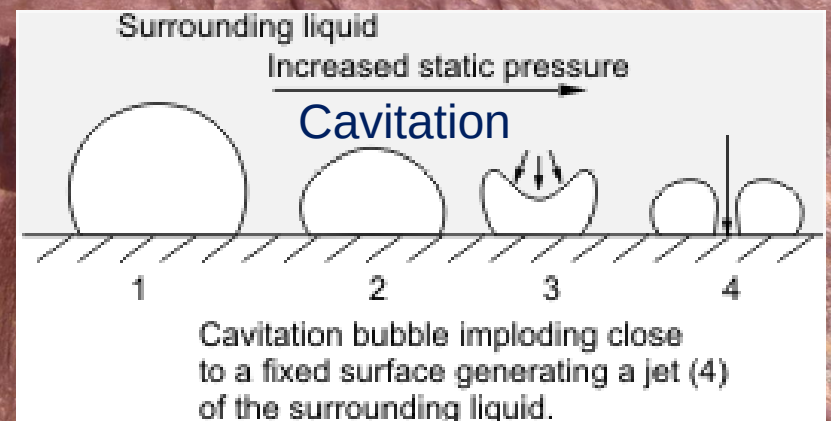
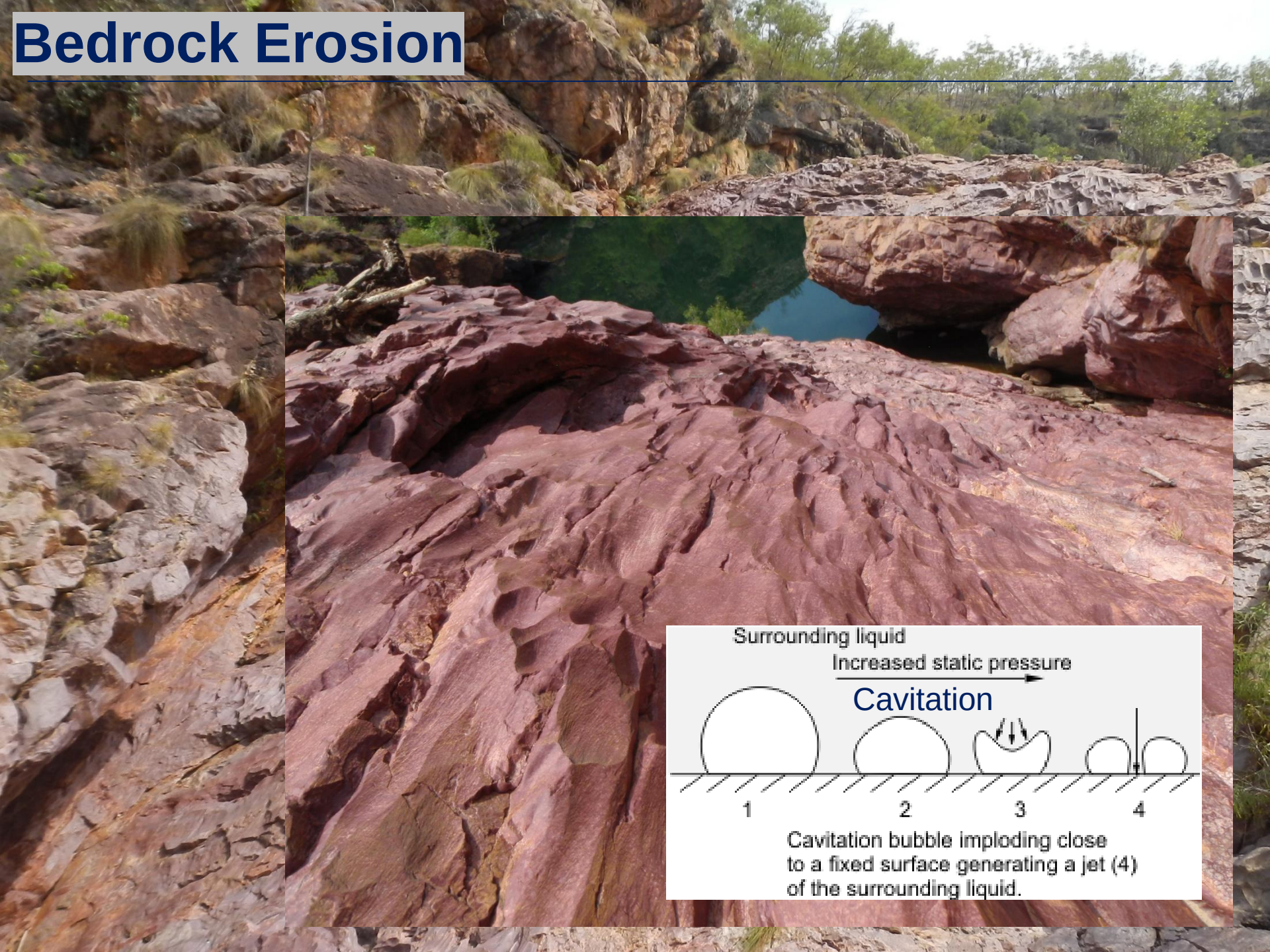
Flutes

Impact marks

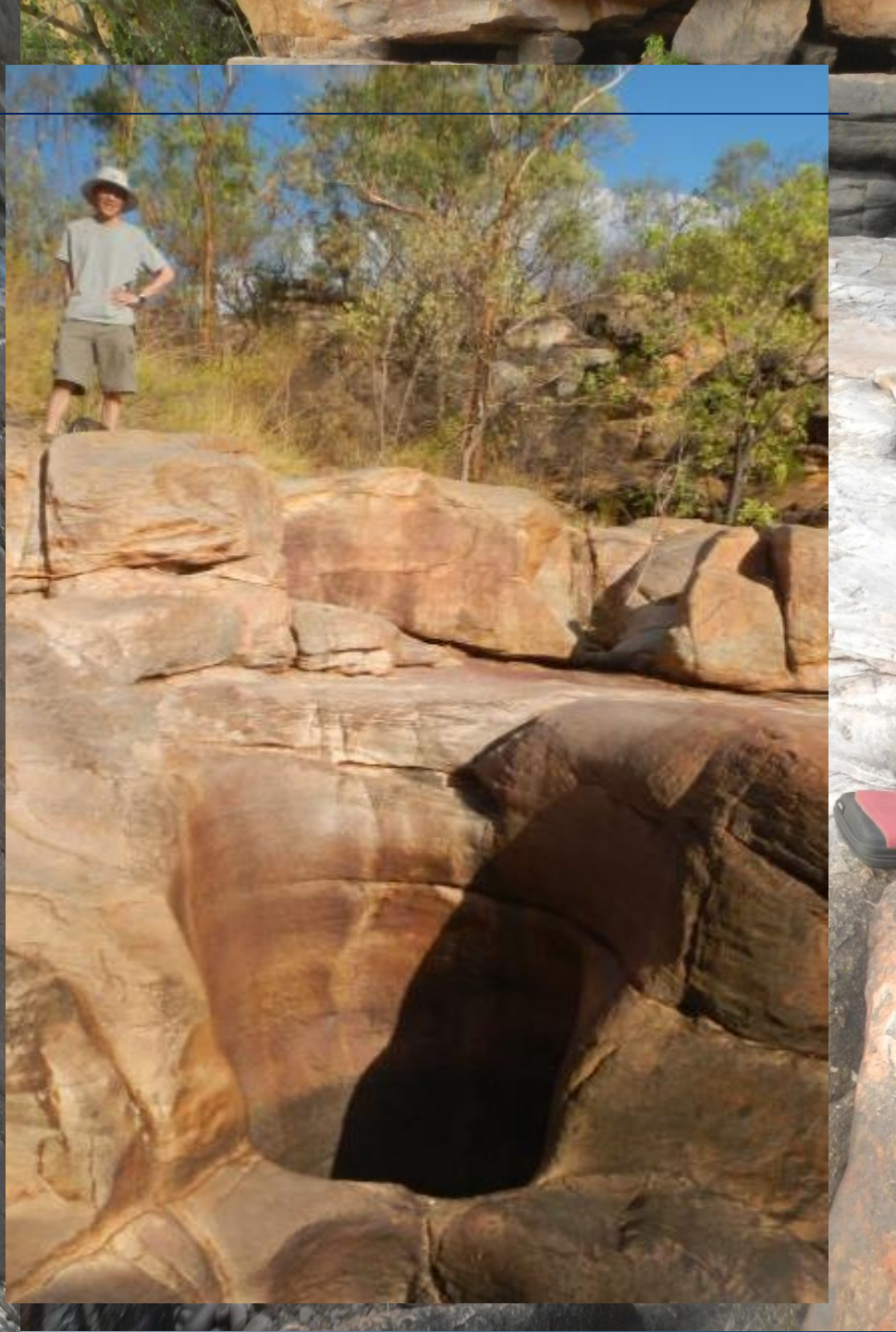
Abrasion



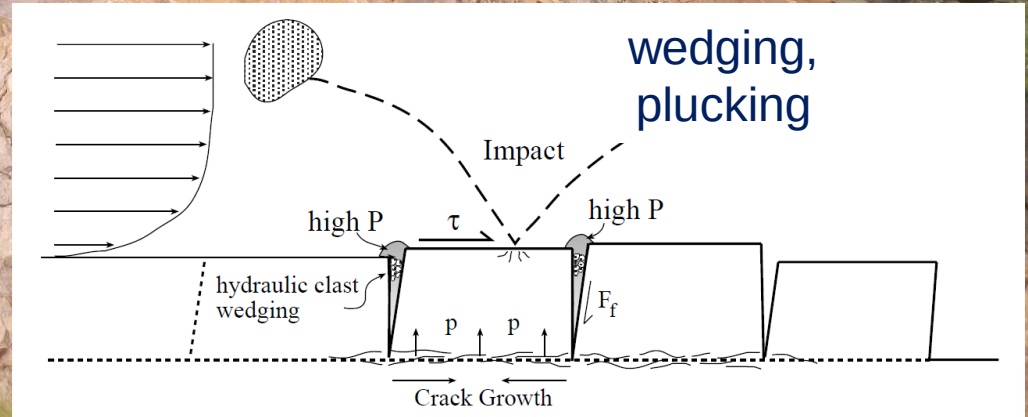
Bedrock Erosion



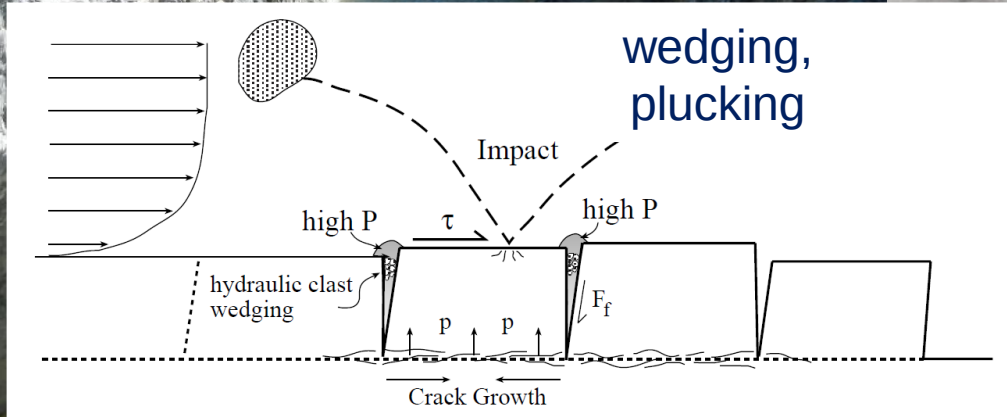
Bedrock Erosion



The role of bedrock properties

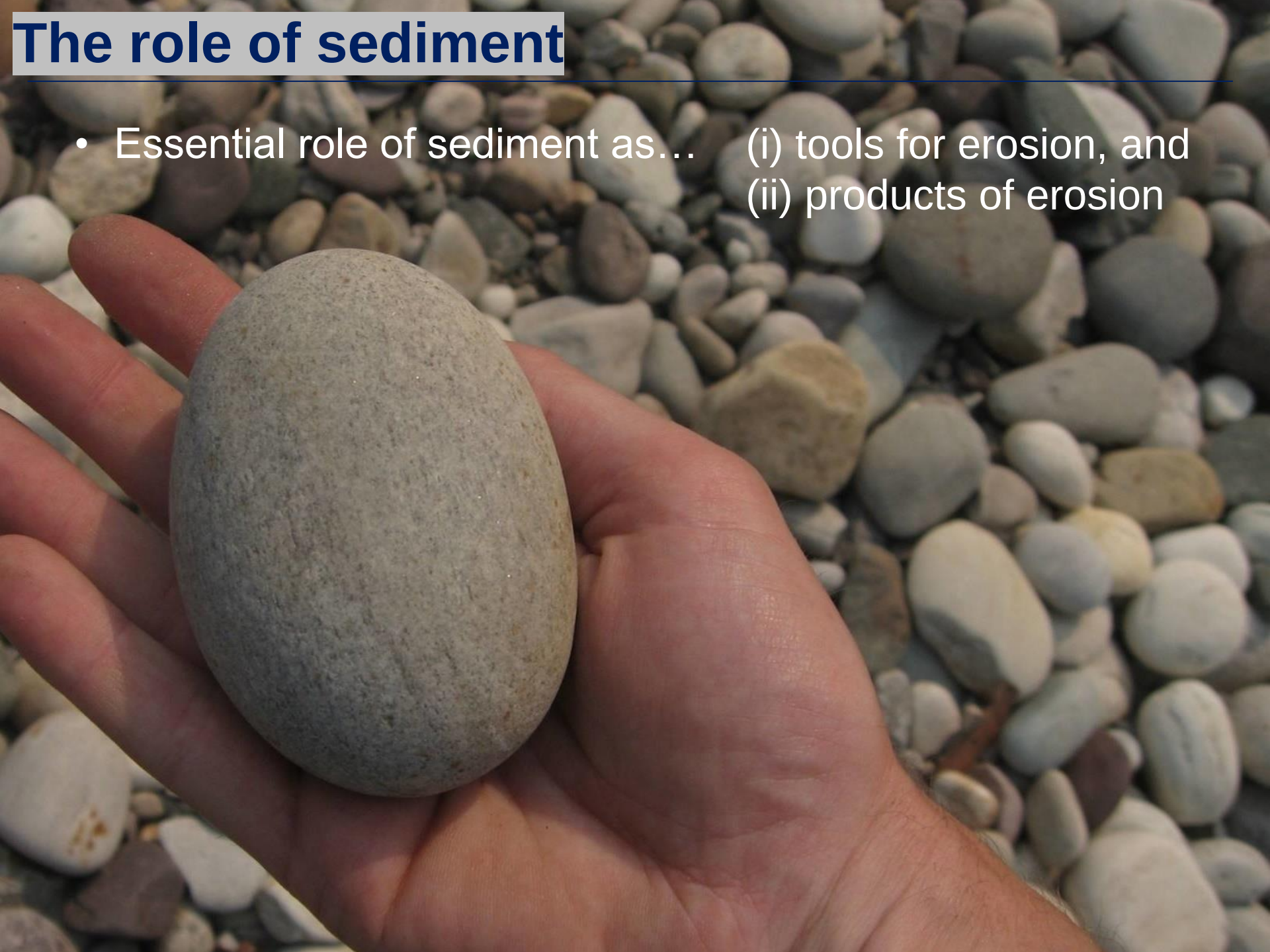


The role of bedrock properties



The role of sediment

- Essential role of sediment as...
 - (i) tools for erosion, and
 - (ii) products of erosion



The role of sediment

- Essential role of sediment as... (i) tools for erosion, and (ii) products of erosion

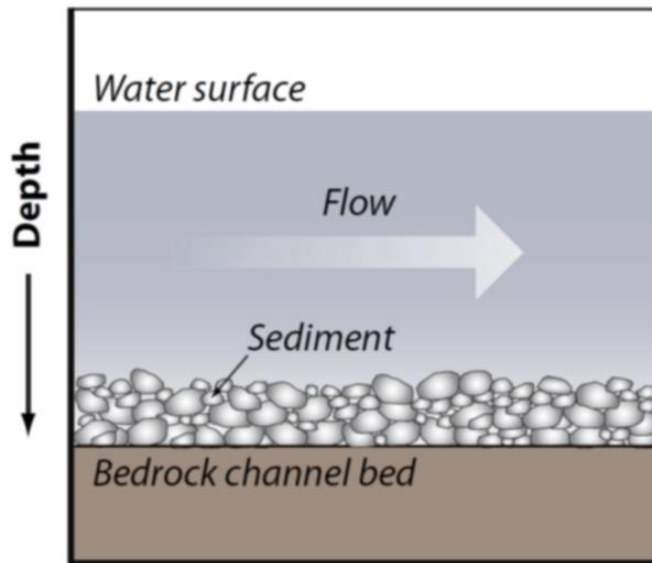
- Modes of movement
- Size dependence
- Interaction between clasts
- Quantity of sediment



Flow competence = Capability of flow to activate sediment increases with... ?

The role of sediment

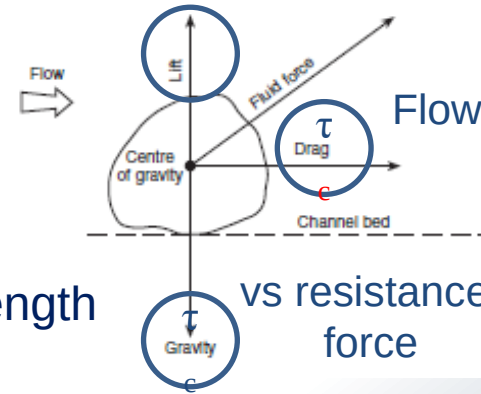
- Processes at river bed: **Force** (fluvial τ_0 or ω) vs **Resistance** (gravity, rock strength)



Critical
shear stress

τ_c

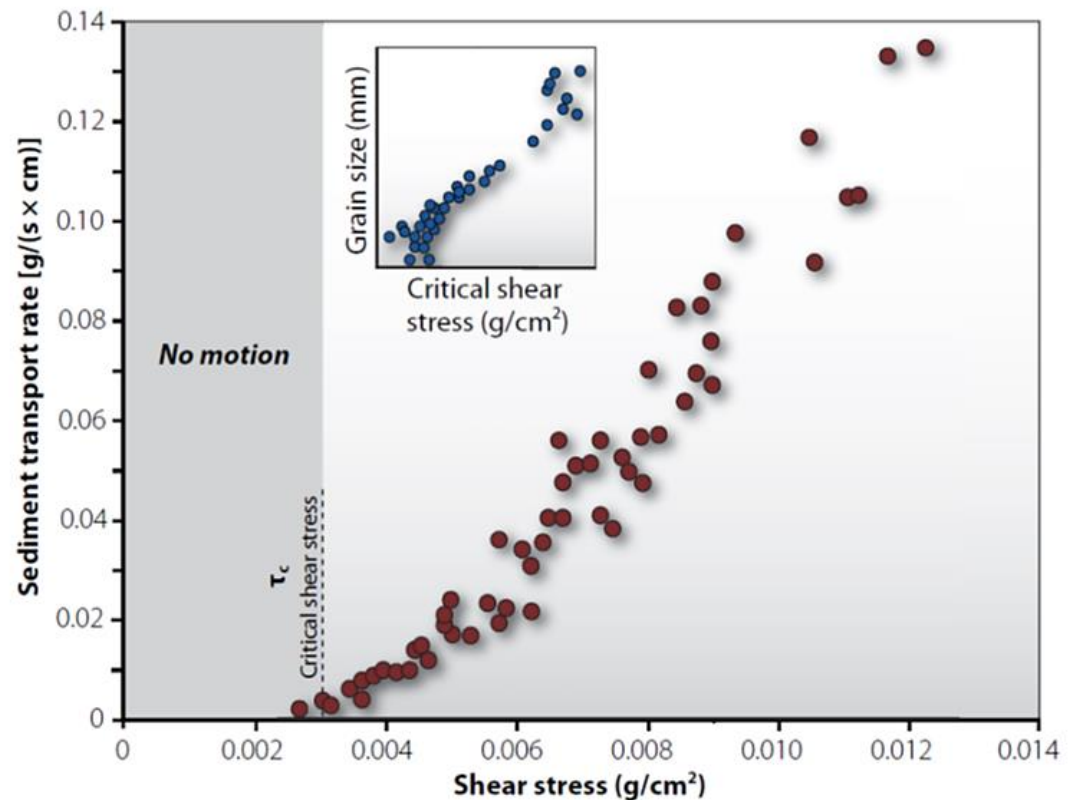
Pressure difference



1. local
shear stress

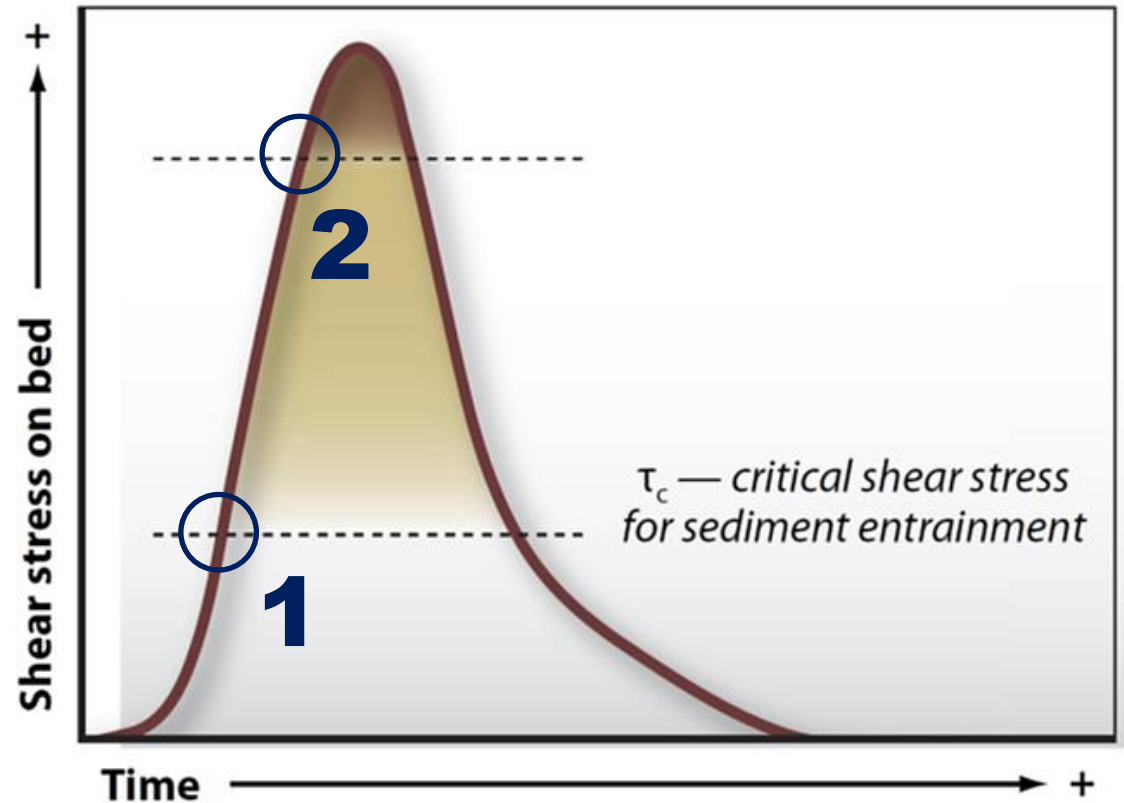
2. shear strength

vs resistance
force



The role of sediment

- During a **flood**, shear stress on the stream bed increases as the **depth and velocity** of water increase
- Critical shear stress above which bedrock erosion occurs (τ_{cb}) is higher than that required to entrain sediment from the channel bed (τ_c)

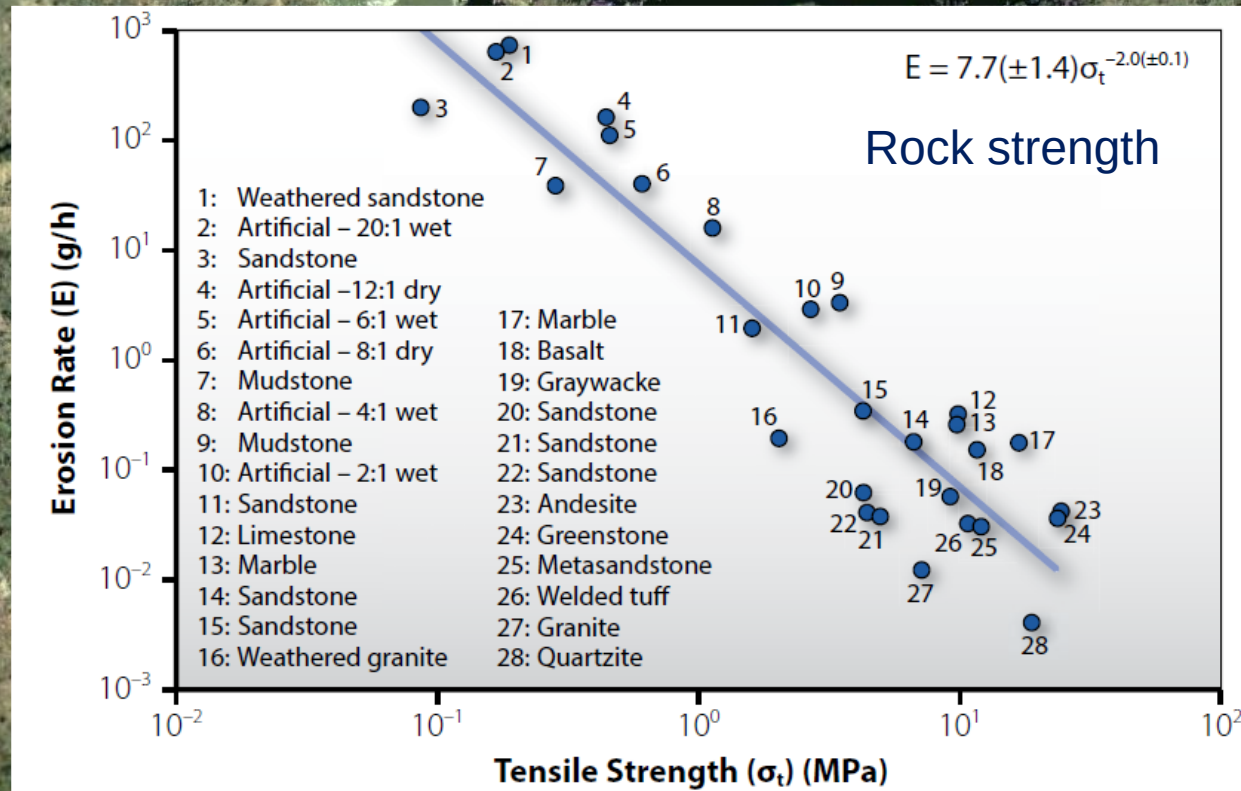


- Thus, **rare floods, high-stream power events** that generate large shear stresses on the bed, are required to erode rock

The role of bedrock properties

- What controls the rate of bedrock incision (E) ?

$$E = f(Q_c, S, k)$$



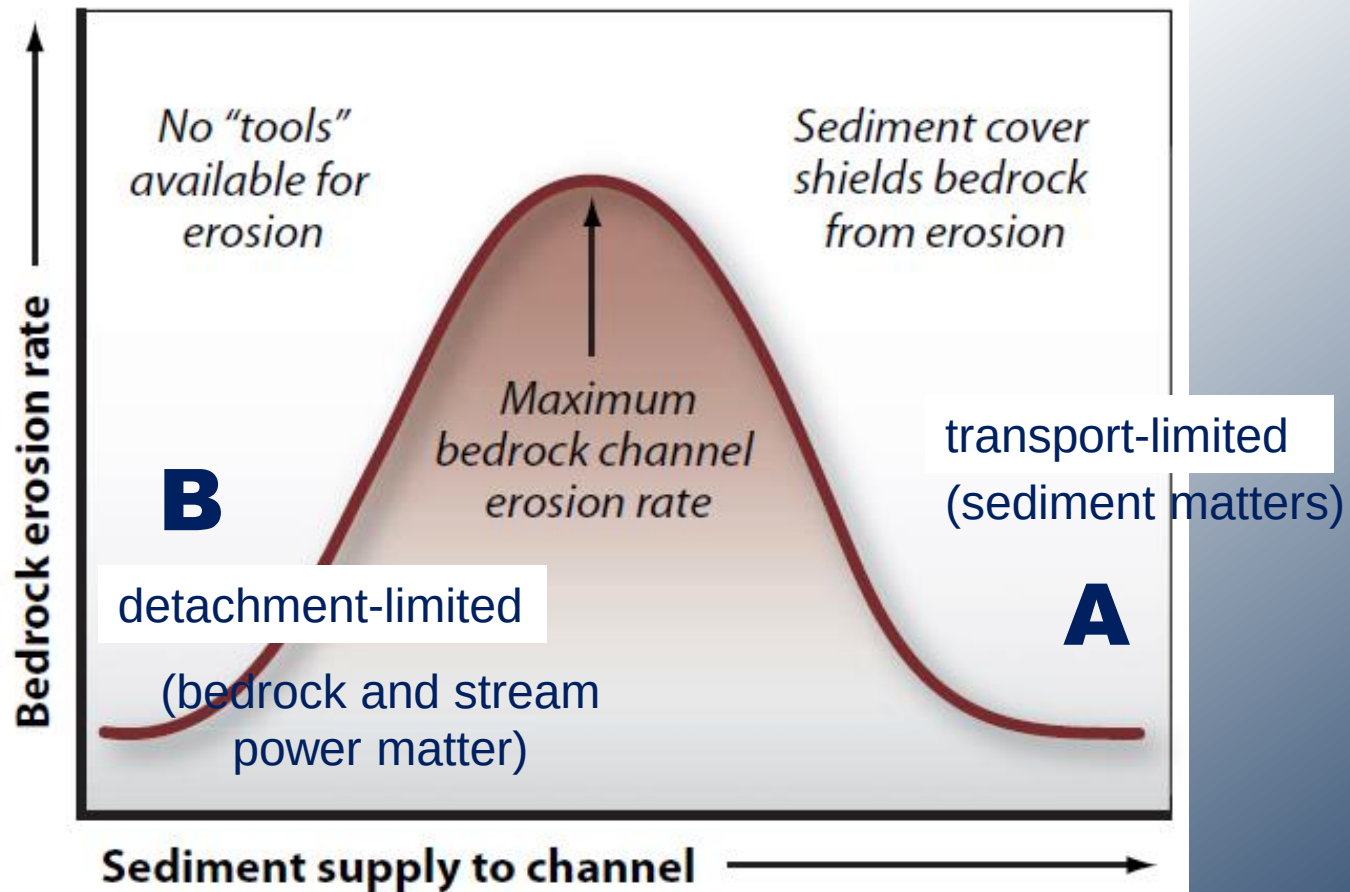
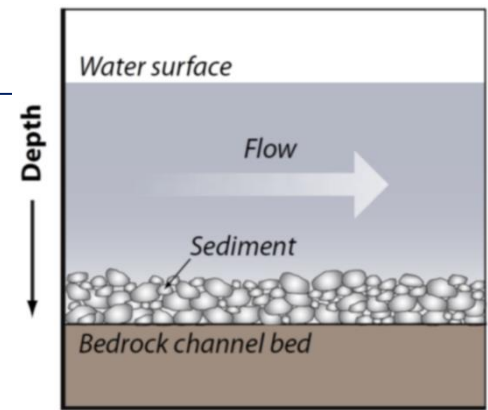
- constant k** represents erosivity role of rock type/ properties (often estimated instead of measured)... i.e. steepness index

Bedrock Incision Rates

- What controls the rate of bedrock incision (E) ?

$$E = f(Q_c, S, k, Q_s)$$

- Rate of **bedrock incision** also depends on the sediment supply to the channel



Bedrock River Dynamics

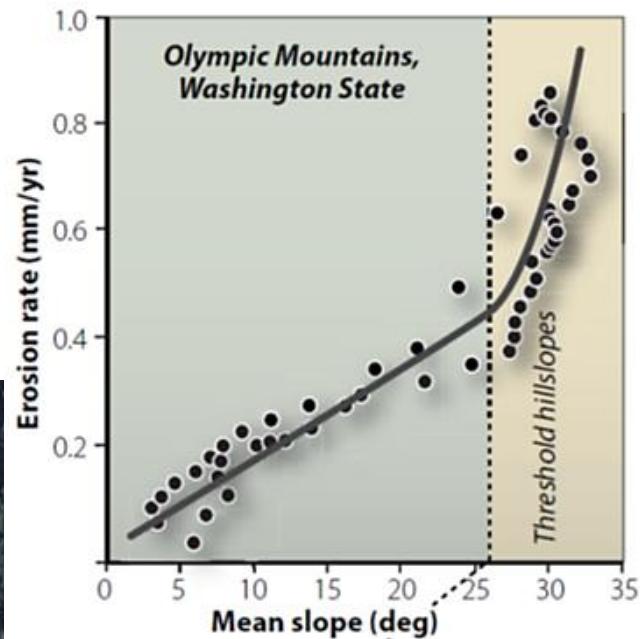
30-40 degrees

$$Q_s < Q_c$$

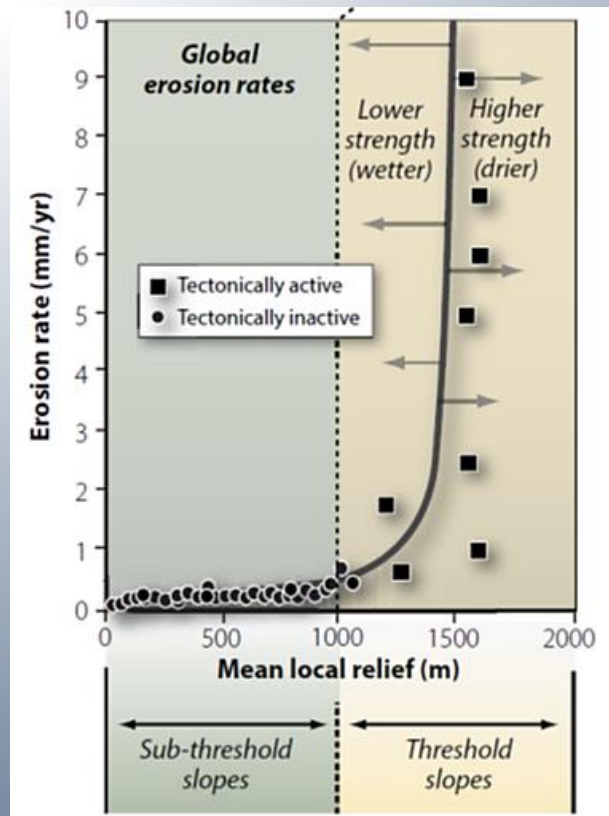
B

Detachment-limited
bedrock incision

Bedrock River Dynamics



- Hillslope steepening (fluvial incision causes hillslope erosion...)
- **Threshold hillslopes** – erosion rates controlled by mass-wasting frequencies (and rock strength) instead of slope



Bedrock River Dynamics



Slot Canyons



Blue Mountains, NSW

Gulch Canyon, Utah

Bedrock River Dynamics

A Transport-limited bedrock incision
 $E \sim$ sediment transport rate

$$Q_s \sim Q_c$$

Bedrock erosion in flood conditions across valley

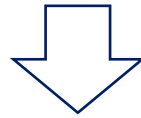
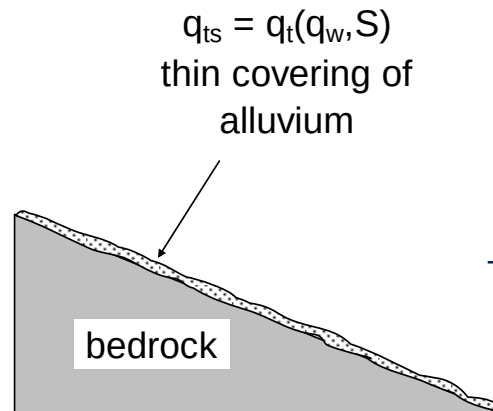


- Channel lowering by diffusive erosion (top-down...)

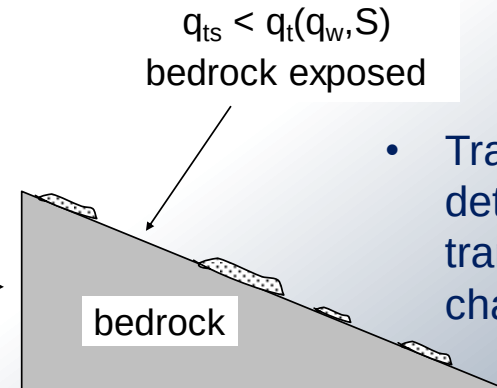
Bedrock River Dynamics

- Change in conditions over time leads to adjustment... !

2

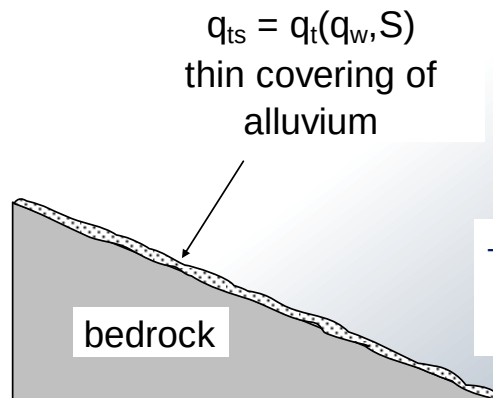


- sediment supply
+ discharge
+ slope

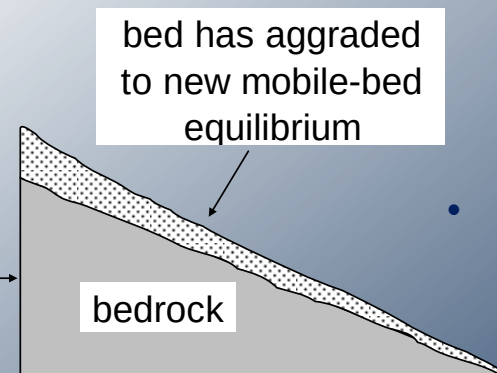


- Transformation from
detachment-limited to
transport-limited river
channel

1



+ sediment supply
- discharge
- slope



- Aggradation

Bedrock River Dynamics

1

Increase in Q_s
Decrease
in Q_c

$Q_s > Q_c$

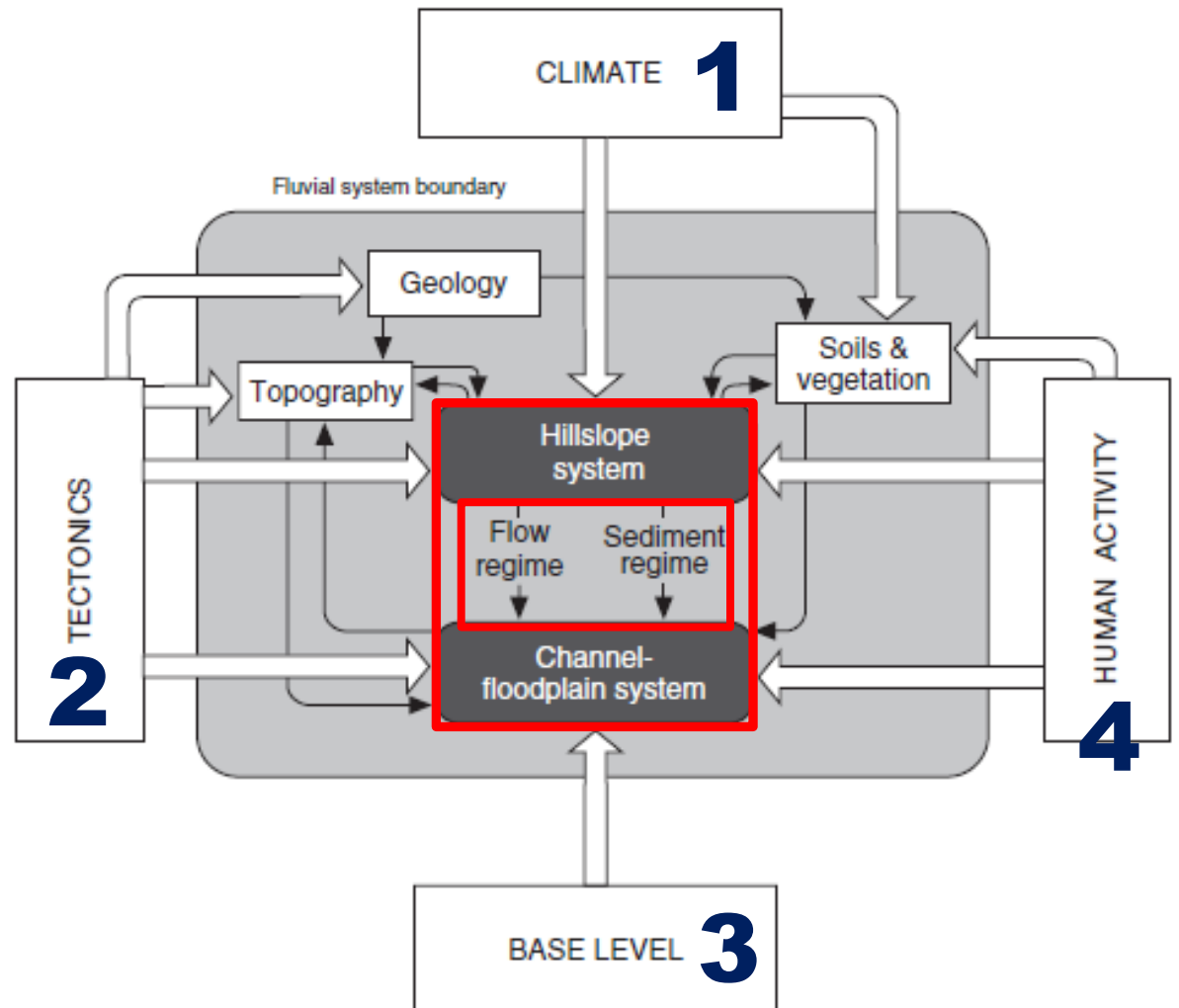
Aggradation... (vertical
deposition and filling)

Adjustment to new situation
until...?

Change and Adjustment

Which climate parameters would influence fluvial system ??

- Internal vs External controls
- Driving variables vs boundary conditions



Climate Change, Incision and Terraces

Cold-climate conditions

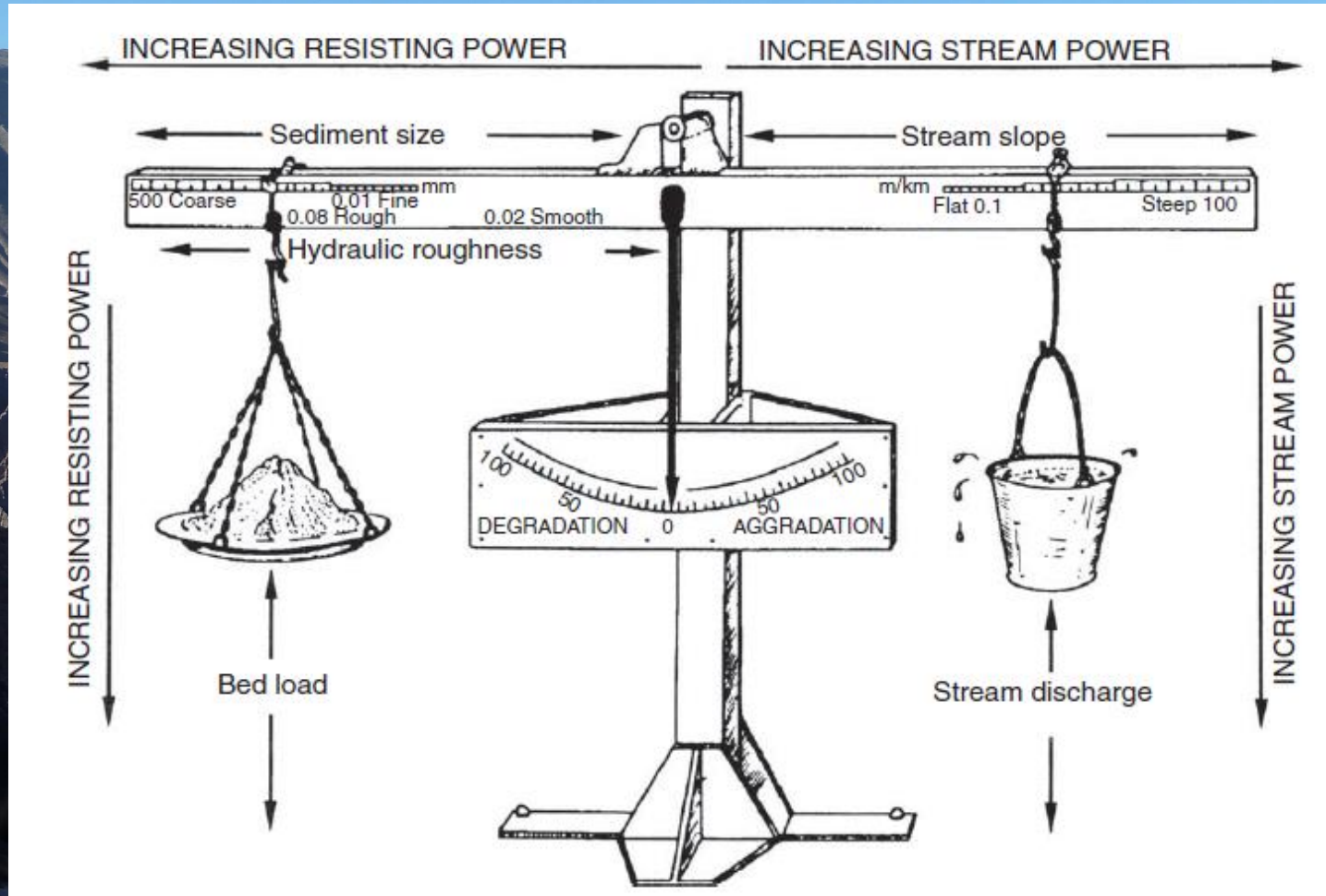
Sediment production, general aridity
and channel aggradation

$$Q_s > Q_c$$

Warm-climate conditions

More rainfall, less sediment supply
and channel incision

$$Q_s < Q_c$$



Climate Change, Incision and Terraces

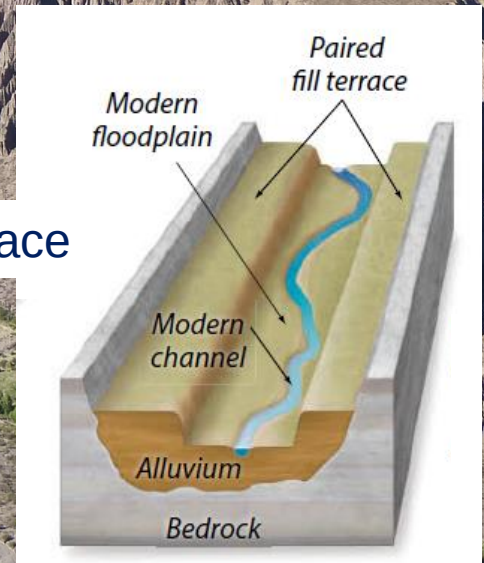
- **Fill Terraces** vs Straths
- Tectonics vs Climate...
- Uplift = Slope change = stream power ?
- Climate change = more rain = stream power ?

4000 m asl = $\sim 0^{\circ}\text{C}$ mean annual temp. = intense frost dynamics = sediment production



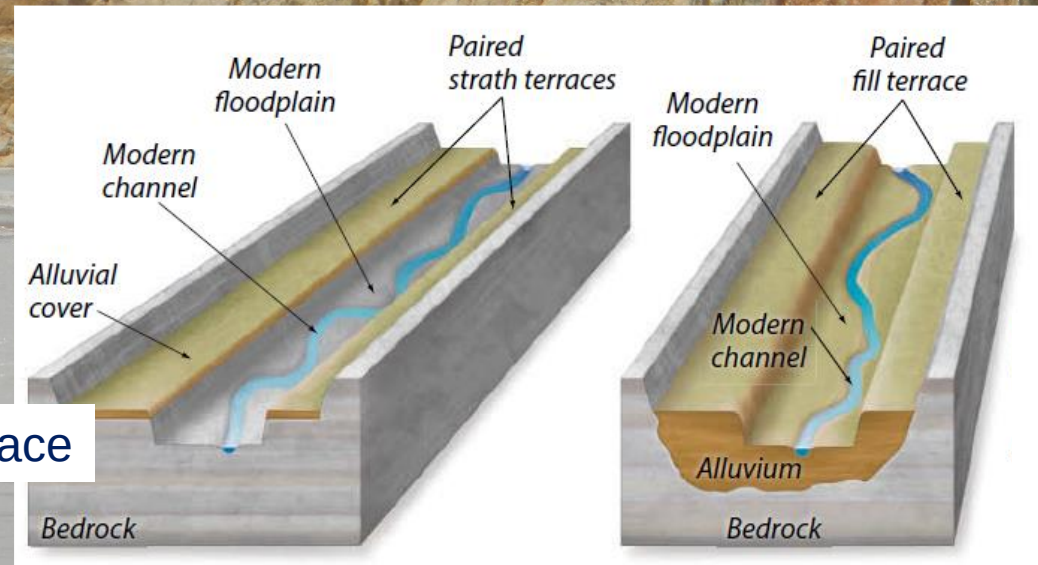
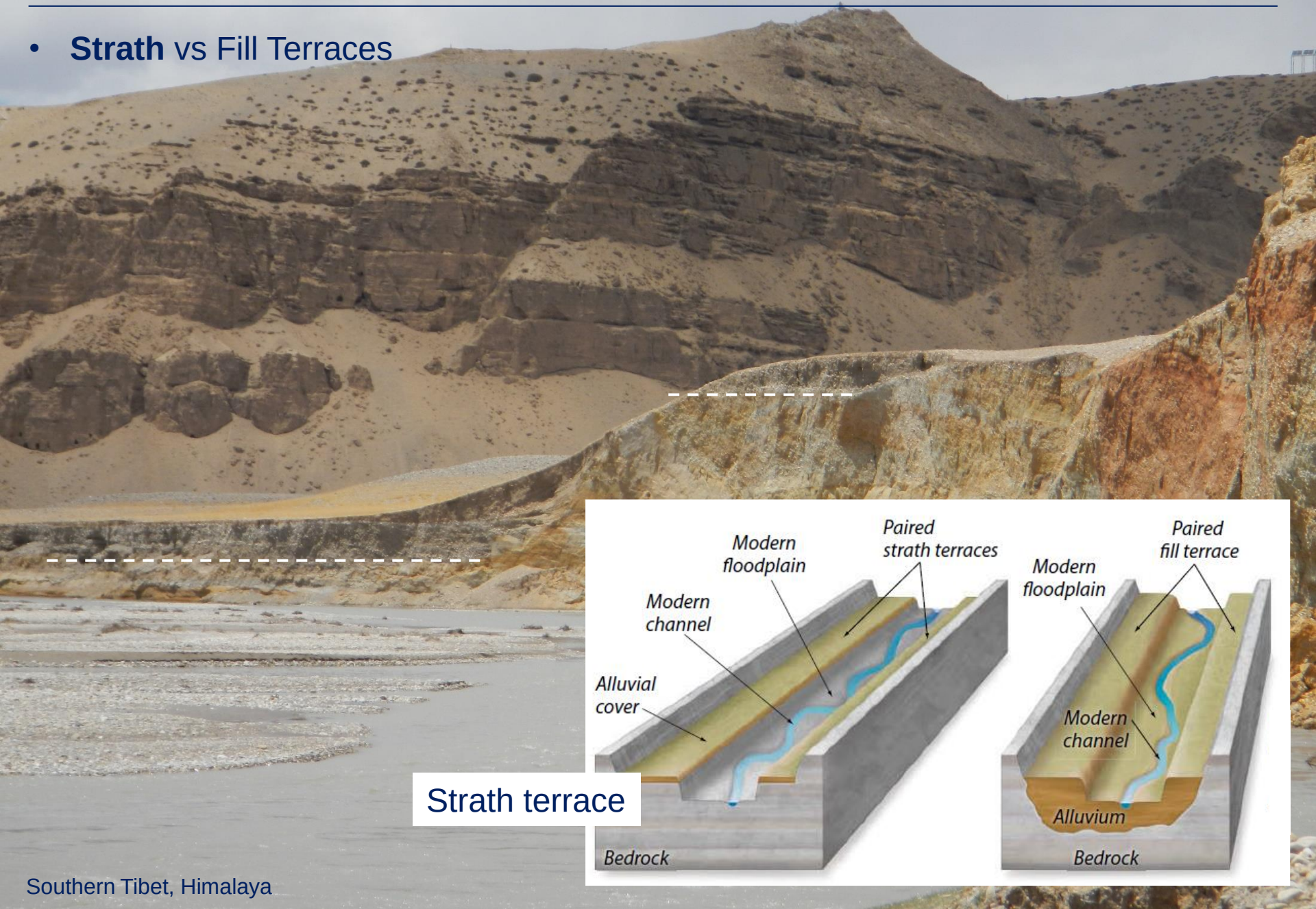
Last cold stage (20-100 ka)

Fill terrace



Climate Change, Incision and Terraces

- Strath vs Fill Terraces



Strath terrace

2 minutes...



River longprofile

- What causes 'bedrock rivers' & why do they predominate in mountain regions?

1

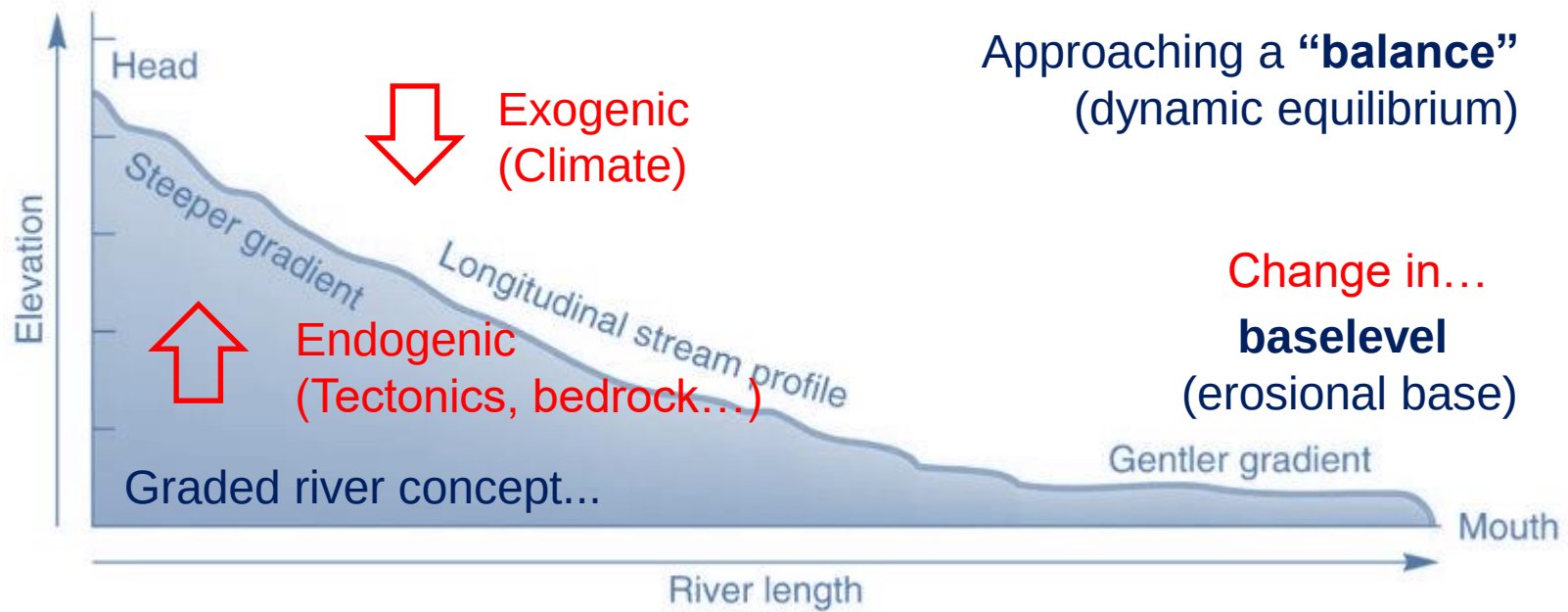
Bedrock rivers: $Q_c > Q_s$ (i.e. excess power)

>50% 'bedrock' exposed, minimal sediment storage (frequent flushing), steep headwaters, high Ω

2

Alluvial rivers: $Q_s > Q_c$

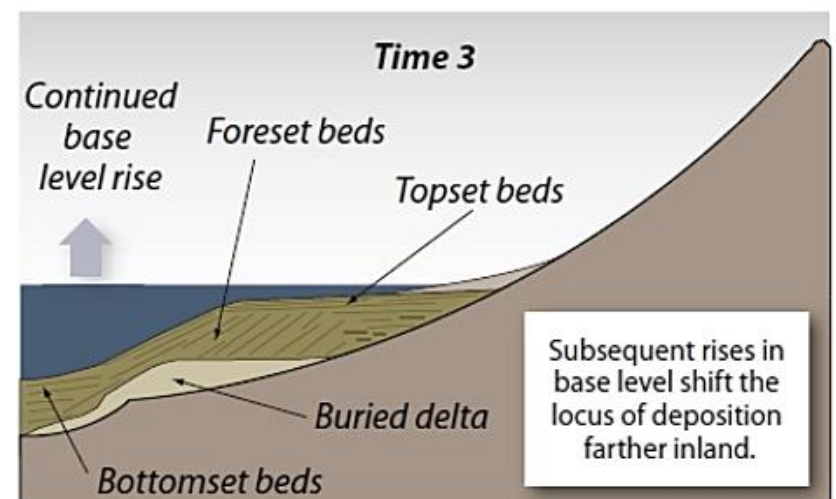
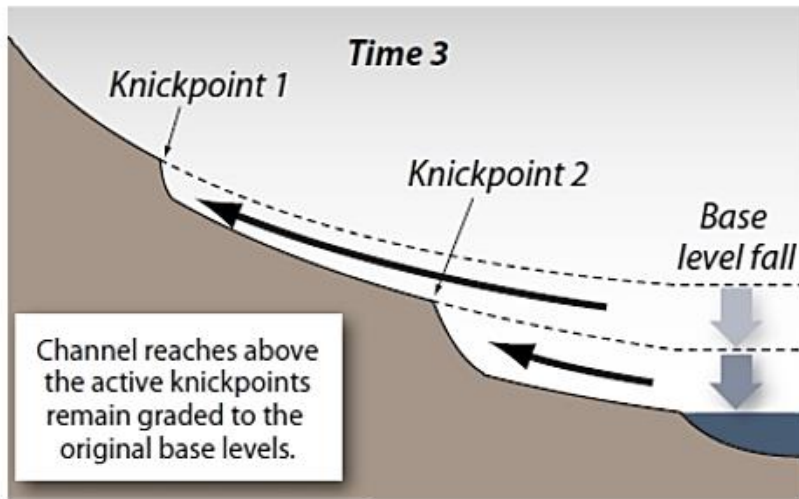
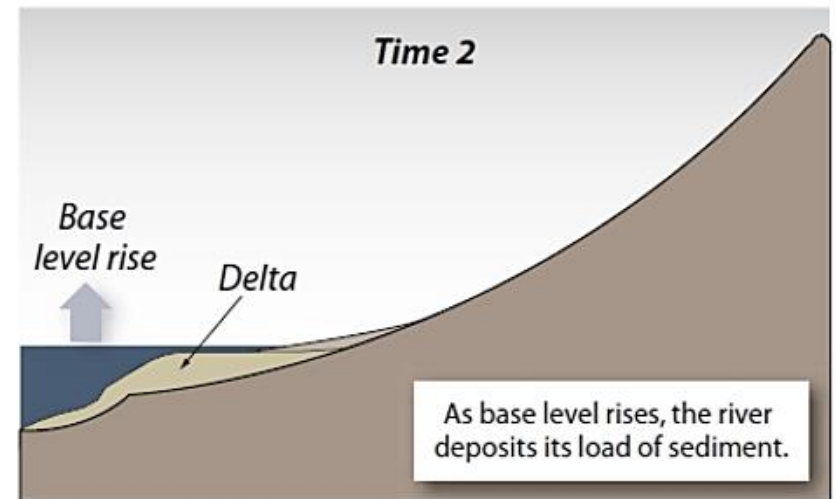
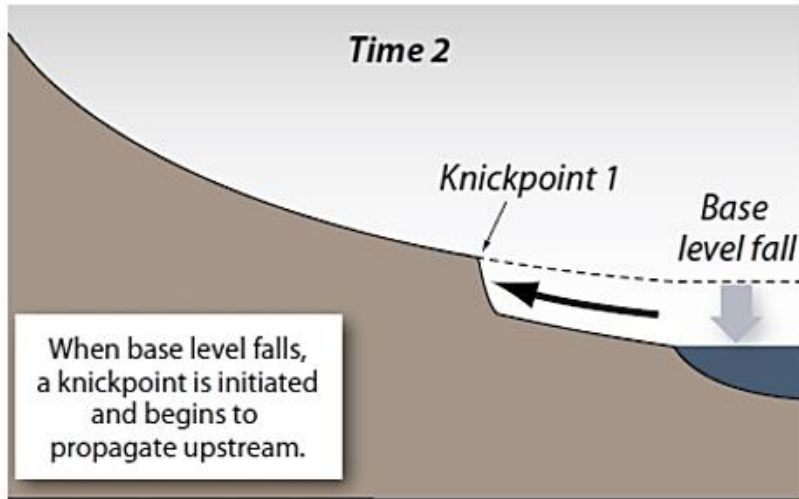
sediment storage in floodplains - lowlands, high Q , low S



- Rivers** only want the energy to transport their water and supplied sediment to ocean basins, and nothing more!

Baselevel change

- Longprofile trying to approach a “**balance**” (dynamic equilibrium)

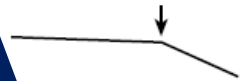


- Rapid change in slope (“**knickpoints**”) = ‘hotspots’ of erosion

Knickpoints...

Break-in-gradient knickpoints

A

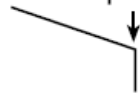


cohesive
substrates

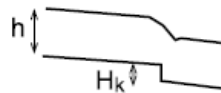
non-cohesive
substrates

Break-in-elevation knickpoints
(vertical knickpoints)

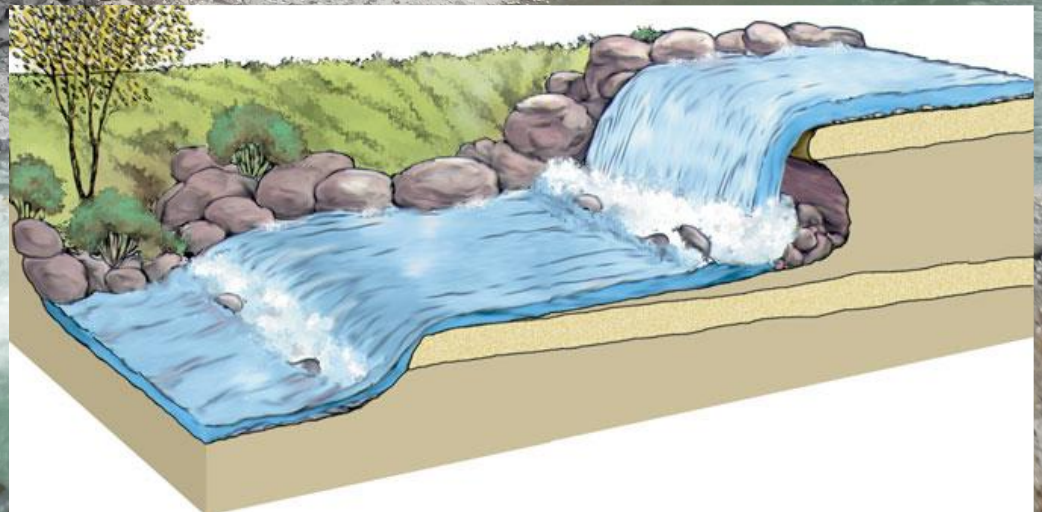
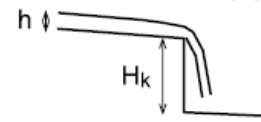
B



knickpoint height (H_k)
 $\leq$ flow depth (h)



knickpoint height (H_k)
 $\gg$ flow depth (h)

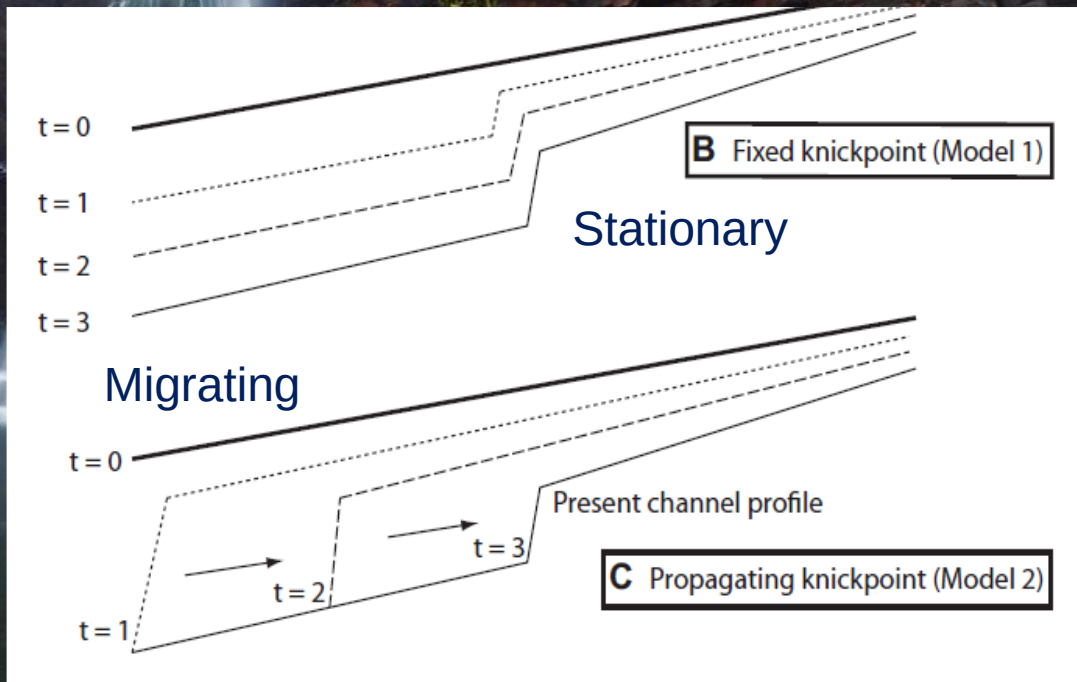
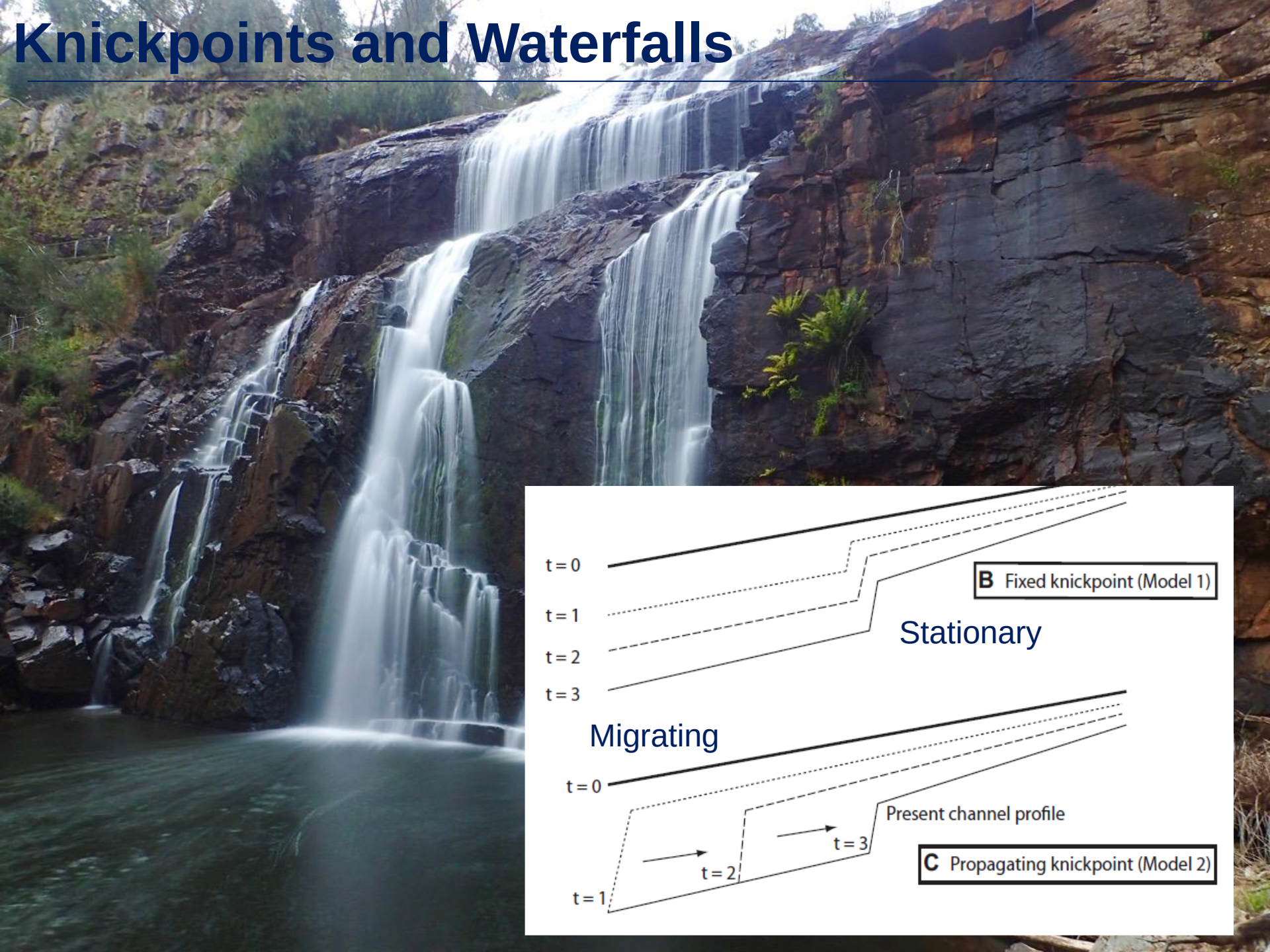


Knickpoints and Waterfalls

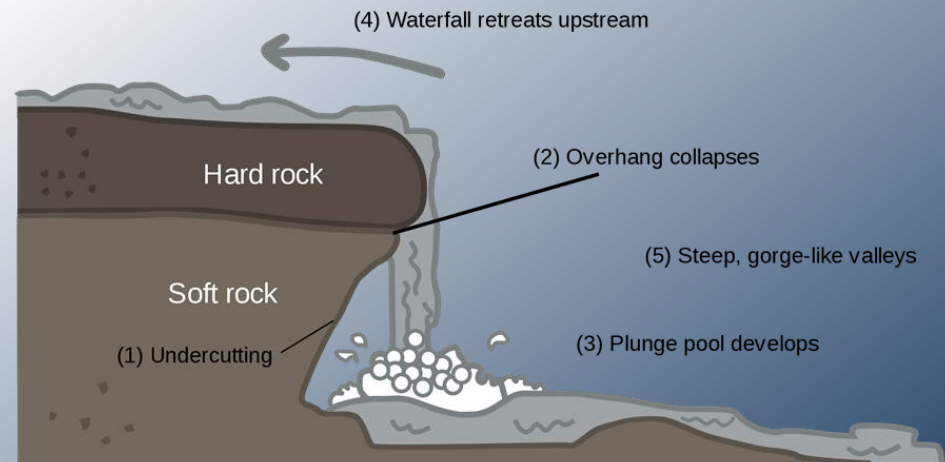
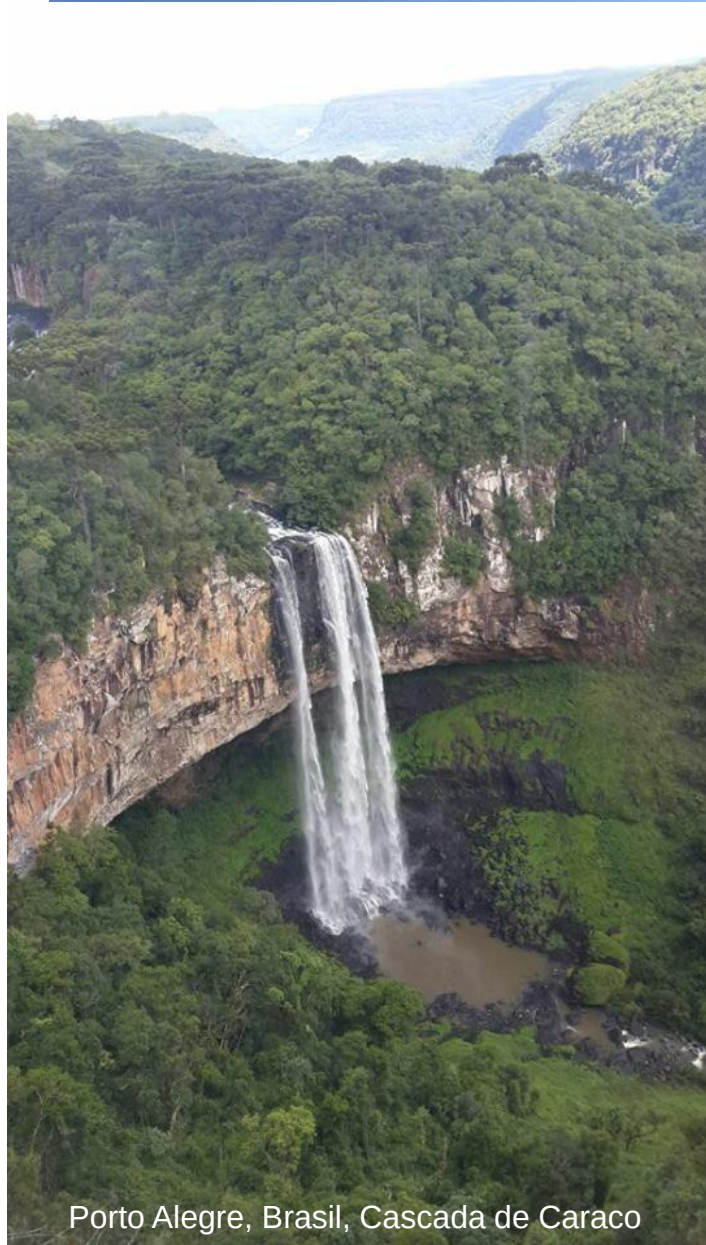


Angel Falls, Venezuela

Knickpoints and Waterfalls



Knickpoints and Waterfalls

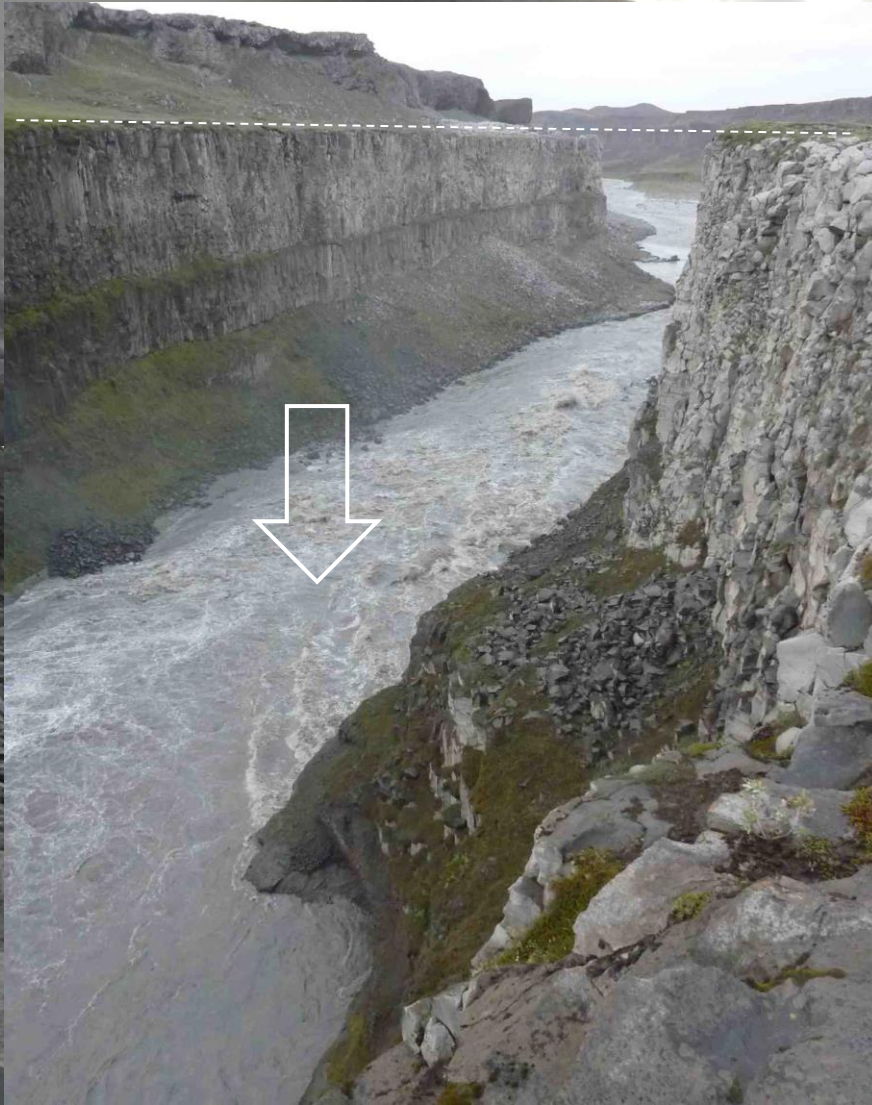


Knickpoints and Waterfalls

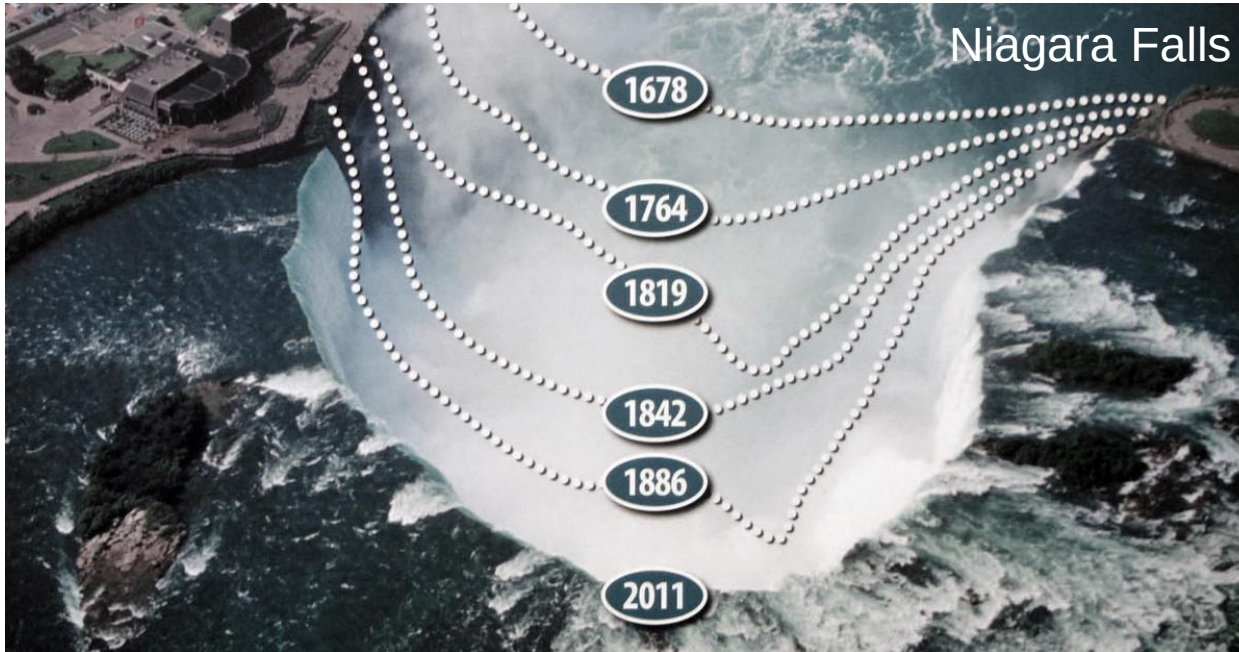


Iguazu Falls, Argentina
resistant bedrock steps ~ lithogenic knickpoints

Baselevel controls...



Knickpoints Migration



- Headward migration of knickpoint
- 0.3 m/yr (0.91 m/yr historically)
- Expected lifetime of 50.000 yrs

- Adjustment to new baselevel: **Transient landscapes** (headward propagation...)
- Rapid initial knickpoint propagation rates, which decline as drainage area decreases stepwise at tributary junctions
- Transmission of **information** (event of base-level change in the past)

<https://youtu.be/B3FOBcOKmok>

Bedrock and Mountain Rivers....

- Bedrock rivers occur where $Q_c > Q_s$
- Erosion proceeds via plucking, abrasion & solution
- Bedrock erosion rate, $E = f (Q, S, q_s, K)$
- Knickpoint retreat is the key mechanism for transmitting base level fall
- Sediments exert strong control on rates & processes of bedrock erosion via 'tool & cover effect'

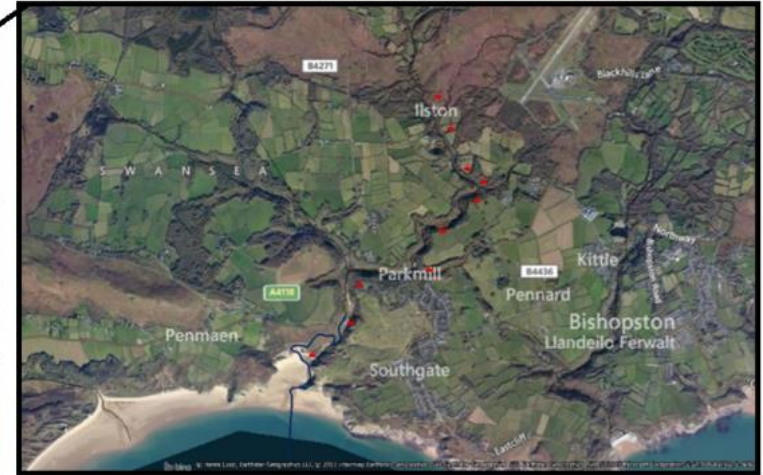


Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

River Ilston Assignment

Dr Alissa Flatley
ACNA4007 – Physical Landscape and the Geosphere

Logistics....



[Directions – Three Cliffs Parking \(threecliffscarpark.co.uk\)](http://threecliffscarpark.co.uk)

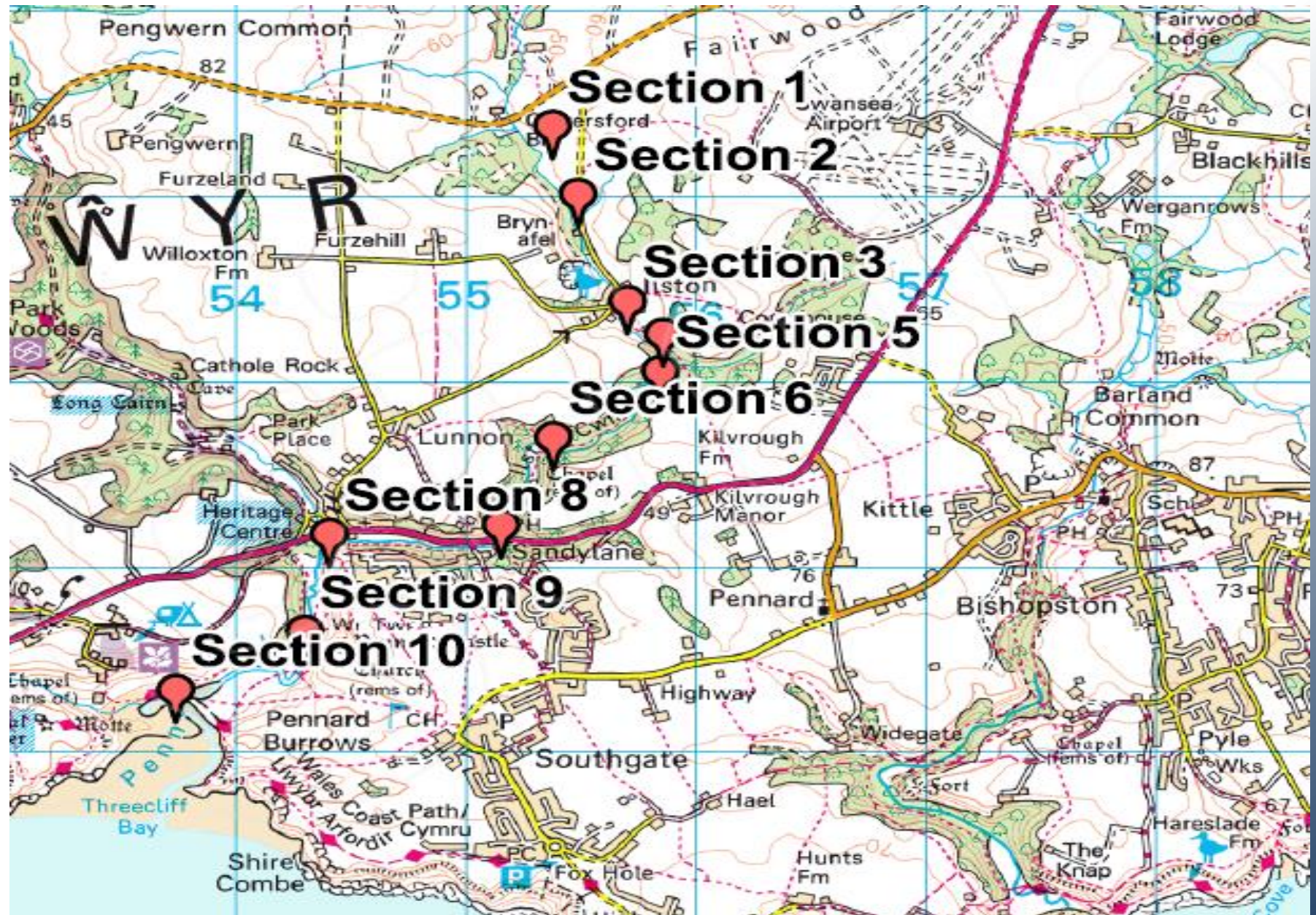
- Parking at the Gower Heritage Centre

[Parking & Entry - Gower Heritage Centre](#)

Logistics....

- Monday 6th November – Field day
- Data will be provided in the case of poor weather
- Create field groups (x2)
- Review assignment

Logistics....



Logistics....



Logistics....



Logistics....



Logistics....

