143SRPP

Stream Revitalization: Principles & Practices

LECTURE 2

Fluvial Geomorphology

Fluvial Systems: Watersheds, Hierarchical Structure, Morphological Forms, and Scale Characteristics and Classifications

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Fluvial Geomorphology

Fluvial Geomorphology is the study of landforms and the processes that shape them by the *transport of water and sediment* through a drainage network.

River Mechanics is the branch of fluvial geomorphology that quantifies the relationship between process and form in rivers and streams. Relationships are developed through a combination of field observations, physical experiments, and numerical modeling.





Fluvial Geomorphology

Fluvial Geomorphology is the study of landforms and the processes that shape them by the transport of *water and sediment* through a fluvial system.

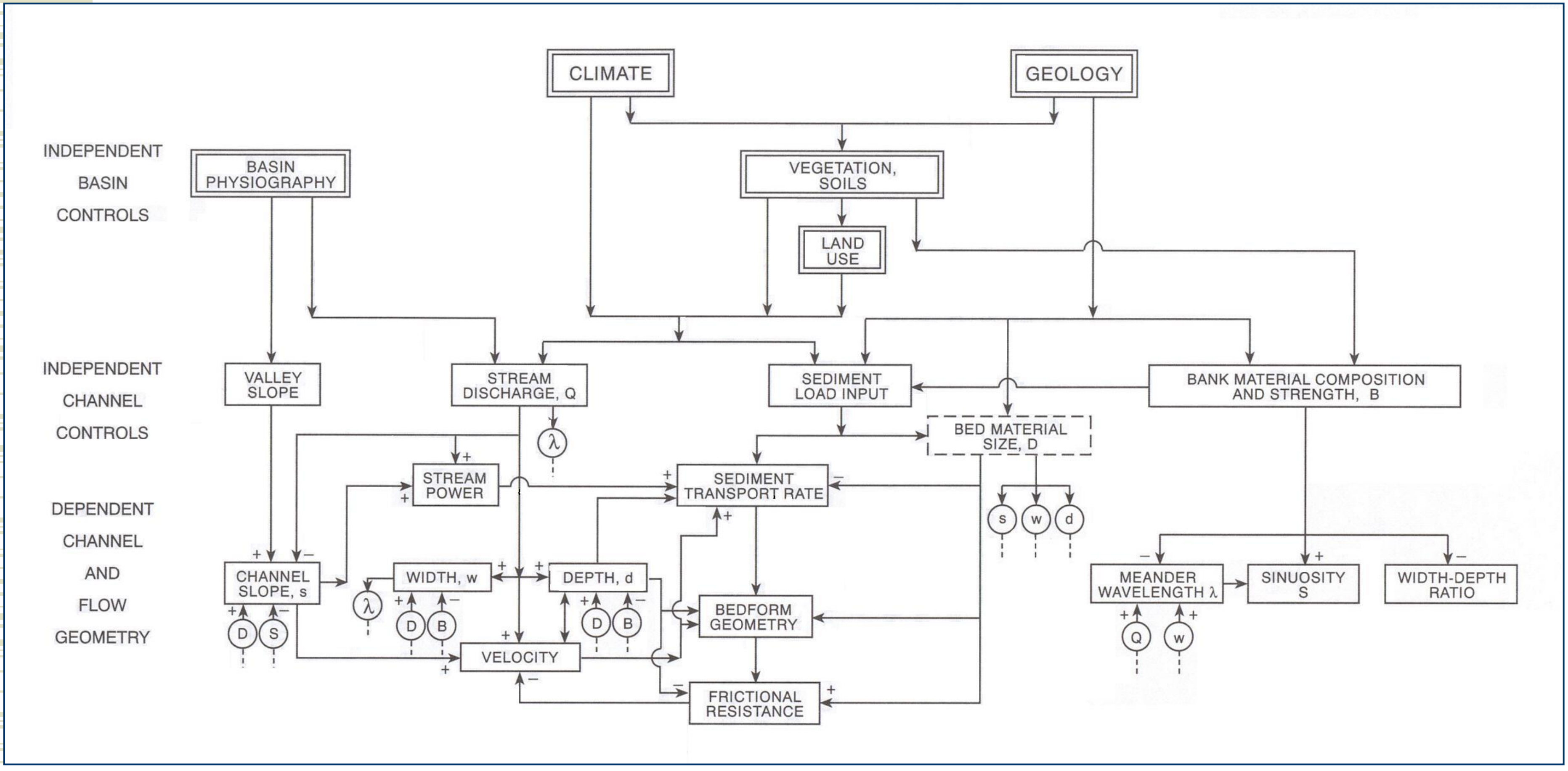
Fluvial forms: structural patterns of landforms at various spatial scales, from watersheds to channel bedforms.

Fluvial processes: the action when a hydraulic force from moving water induces a landform change by transporting sediment (erosional degradation) and/or lack of force causing sediment deposition (aggradation).

Hydraulic forces are dependent on flow, slope, landform\channel roughness (flow resistance) influencing local degradation and aggradation.

Classic Reference: Knighton, D. 1998. Fluvial Forms and Processes: A New Perspective. Taylor and Francis Group, London. 383 p.

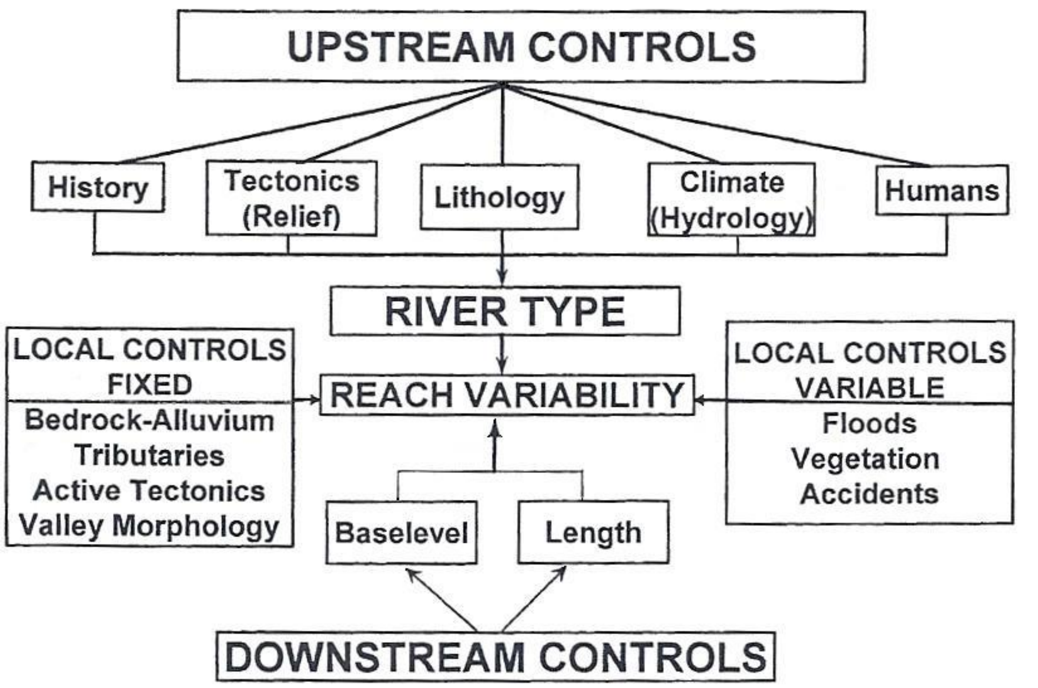
Fluvial Systems: Dominant Controls



Knighton (1998)

Fluvial Systems: Dominant Controls

Fluvial System landforms are dependent on dominant upstream and/or downstream controls.



Fluvial Processes

Vertical adjustment processes: knickpoint migration

Schumm (1977, 2005)

Fluvial Systems: Dominant Upstream Controls

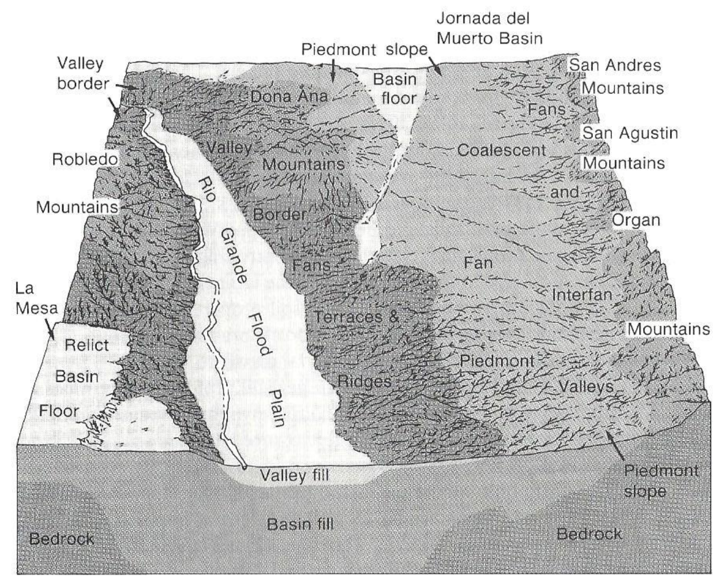
The naming of a **lithology** is based on the rock type: three major types: sedimentary, igneous, and metamorphic.

Lithology may be either a detailed description of these characteristics or be a summary of the gross physical character of a rock.

Other definitions

Alluvial deposition zones occur at breaks from mountainous regions into valleys and tributary junctions.

Piedmont is a landform created at the foot of a mountain or mountains by debris deposited by shifting streams.



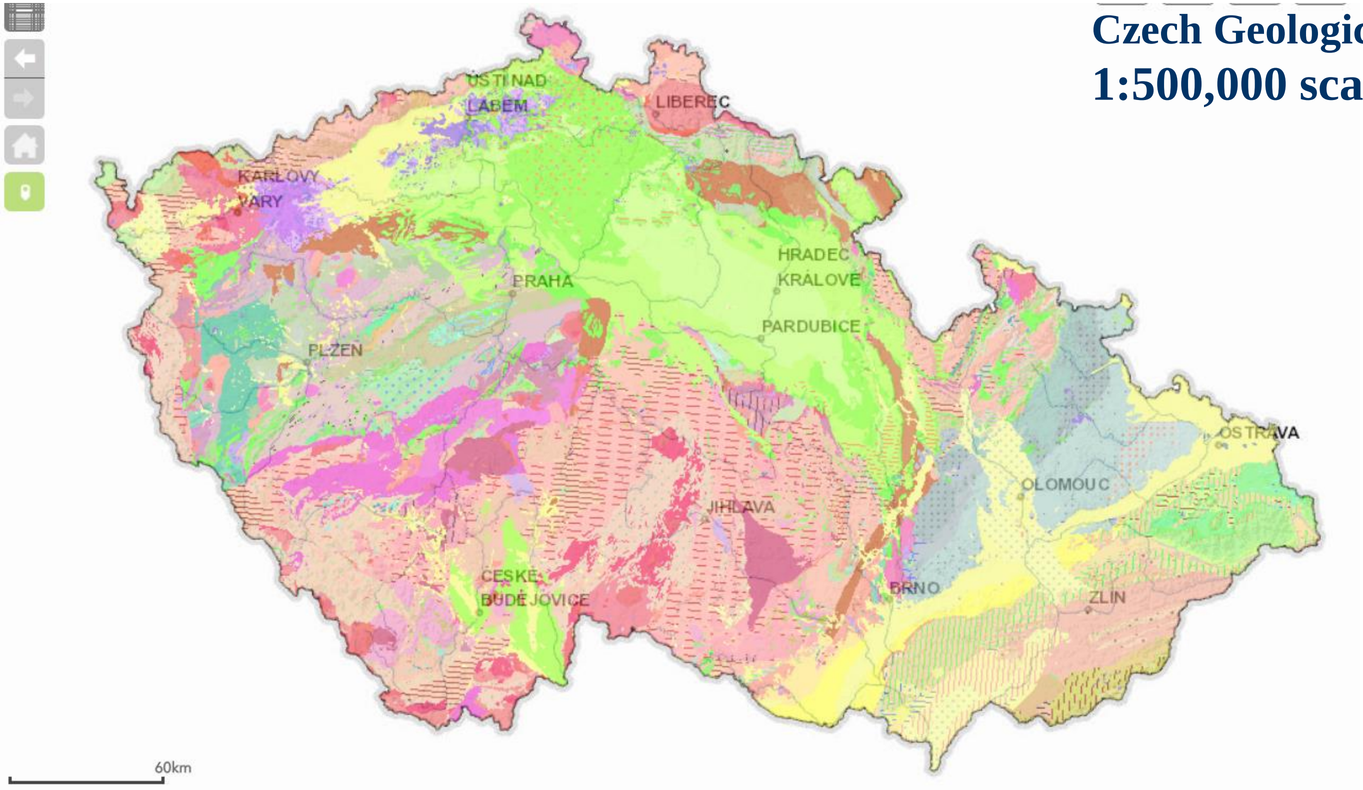
Landforms / Geological Controls
New Mexico, USA (Ritter 1986)

Knighton (1998)

Fluvial Systems: Dominant Upstream Controls

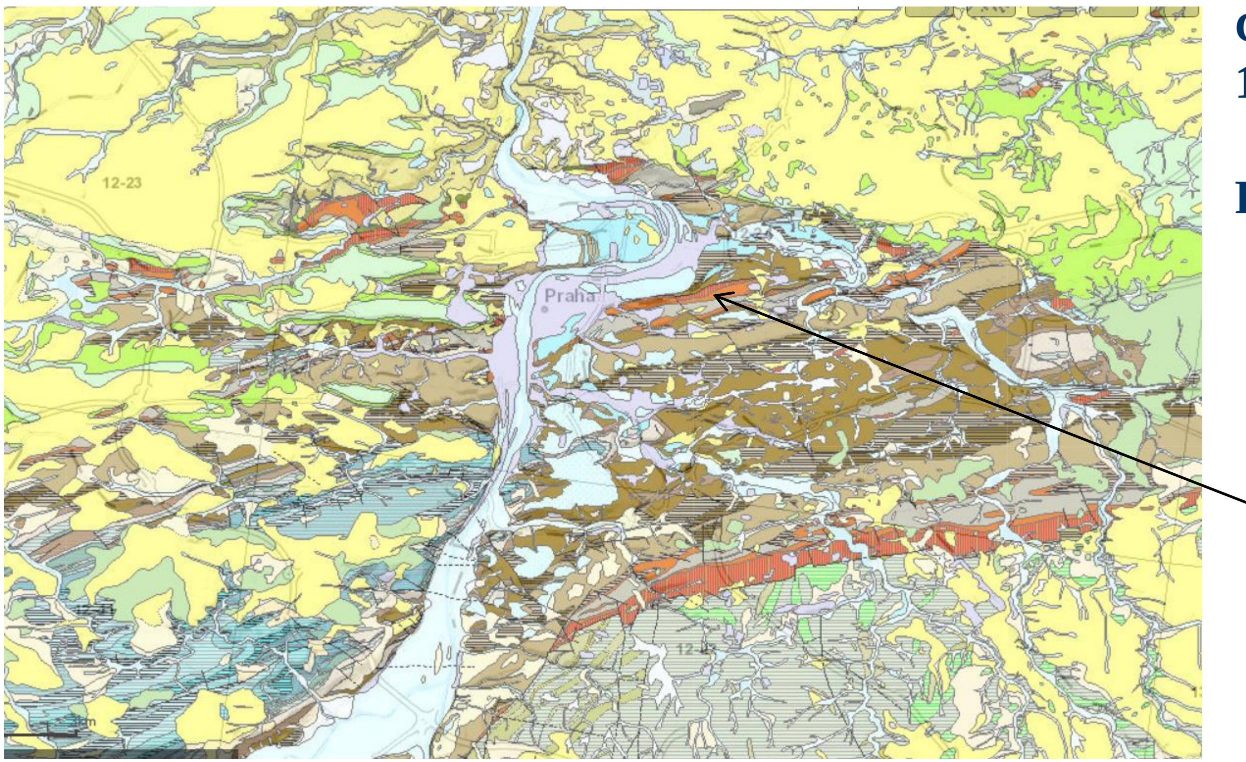
Geology: Tectonics (relief) and Lithology

Source:
Czech Geological Survey
1:500,000 scale



Fluvial Systems: Dominant Upstream Controls

Geology: Tectonics (relief) and Lithology

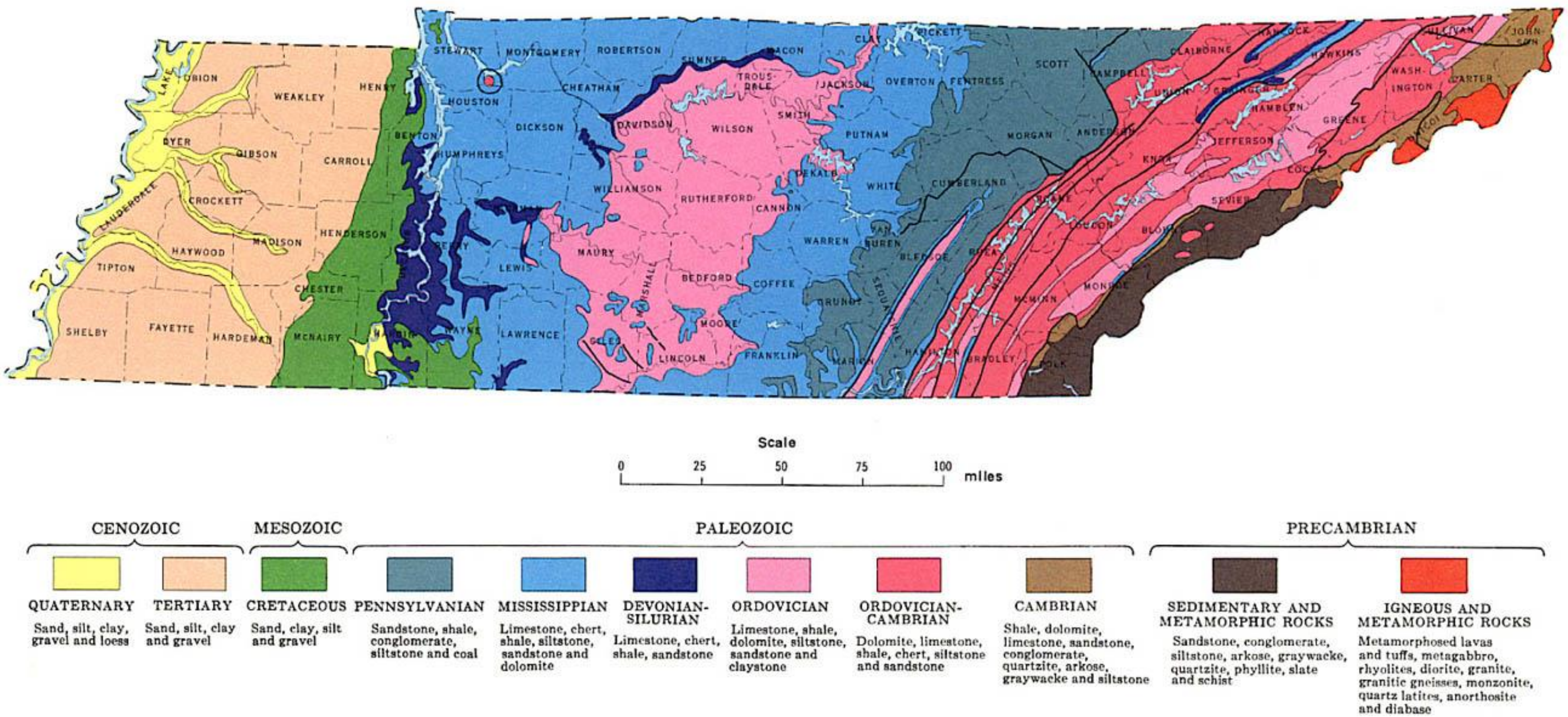


Source:
Czech Geological Survey
1:50,000 scale

Praha

Fluvial Systems: Dominant Upstream Controls

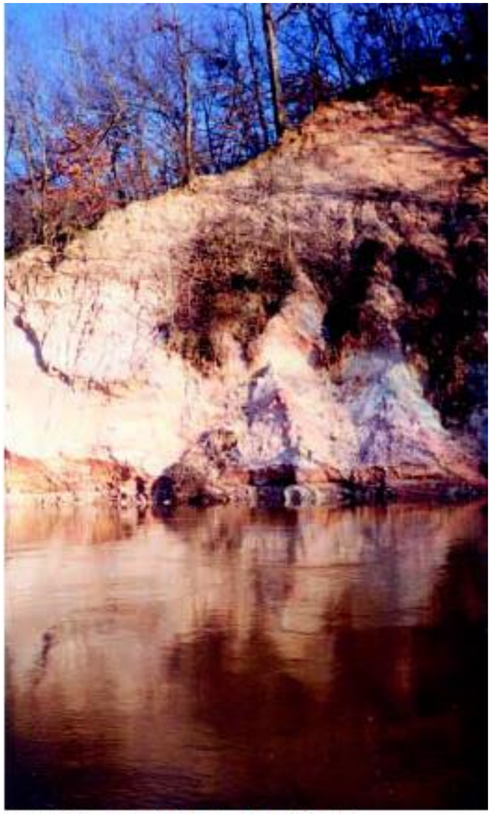
Geology: Tectonics (relief) and Lithology -- State of Tennessee, USA



GENERALIZED GEOLOGIC MAP OF TENNESSEE

Fluvial Systems: Dominant Upstream Controls

Geology: Tectonics (relief) and Lithology -- State of Tennessee, USA


High bluff along Hatchie River showing sand formation.

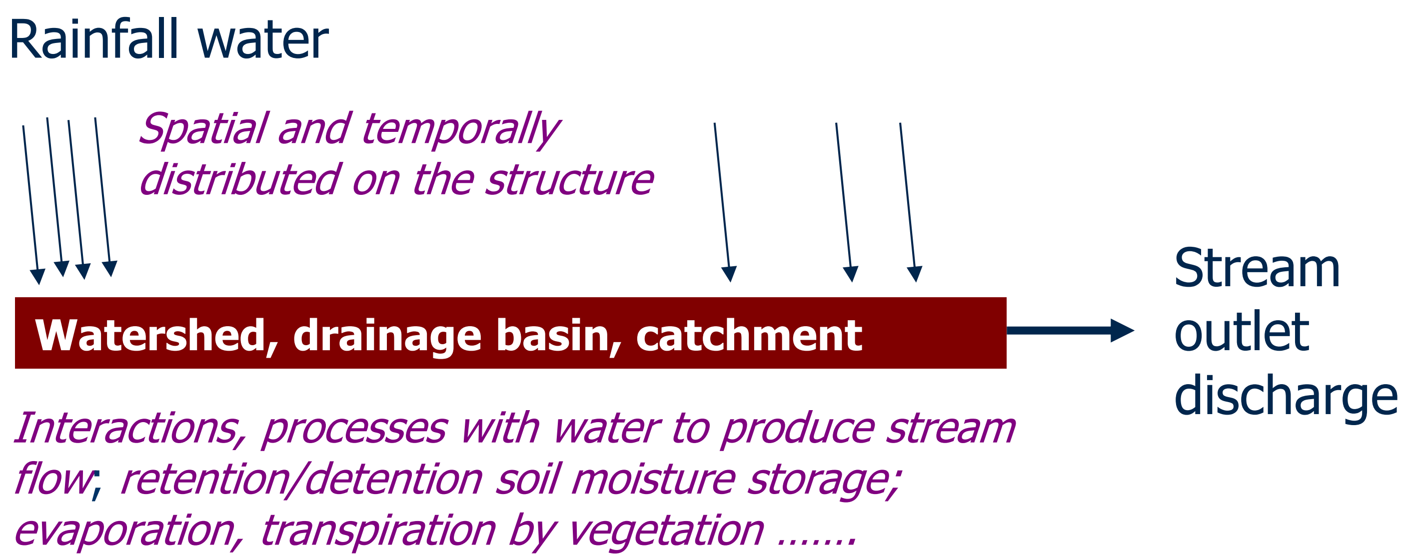
West TN - Quaternary


Sand-laden tributary, Muddy Creek, near Hatchie Station, Tennessee.

Hydrologic Systems: Climate and Hydrology
Dominant Upstream Controls: A Review

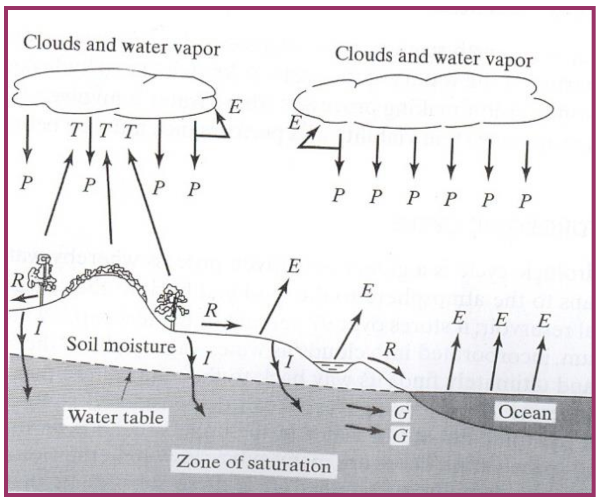
Hydrologic System

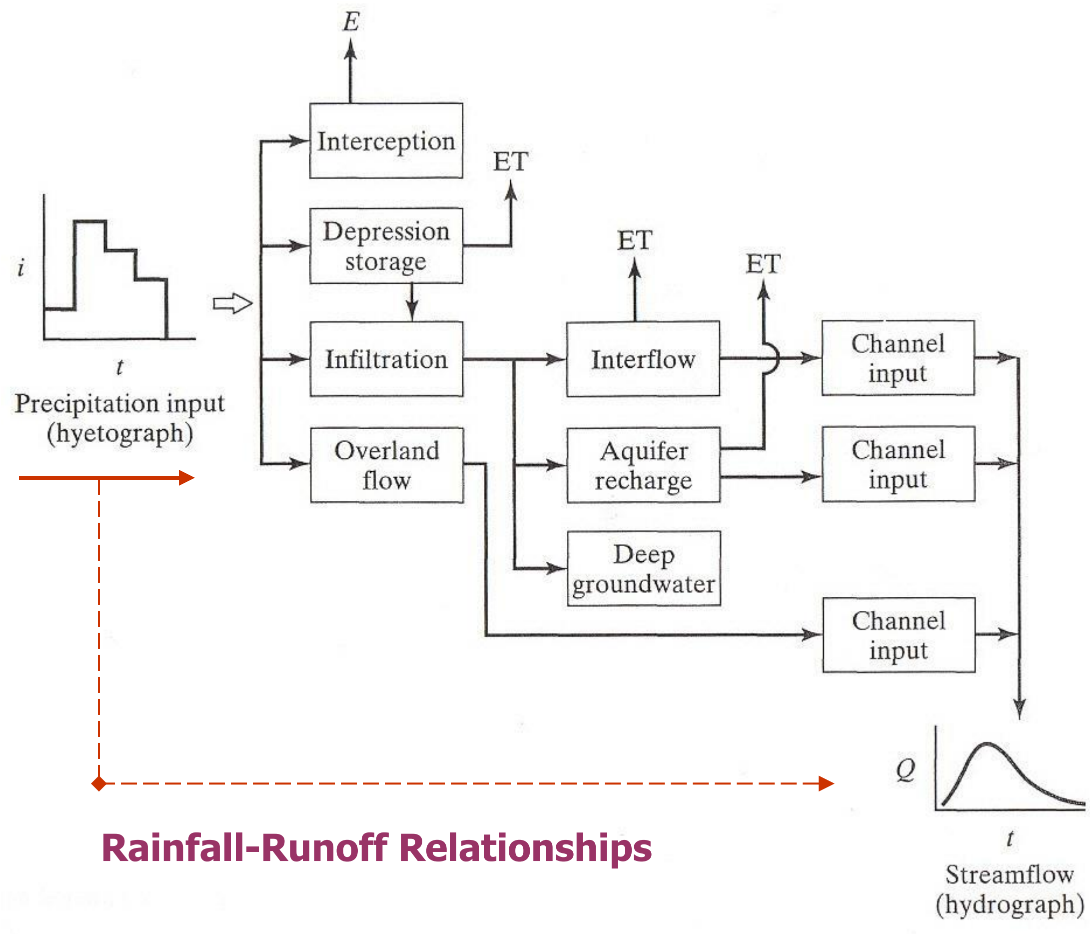
A hydrologic system is defined as a **"structure"** in space with a boundary, that accepts a **"working medium"** -- water and other inputs (air, heat energy, organic matter, chemical ions) operating internally on them to produce transformed outputs.



Hydrologic Systems: Climate and Hydrology
Dominant Upstream Controls: A Review

Distribution of precipitation input in the water budget





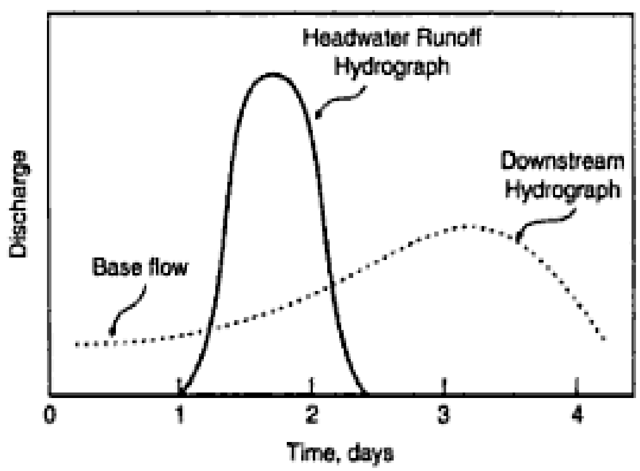
Rainfall-Runoff Relationships

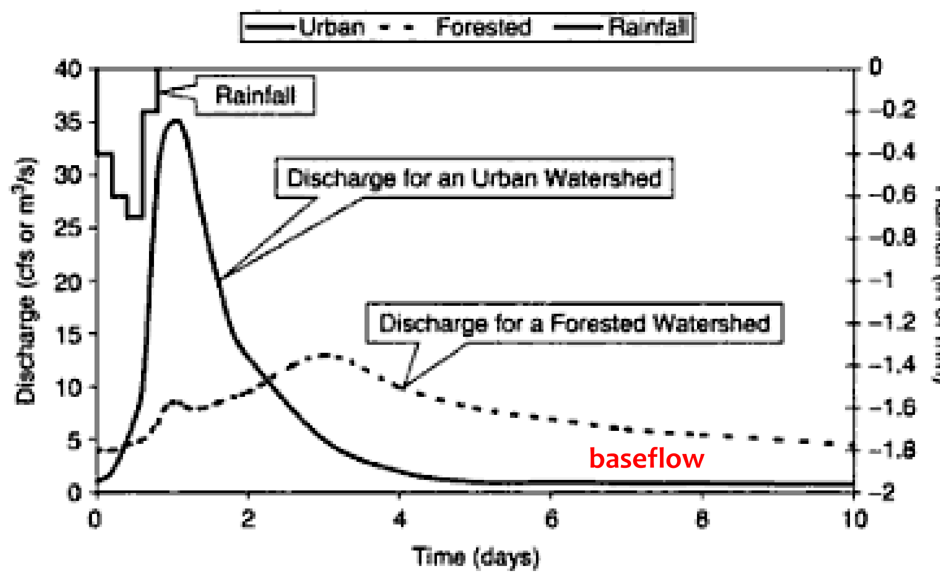
Viessman & Lewis (2003)

Hydrologic Systems: Hydrology and Land Use
Dominant Upstream Controls – A Review

Runoff Concepts: Stream Hydrographs

Headwater vs downstream hydrographs





Urban vs forested watershed hydrographs

Wards and Trimble (2003)

Fluvial Systems: Dominant Controls

- **Watersheds are the fundamental spatial unit in fluvial geomorphology**
- **Drainage network patterns reflect form and process relationships.**

Geomorphic character is dependent on:
Geology (valley shape, bank/bed material, knickpoints), watershed and riparian vegetation, channel slope, hydrology (climate), sediment supply and size, watershed position (stream order).

Fluvial Processes:

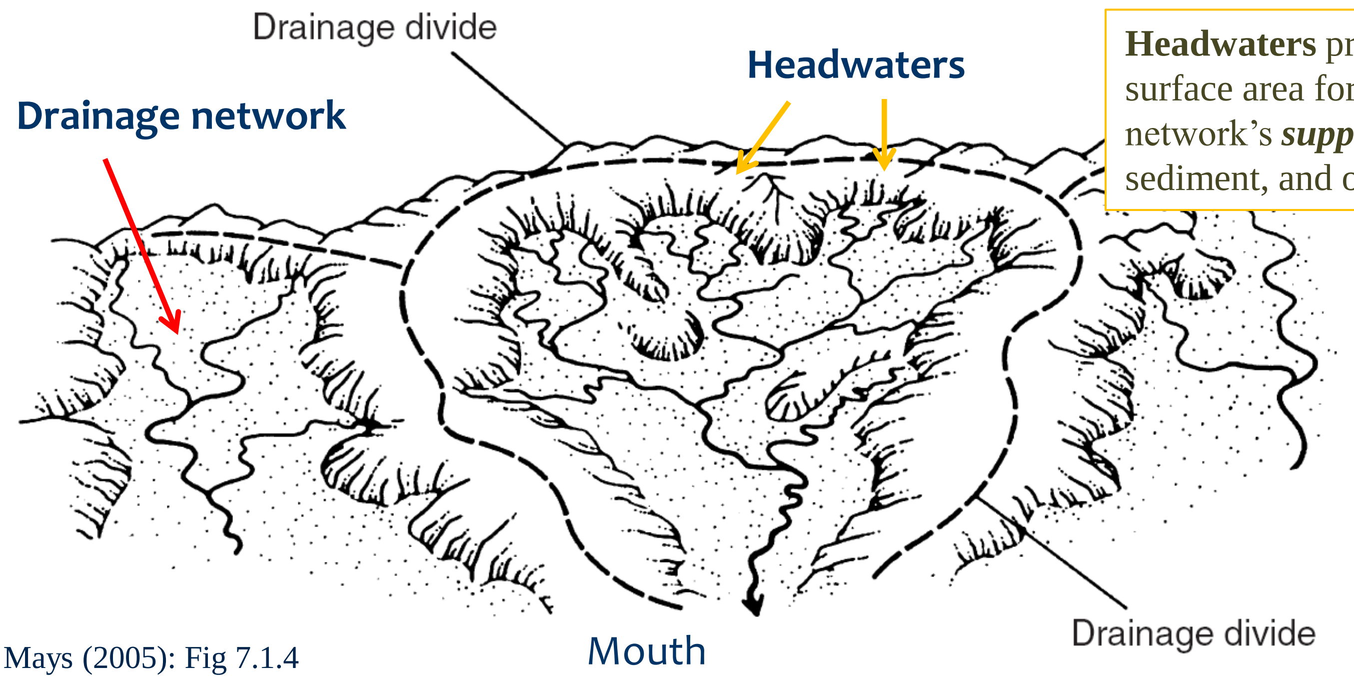
Force vs Resistance
Erosion vs Deposition

Beaver Creek, Knox County, Mill Run Section

Fluvial Systems: Watersheds

Watersheds: *…..the fundamental unit*

A watershed is a topographic area
that collects water, sediment and organic matter, and discharges of stream flow with transported materials through an outlet or mouth.



Headwaters provide largest surface area for a drainage network's ***supply of*** water, sediment, and organic matter.

Mays (2005): Fig 7.1.4

Fluvial Systems: Watersheds

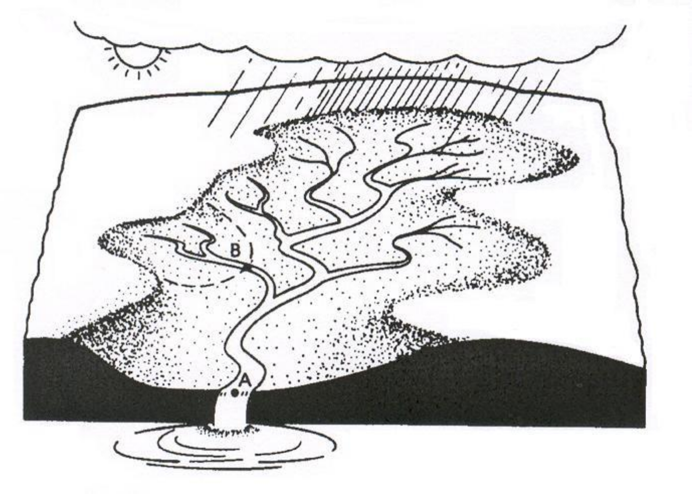
The watershed, the functional unit of all hydrologic and geomorphic analyses.

Watershed geomorphology refers to the physical characteristics of the watershed.

Common measures for watersheds ≤ HUC8

Watershed Characteristics:

1. Drainage Area
2. Length (longest flow path)
3. Slope (elevation difference of flow path)
4. Shape
5. Drainage density (stream length / area)



Knighton (1998)

Fluvial Systems: Watersheds

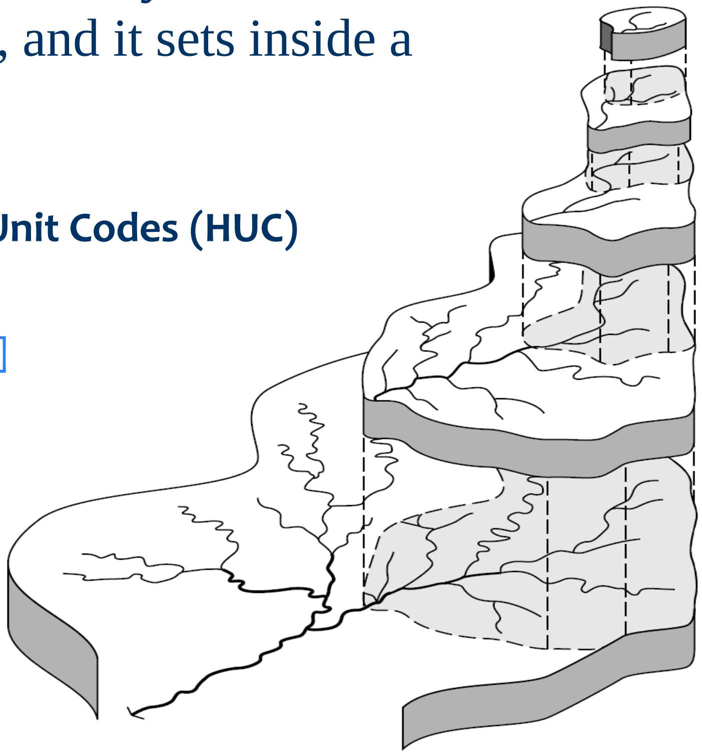
Watersheds are organized as a **nested hierarchy**, as each small watersheds sets inside a larger one, and it sets inside a larger one and so on …….

Used by the US Geological Survey: **Hydrological Unit Codes (HUC)**

watershed/stream identification numbers

[http://nwis.waterdata.usgs.gov/tutorial/huc_def.html]

2-digit HUC first-level (region)
4-digit HUC second-level (subregion)
6-digit HUC third-level (accounting unit)
8-digit HUC fourth-level (cataloguing unit)
10-digit HUC fifth-level (watershed)
12-digit HUC sixth-level (subwatershed)

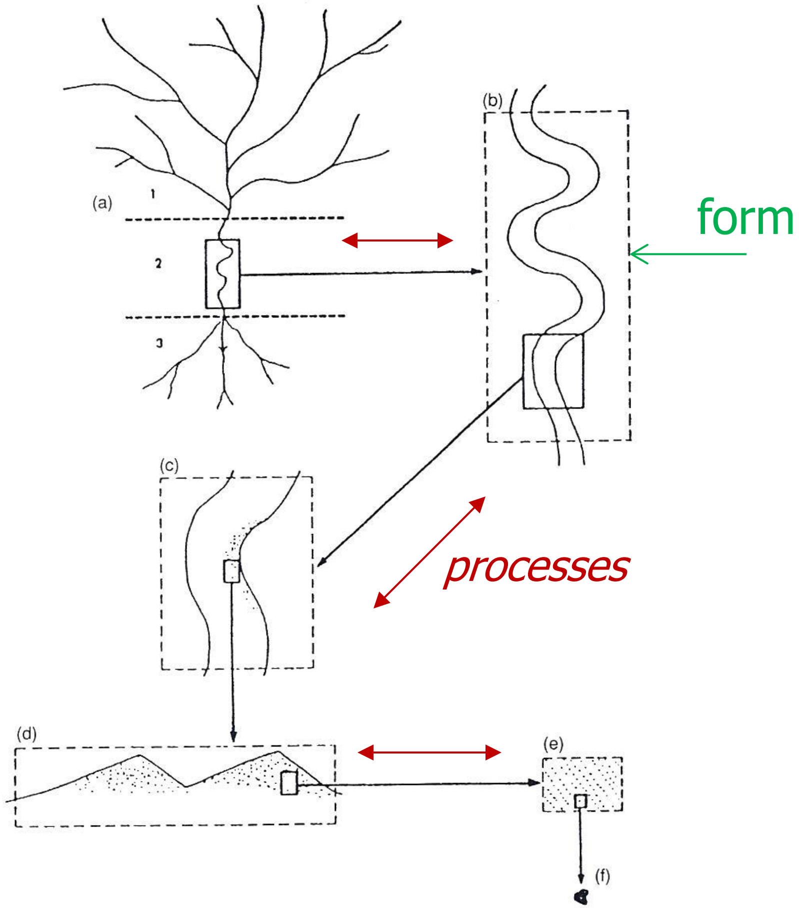


Mays (2005): Fig 7.1.5

Fluvial Systems: Spatial Scales

Fluvial Systems can consider landforms at different spatial scales with the largest scale starting with the **watershed/drainage network**, and hierarchically reducing in scale to a **segment/valley scale** and/or **reach channel/planform**, **bar unit** (pool-riffle-bar elements), **bedforms**, and then to the channel bed **sediment particle**.

~ hierarchically nested

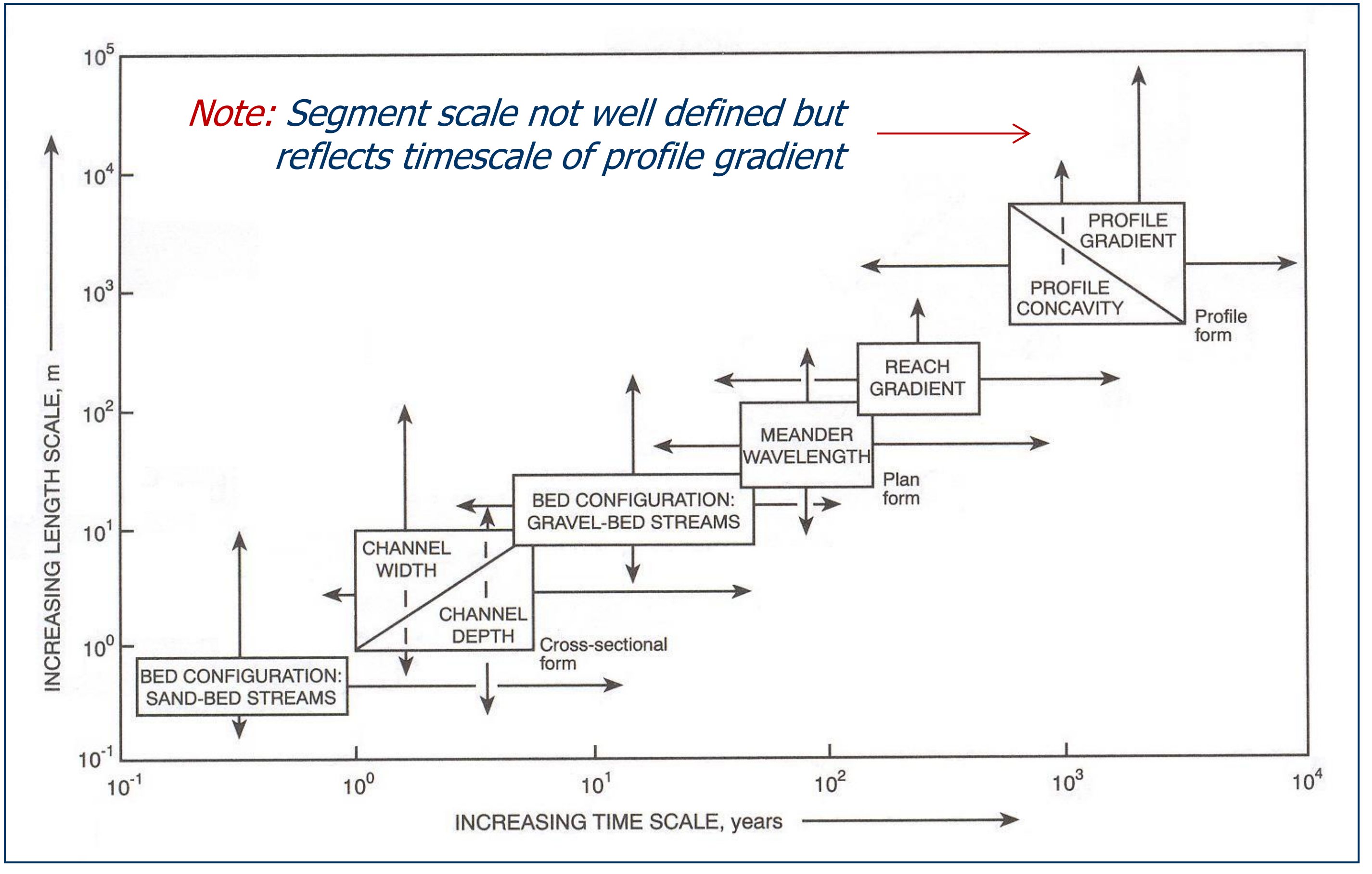


Schumm 1977, 2005;
Frothingham et al. 2002

Fluvial Systems: Spatial Scales

Fluvial Spatial Scaled and Process Timescales:

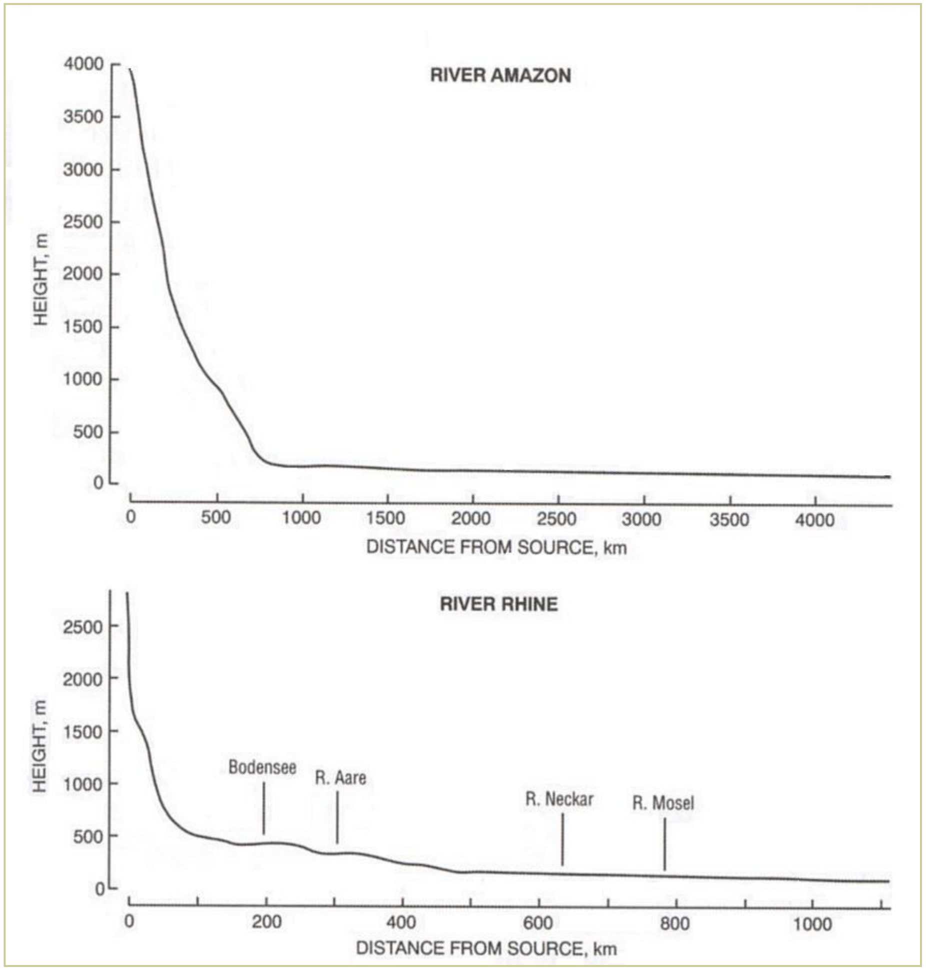
Timescales of various channel form components related to spatial scale of fluvial processes and form adjustment:



Knighton (1998)

Drainage Network: Longitudinal Profile

Examples



Watershed Longitudinal Profile

Elevation vs Distance

headwaters 0 m → downstream to mouth

Concave Upward Shape

~ a function of discharge and sediment transport (increase)

Bed Sediment

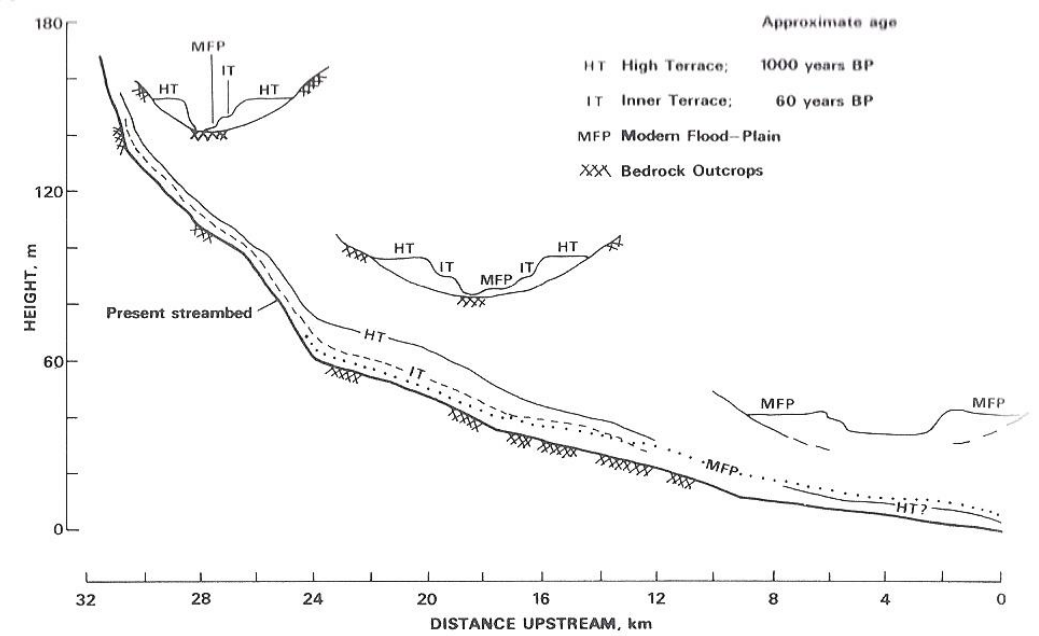
~ bed material size decreases in downstream direction; abrasion and selective sorting of sediment

Knighton (1998)

Drainage Network: Longitudinal Profile

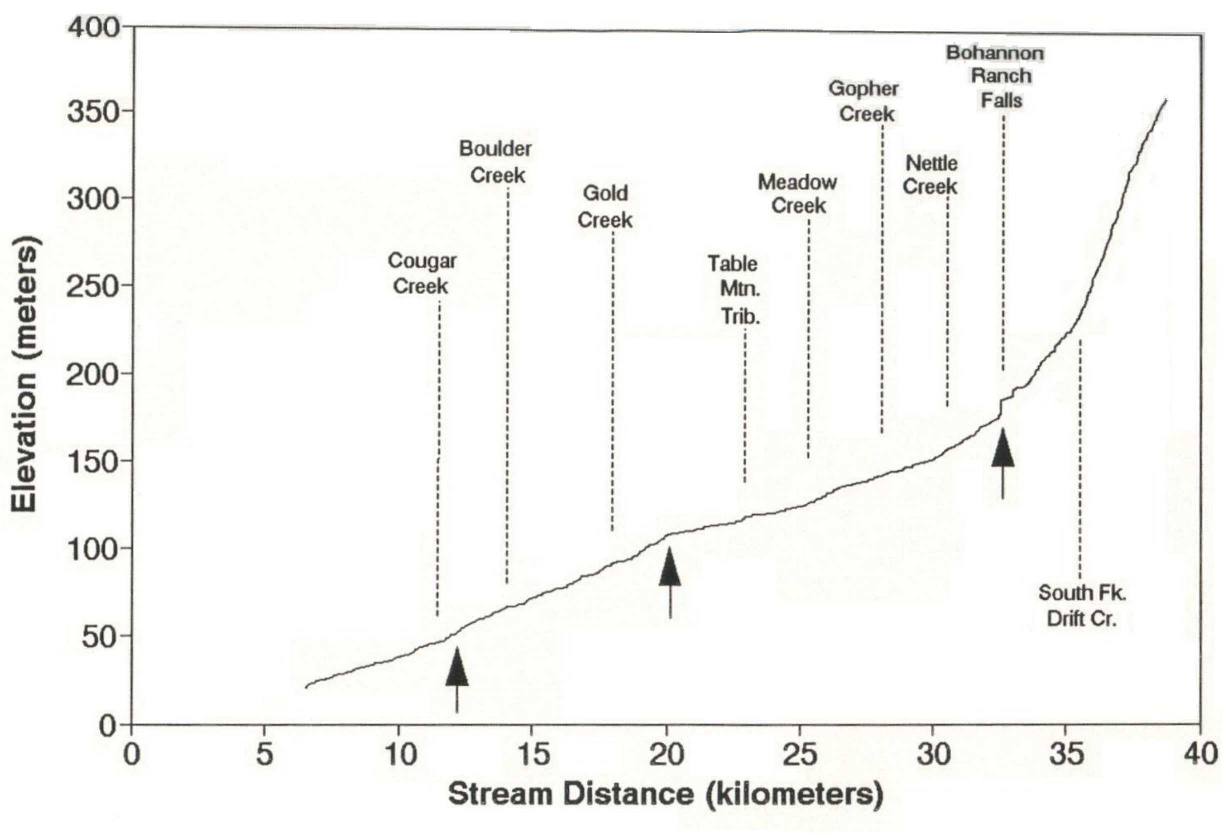
Profile concavity: influence of hardpoints and lithology

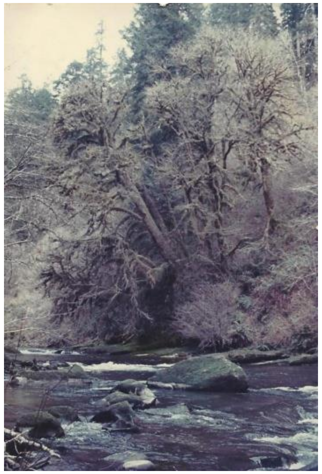
- Profiles more concave bed material decreases in size downstream
- Profiles less concave bed material remains constant in size downstream



Knighton (1998)

Drainage Network: Longitudinal Profile





geologic knickpoints

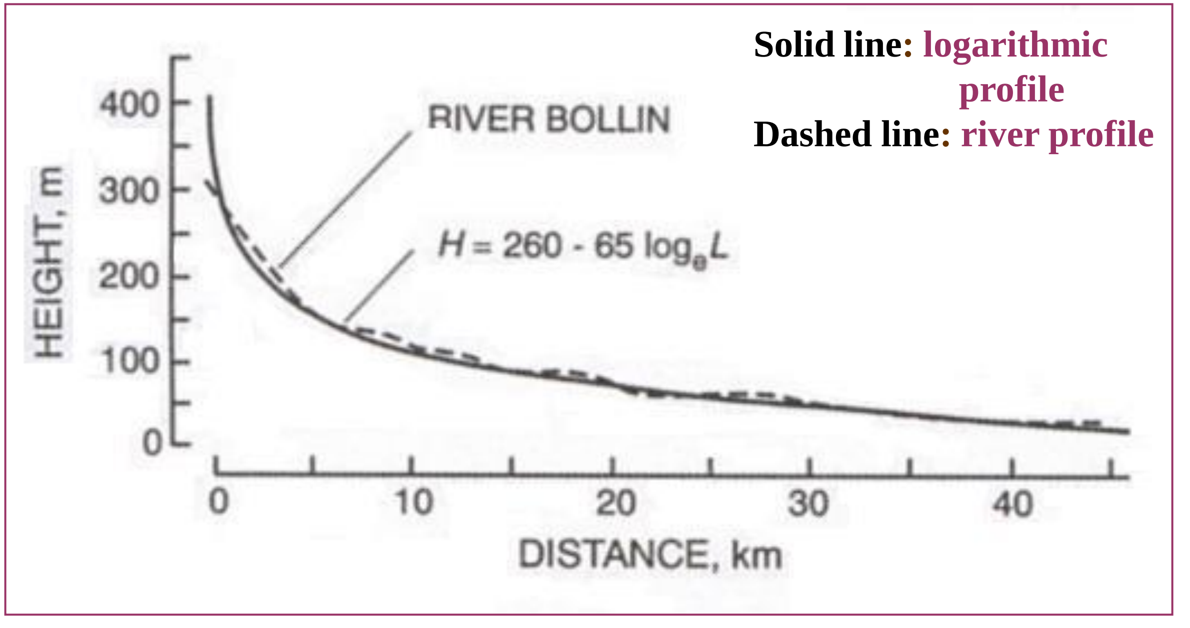
Drift Creek, Oregon

Longitudinal Profile: Channel Gradient

Concave upward shape quantified by logarithmic profile:

Hack stream-gradient index: **$k = (H_1 - H_2)/(\ln L_2 - \ln L_1)$**

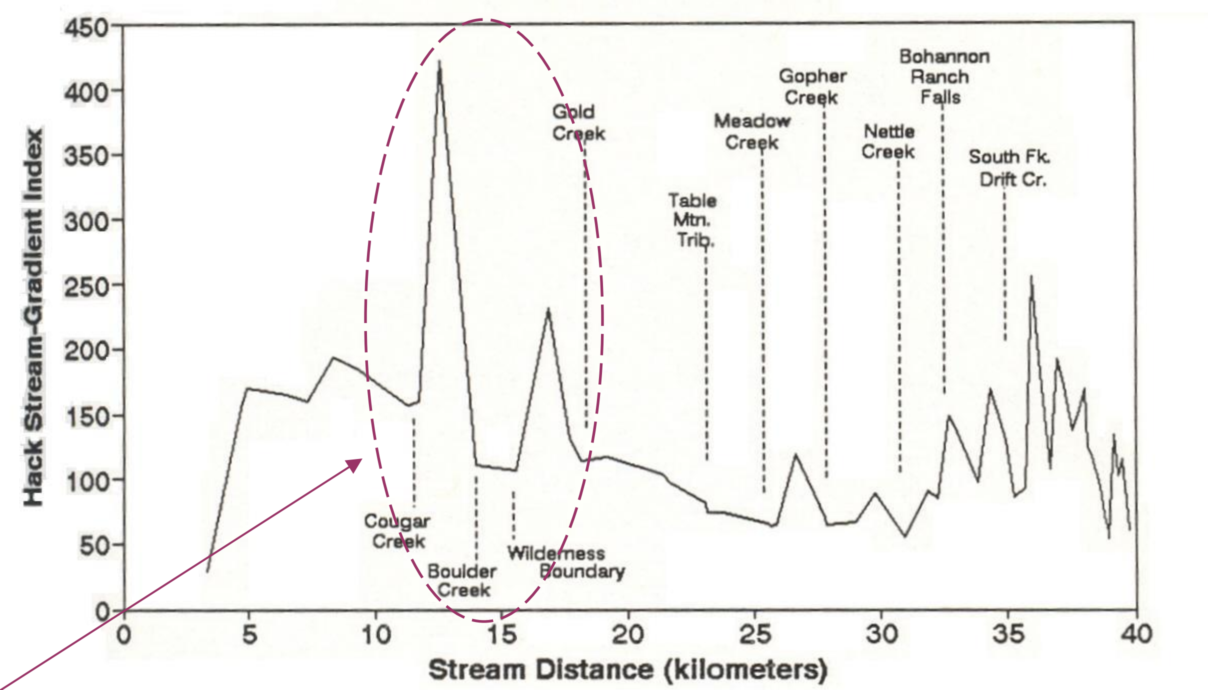
H_1 , H_2 ; upstream (up/s) and downstream (d/s) elevations, respectively
L_1 , L_2 ; up/s & d/s distances from headwaters datum 0 distance, respectively



Hack (1973)

Drainage Network: Longitudinal Profile

Hack Stream-gradient Index



Longitudinal profile of Hack stream-gradient indices along Drift Creek.

Drift Creek, Oregon

canyon-section, increased slope

Stream Power

Stream Power is the potential energy drop is equal to the work done to the bed and banks. All of the *potential energy* lost as the water flows downstream must be used up in friction or work against the bed: none can be added to *kinetic energy*.

Stream Power = $\Omega = (\gamma \cdot Q \cdot S)$ (specific weight * gravity * discharge * slope)

Unit Stream Power per channel width, where *b* is the width of the channel.
Unit Stream Power = $\omega = (\gamma \cdot Q \cdot S)/b$

Unit Stream Power = $\omega = \tau_0 \cdot V$ (τ_0 = boundary shear stress, V = velocity)

$\tau_0 = \gamma \cdot R_h \cdot S$, where R_h is the hydraulic radius = A/P (area/wetted perimeter)
Cross-sectional Area (A) = $b \cdot d$; where d = flow depth;
Q = V/A, and assumes P = b for wide and shallow

Drainage Network: Longitudinal Profile - Stream Power

Stream Power = energy (force x length) per unit time

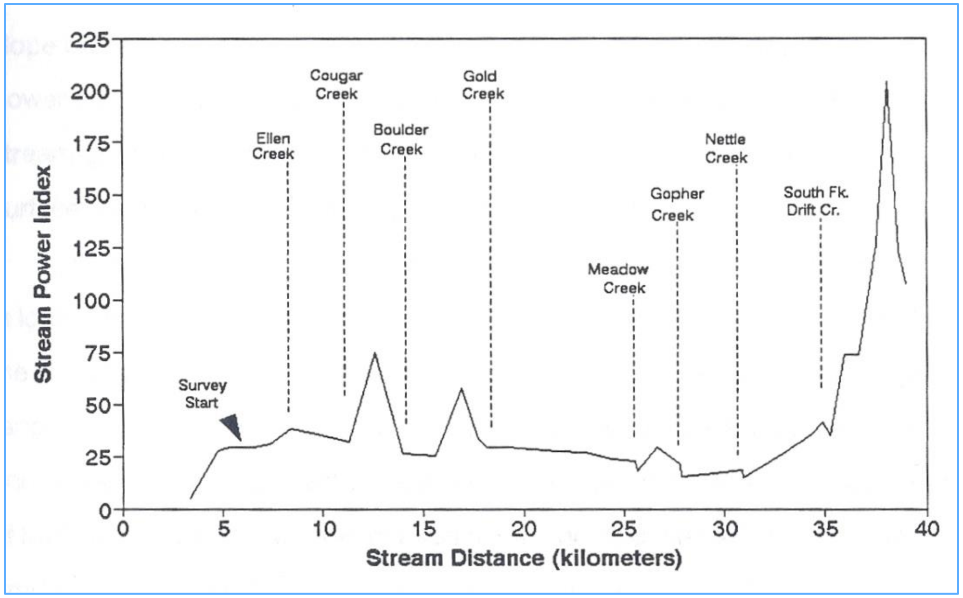
Stream Power is a function of discharge and slope, thus a function of watershed position;

Stream Power = Ω = $(\rho \cdot g \cdot Q \cdot S)$ (fluid density * gravity * discharge * slope)

Drift Creek, Oregon

Stream Power Index = $c \cdot \Omega / w$

A "c" coefficient multiplied by stream power per unit channel width, with drainage area replacing Q as a surrogate for discharge.



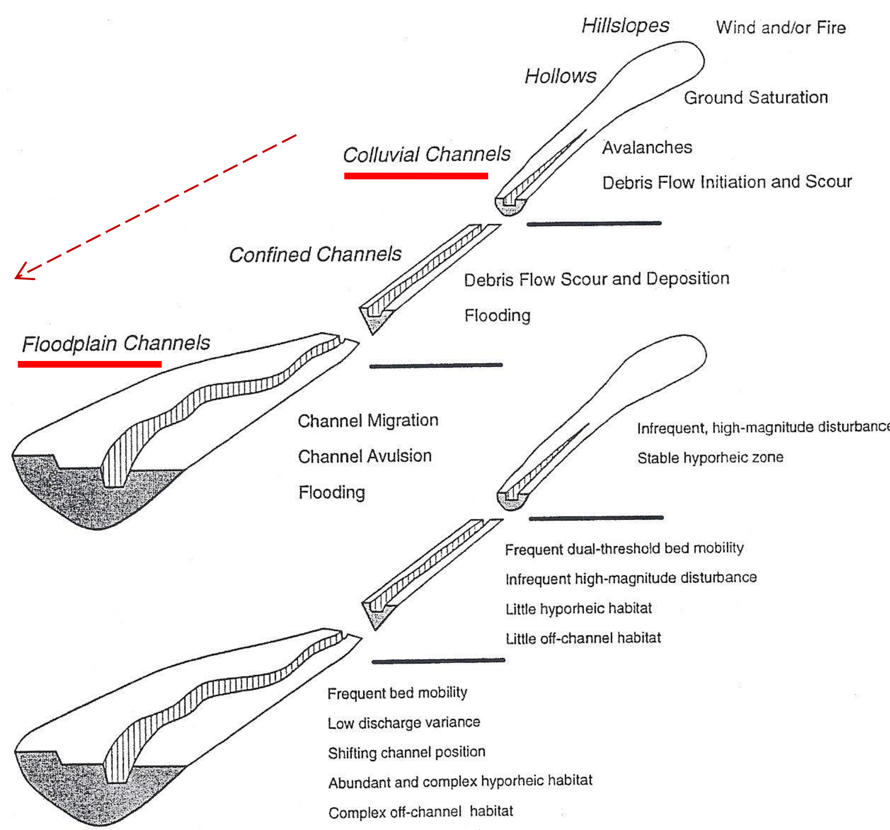
Longitudinal Profile: Geomorphic Process Continuum

Process Domain Concept

Geomorphic processes change from headwaters to large river corridors.

Processes are also hierarchical structured from watershed scale to stream bed scale.

Geomorphic analog to the River Continuum Concept.



Montgomery (1999)

Fluvial Systems: Classification

Fluvial Geomorphic Classification is the categorization and description of the nature, origin and development of watershed and river landforms.

The fundamental framework of classification is that a geomorphic unit can be classified based collectively on: [DM Haskins, 1998; USFS]

1) its origin and development (process);
2) its general structure and shape (form);
3) measurements of its dimensions and characteristics (morphology);
4) the presence and status of observing morphological adjustments (geomorphic generation).

Geomorphic classification systems: form-based vs process-based,
– sometimes difficult to separate.

Lecture 2 *focuses* on form characteristics and classification

Watershed / Drainage Network Classification

Classification of watersheds / drainage networks includes:

1) drainage network patterns a function of geology
2) A classification system to denote river/stream size
3) Valley types based on geology/climate.

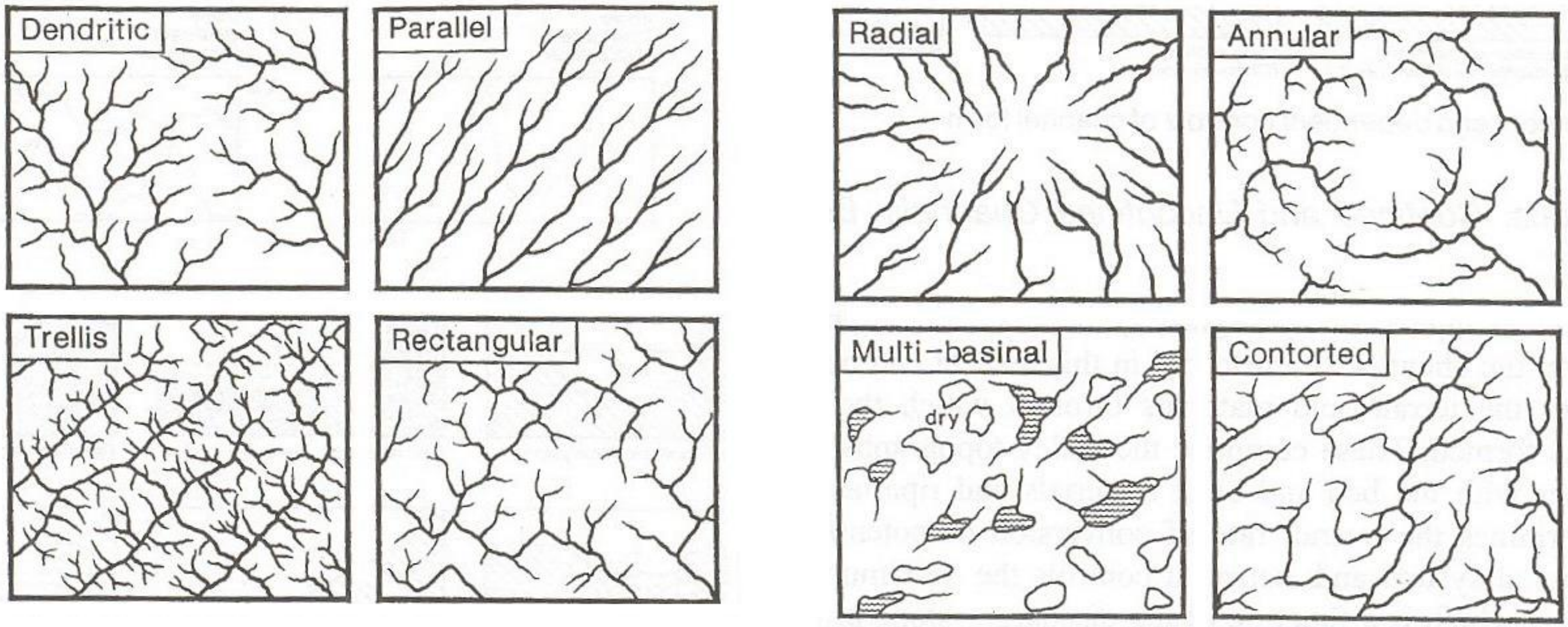
Segments are not well defined in the literature but have been related to *stream power* between major tributary junctions, or at major lithological *slope knickpoints* along the longitudinal profile.

Reflecting on the concept Geomorphic Process Domain, within different Valley Types, different **floodplain forms and processes** occur.

Note: we will revisit floodplain forms and processes in Lecture 4

Drainage Network Classification

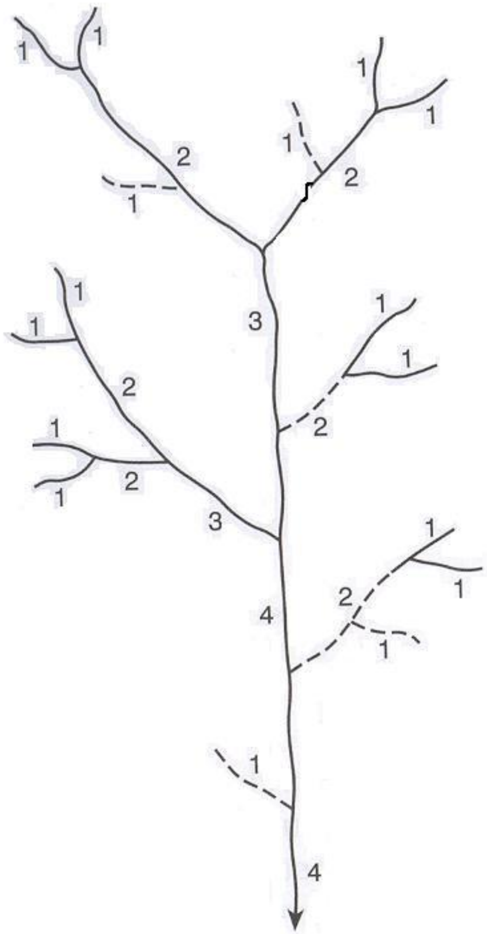
Channel Types and Morphological Classification



Basic drainage patterns (adapted from Howard, 1967)

Knighton (1998)

Drainage Network Classification



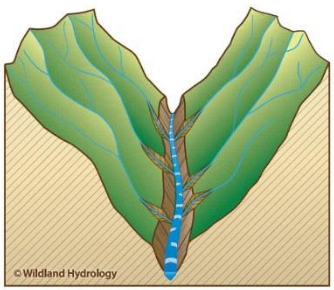
Structure Characteristics:

Stream Order (Strahler 1952)
1^{st}, 2^{nd}, 3^{rd}, 4^{th} ….

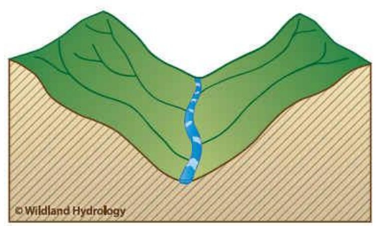
Drainage Density $D_d = \sum L / A_d$

Drainage Network Classification: Valley Types

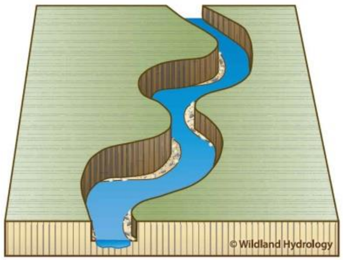
Valley Classification: examples from Rosgen (1996)



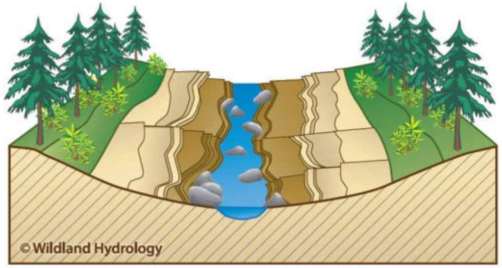
Steep Colluvial



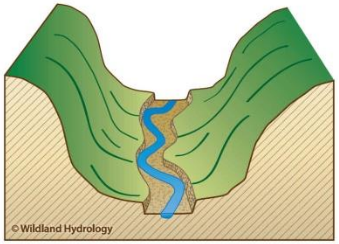
Moderate-steep Colluvial



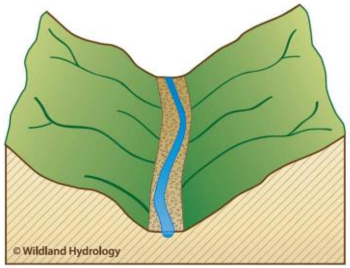
Inner Gorge



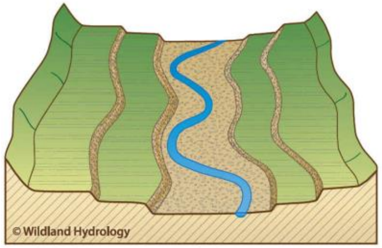
Bedrock



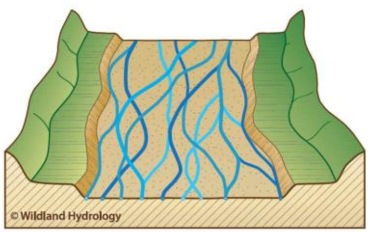
Glacial Trough



Alluvial



Terraced Alluvial

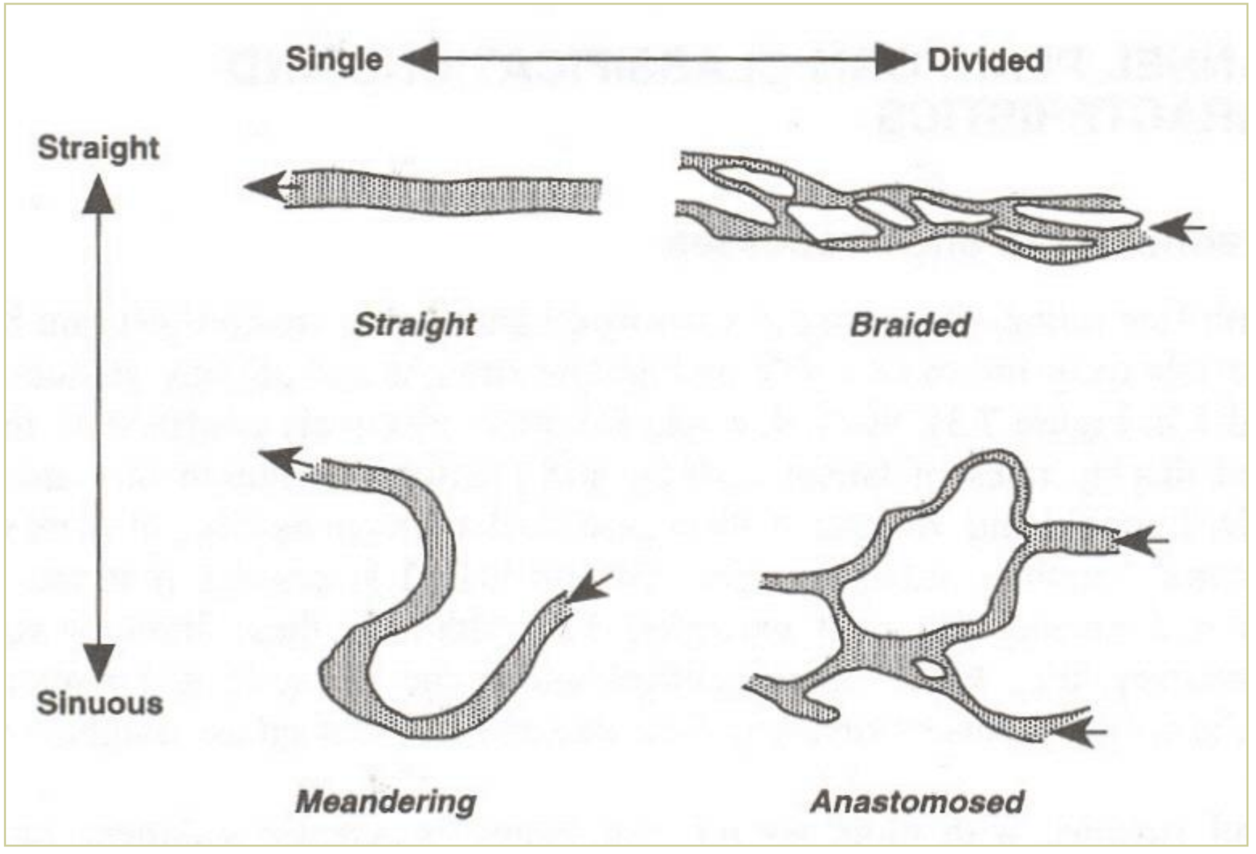


Glacial Outwash

Valley quantified (Rosgen 1996) per **Entrenchment Ratio** is a measure of vertical containment described as the ratio of the flood-prone area width to bankfull width.

Reach-scale Channel Patterns: Planform Classification

Planforms: Straight, Meandering, Braided, & Anastomosed

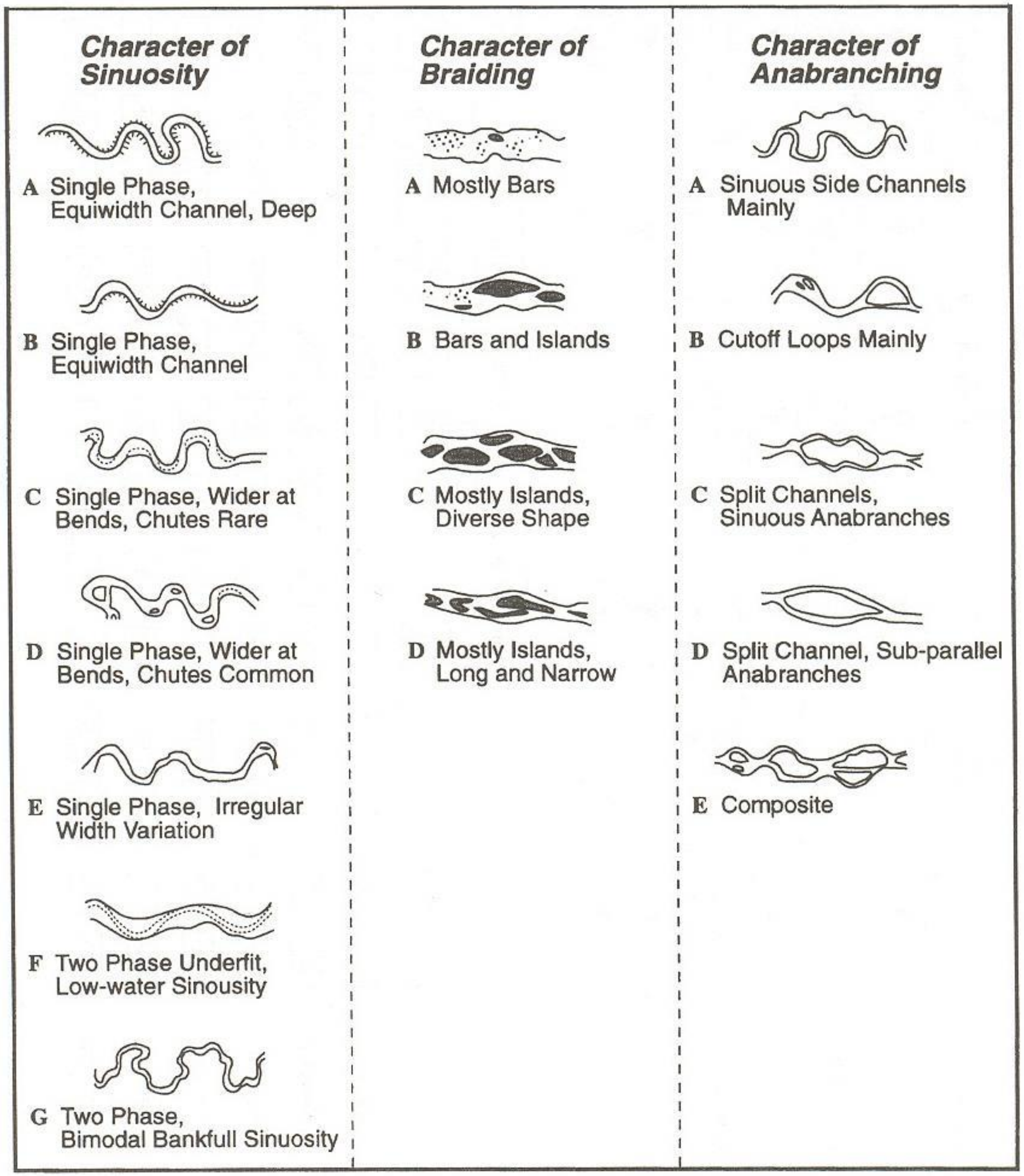


(Thorne et al. 1997)

Planforms

Reach-scale Channel Patterns:

Classic descriptive types/characteristics

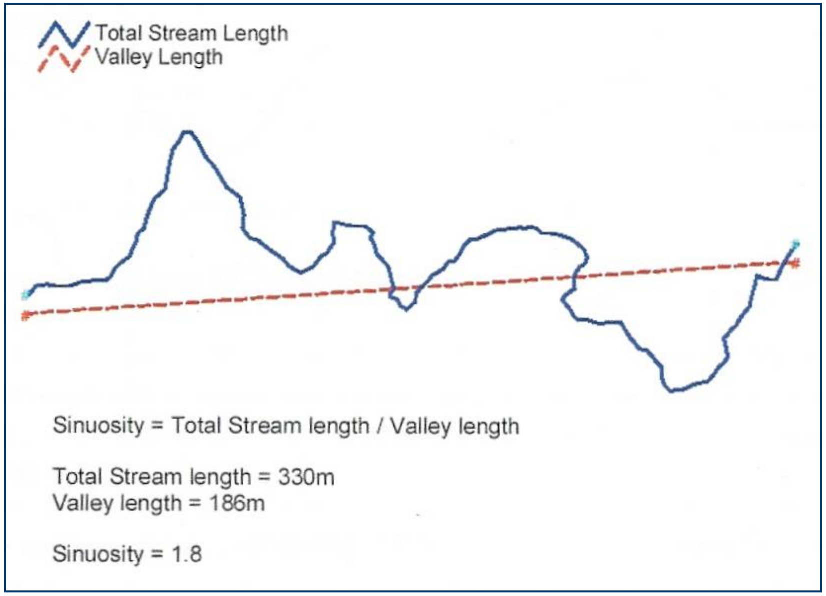


after Brice 1975
(Thorne et al. 1997)

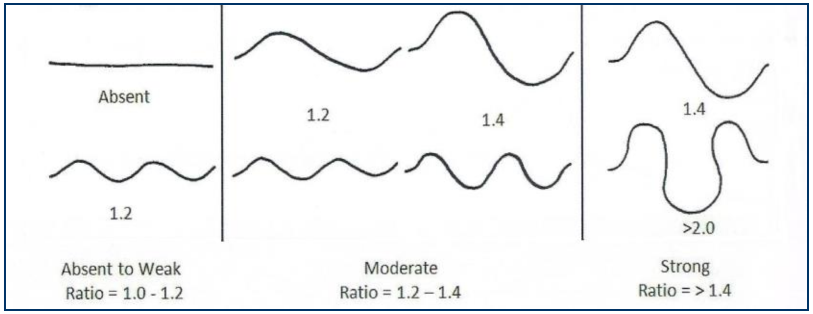
Reach-scale Channel Patterns

Channel Pattern Types:
Measurement of reach-scale sinuosity

Sinuosity =
channel length / valley length



General patterns and relative character of channel sinuosity:

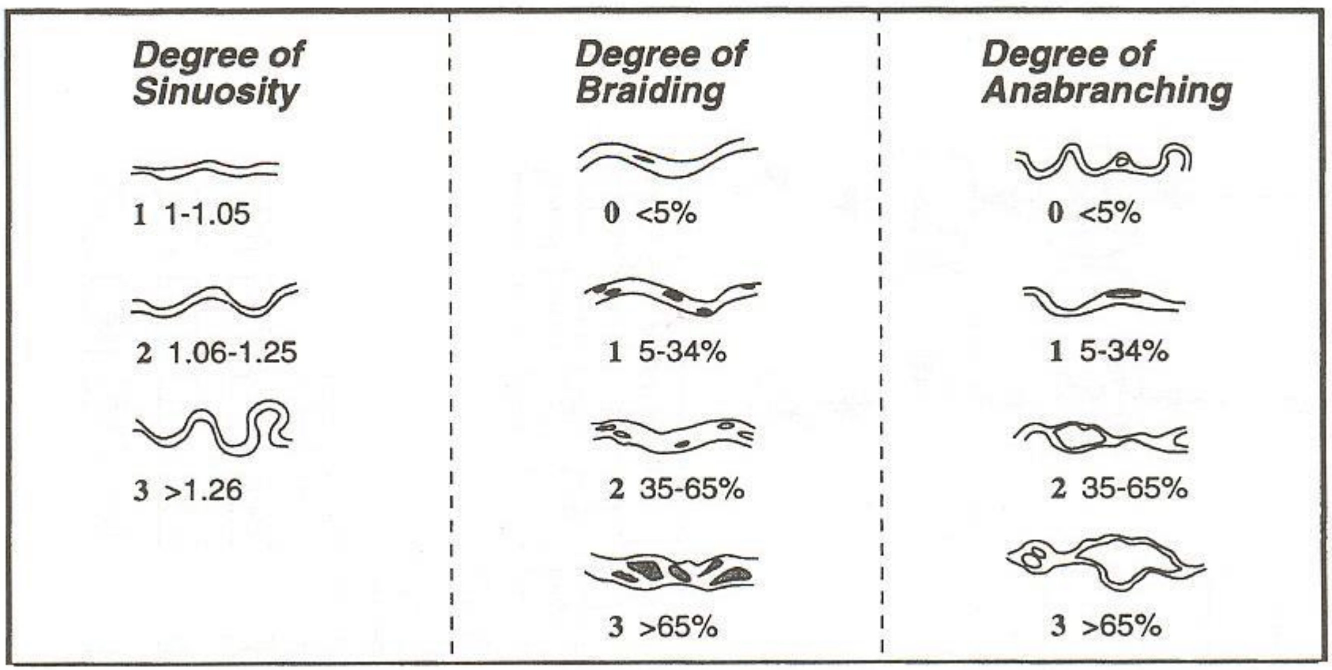


FISRWIG (1998)

Reach-scale Channel Patterns: Planforms

Channel Pattern Types:

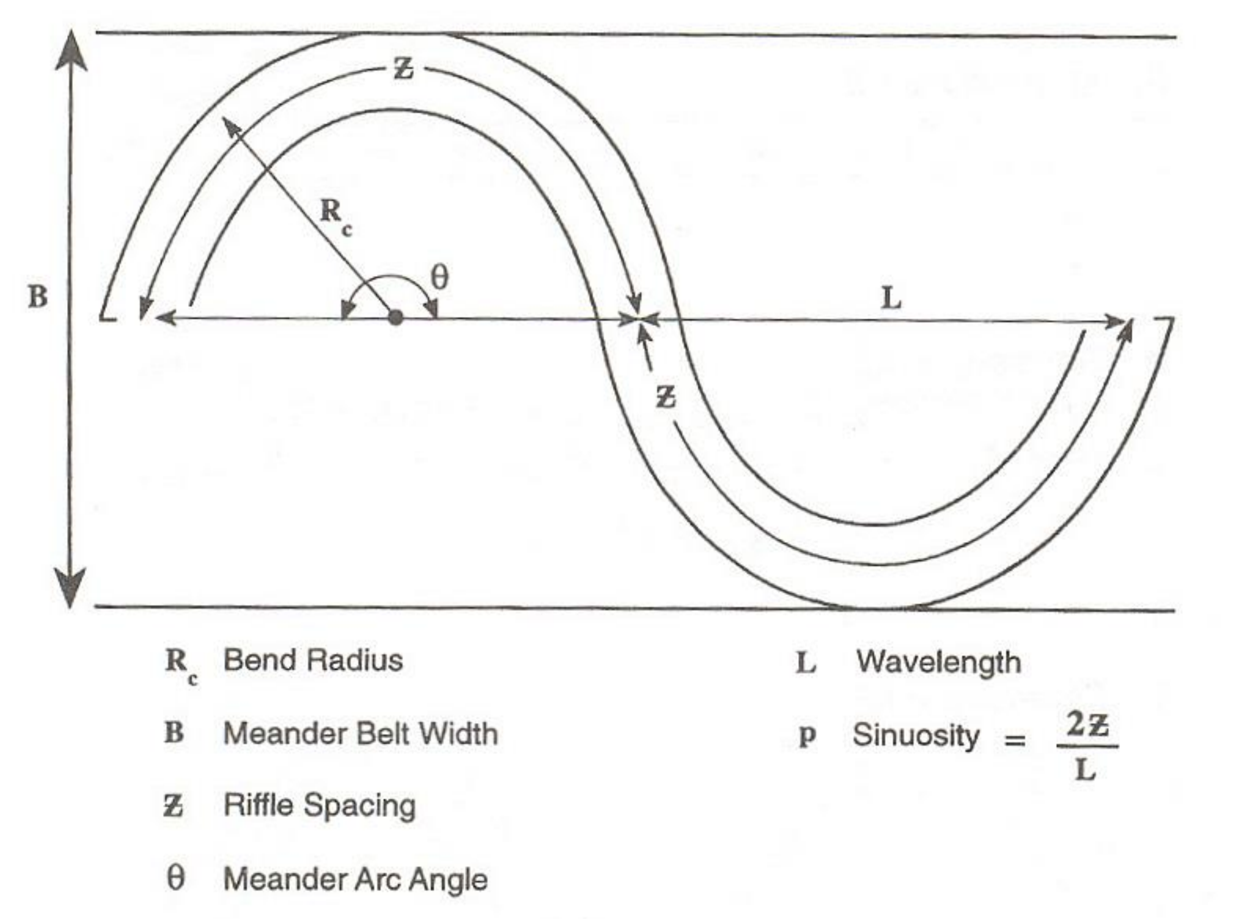
Geomorphic classification, classic descriptions



after Brice 1975 (Thorne et al. 1997)

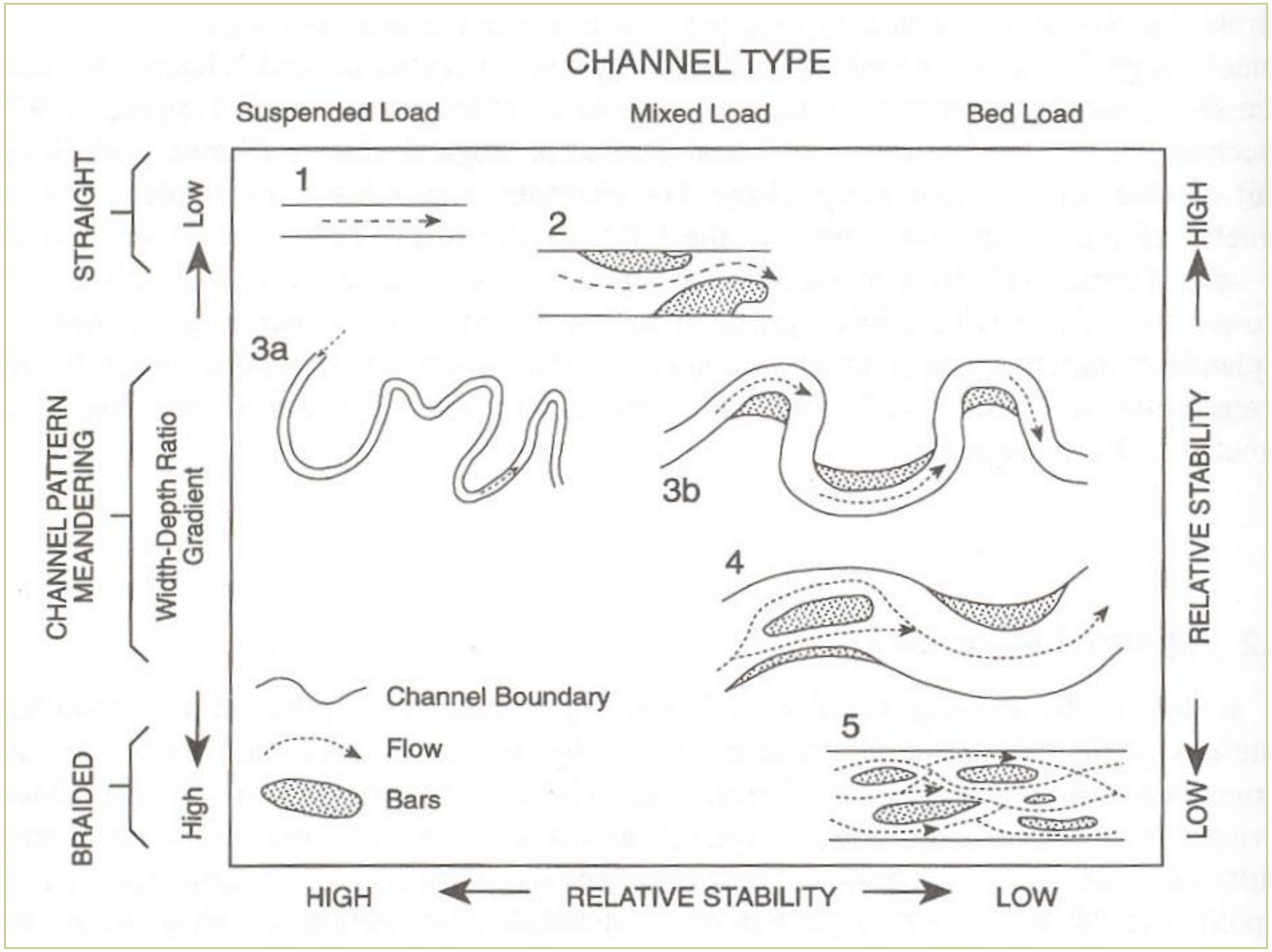
Reach-scale Channel Patterns

Meander Geometry



(Thorne et al. 1997)

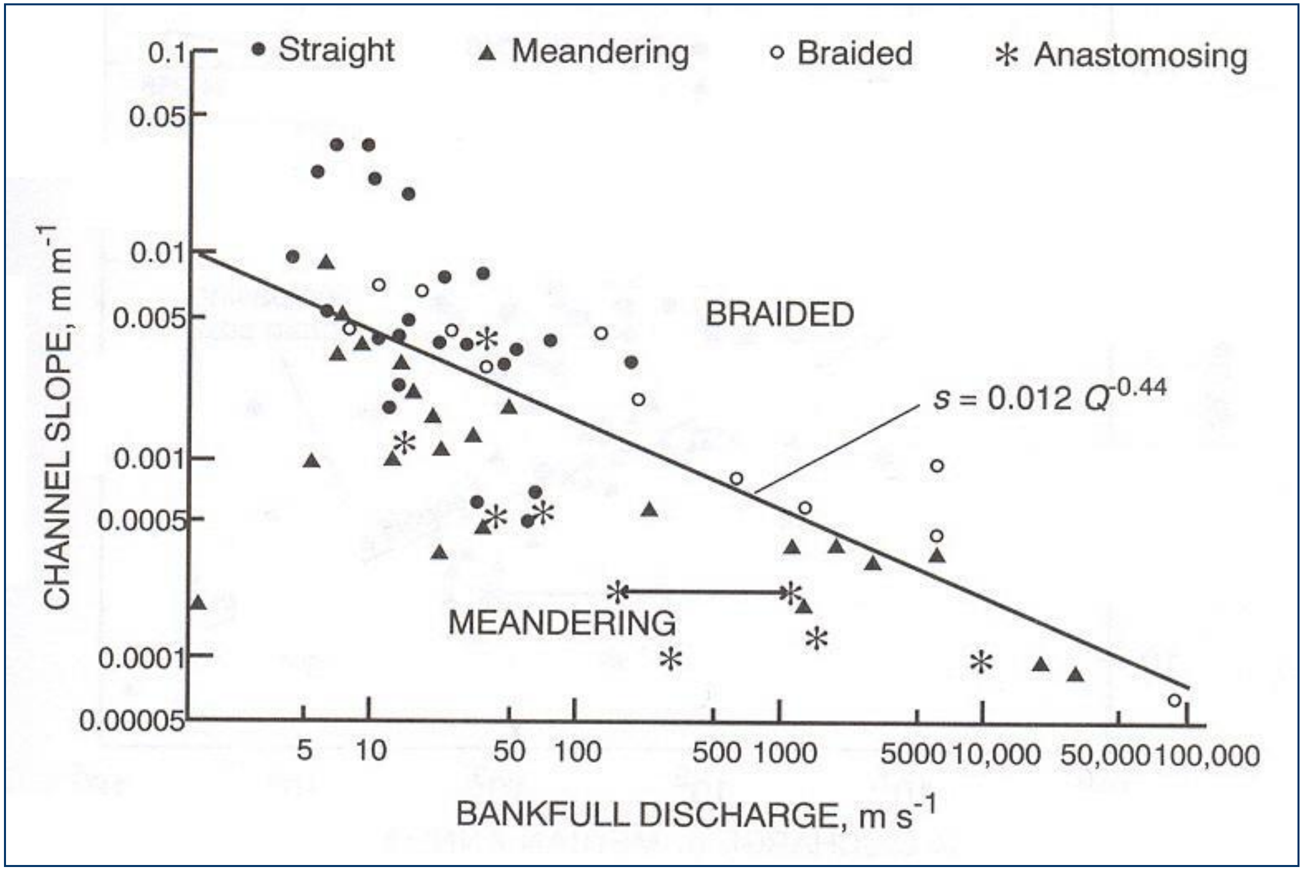
Reach-scale Channel Patterns: Planforms



Planform type relative to:
1) sediment transport load,
2) width-depth ratio, and
3) channel stability.

(Schumm 1977)

Reach-scale Channel Patterns: Planforms



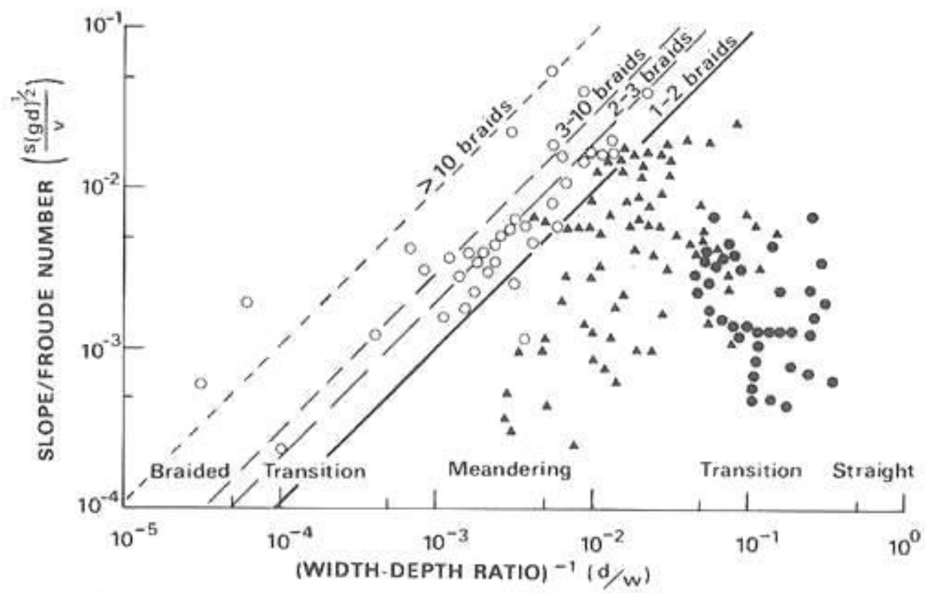
Leopold and Wolman (1957)

Reach-scale Channel Patterns: Planforms

Slope-discharge relationships to planform types

Note the importance of discharge (velocity), slope, bed material type, and channel cross-sectional form (Width/Depth ratio) (Knighton 1996)

Froude No., **Fr** = $V/(gD)^{0.5}$
Ratio of inertia forces
to gravitational forces



Reach-scale Channel Patterns

Flow depth (d) to grain size (D) ratio:

characterizing form types

A. Robert (2003)

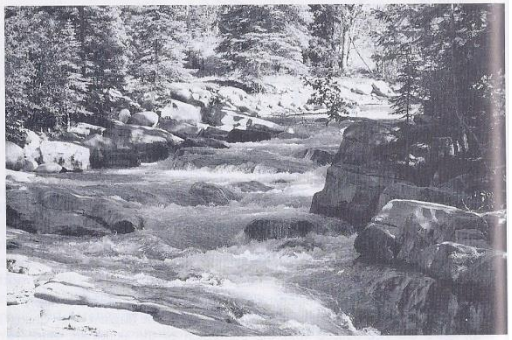


Plate 1.1 Small channel (*d/D* <1), with large clasts protruding above the water surface (Maligne River, Alberta, Canada).

$d/D < 0.1$

$1 < d/D < 10$

Plate 1.2 Example of an intermediate channel (1 < *d/D* < 10). Meandering, riffle-pool stream, Rouge River, Ontario, Canada (channel width ≈ 12 m).

$d/D > 10$

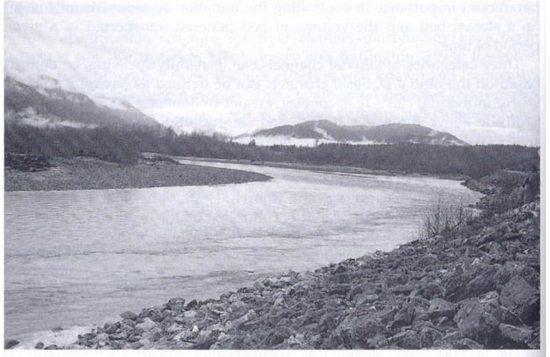


Plate 1.3 Large channel; Squamish River, British Columbia, Canada – *d/D* >10; channel width approximately 35 m.

Related to channel slope and boundary resistance

Reach-scale Channel Classification

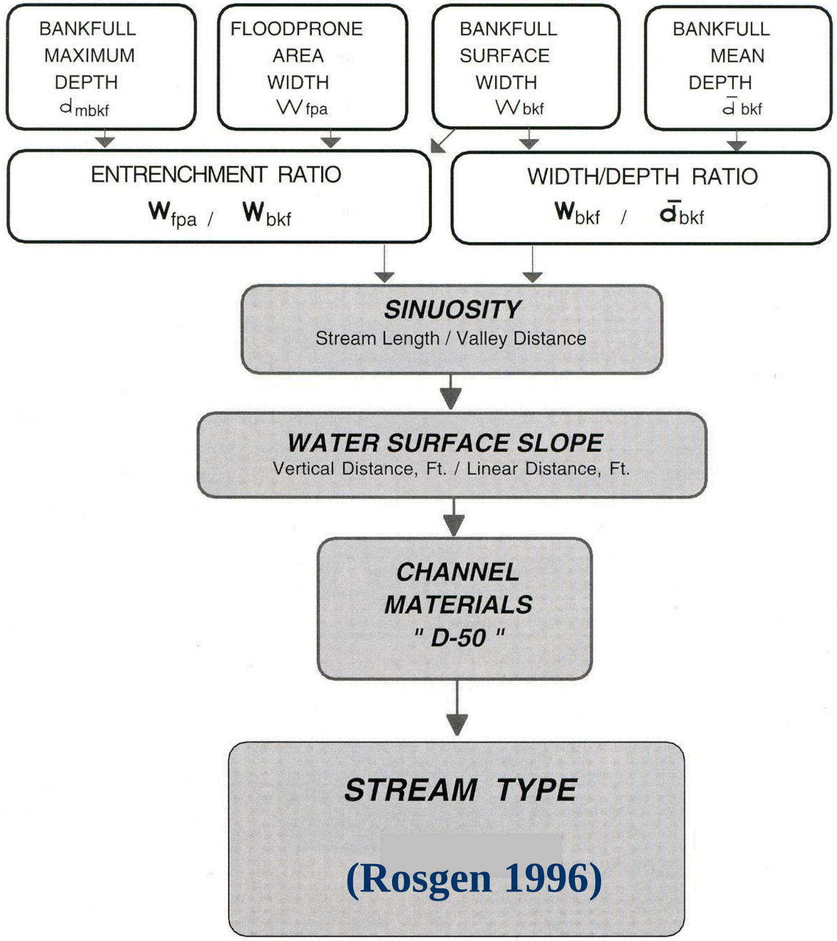
Reach-scale Channel Classification has been used to aid stream restoration design by using analog or reference stream measurements.

Classifications systems vary with level of process-based morphological concepts --- it has been argued *process* determines *form* so all channel classification schemes represent process-form types.

Three Common Channel Classification Schemes:

- Rosgen (Natural Channel Design) Classification
- Buffington and Montgomery (Sediment Transport/Supply) Classification
- Downs (Morphological Change) Classification

Reach-scale Channel Classification



Rosgen System
of Stream Classification

Based on:
1. slope
2. sinuosity
3. Width/depth ratio
4. Entrenchment ratio
5. bed sediment

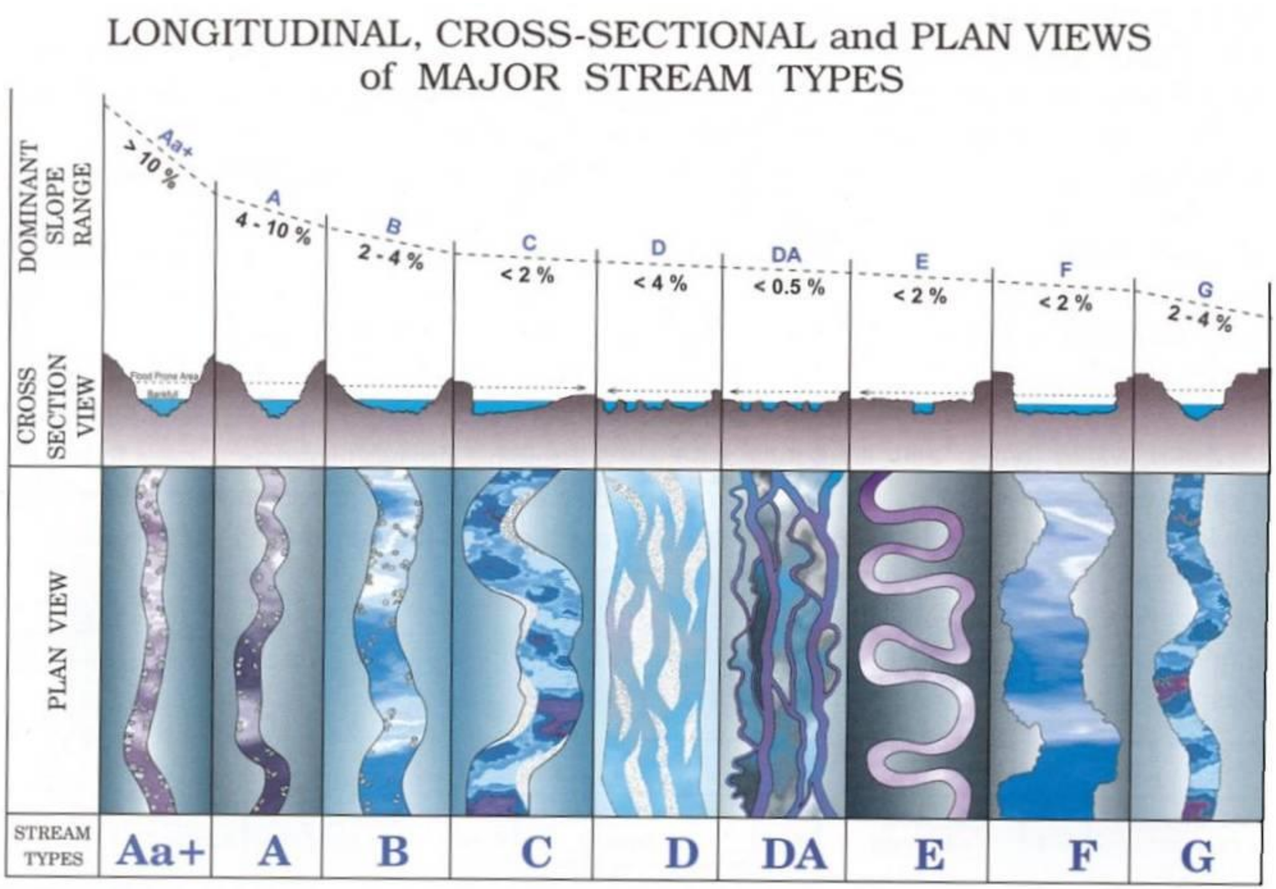
Defines:
Stream types
A, B, C, D, D_A, E, F,G

Reach-scale Channel Classification

Rosgen System
of Stream Classification

Based on:
1. slope
2. sinuosity
3. W/D ratio
4. entrenchment
5. bed sediment

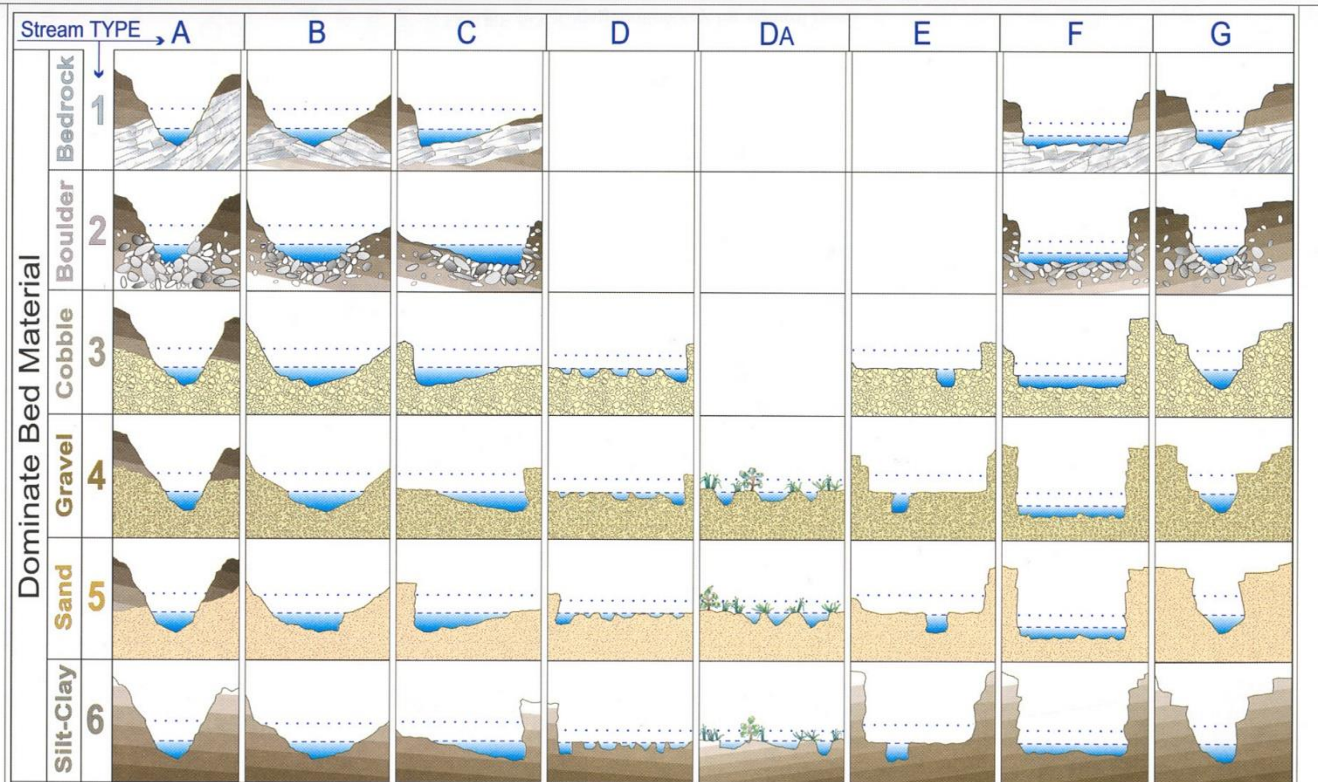
(Rosgen 1996)



Reach-scale Channel Classification

Rosgen System

of Stream Classification



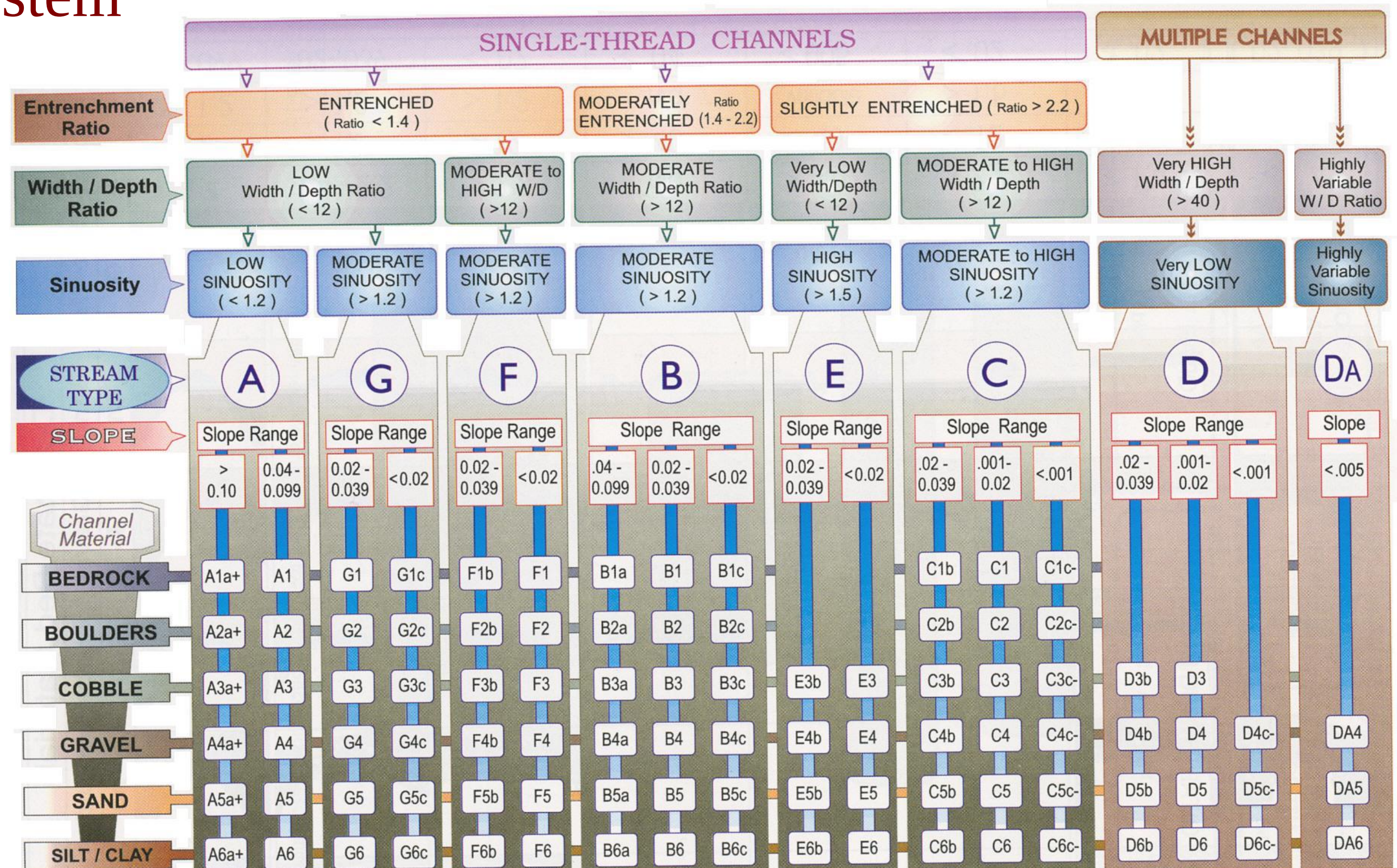
	A	B	C	D	DA	E	F	G
Entrchmnt.	< 1.4	1.4 - 2.2	> 2.2	n/a	> 4.0	> 2.2	< 1.4	< 1.4
W/D Ratio	< 12	> 12	> 12	> 40	< 40	< 12	> 12	< 12
Sinuosity	1 - 1.2	> 1.2	> 1.2	n/a	variable	> 1.5	> 1.2	> 1.2
Slope	.04-.099	.02-.039	< .02	< .04	<.005	< .02	< .02	.02-.039

(Rosgen 1996)

Reach-scale Channel Classification

Rosgen System

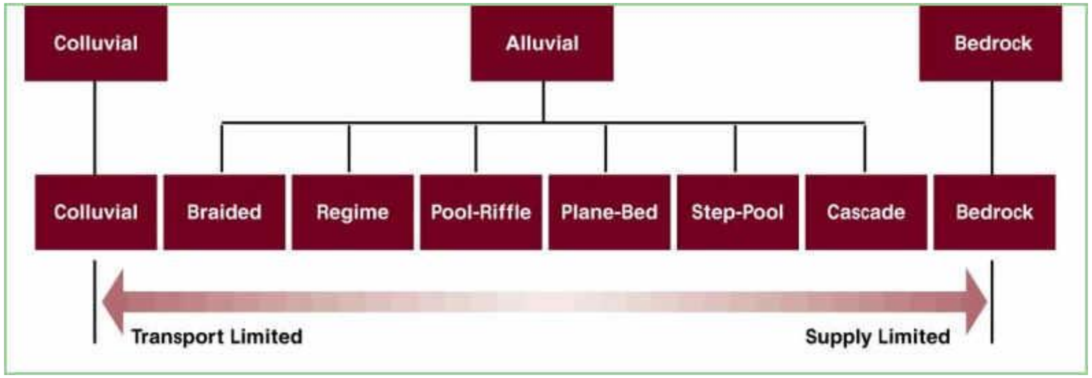
of Stream Classification



KEY to the *ROSGEN* CLASSIFICATION of NATURAL RIVERS. As a function of the "*continuum of physical variables*" within stream reaches, values of ***Entrenchment*** and ***Sinuosity*** ratios can vary by +/- 0.2 units; while values for ***Width / Depth*** ratios can vary by +/- 2.0 units.

(Rosgen 1996)

Geomorphic Classification of Channel Reaches



Buffington and Montgomery (1997)

Transport-limited streams are with sediment loads that exceed hydraulic capacity, and hence deposition may be prevalent.

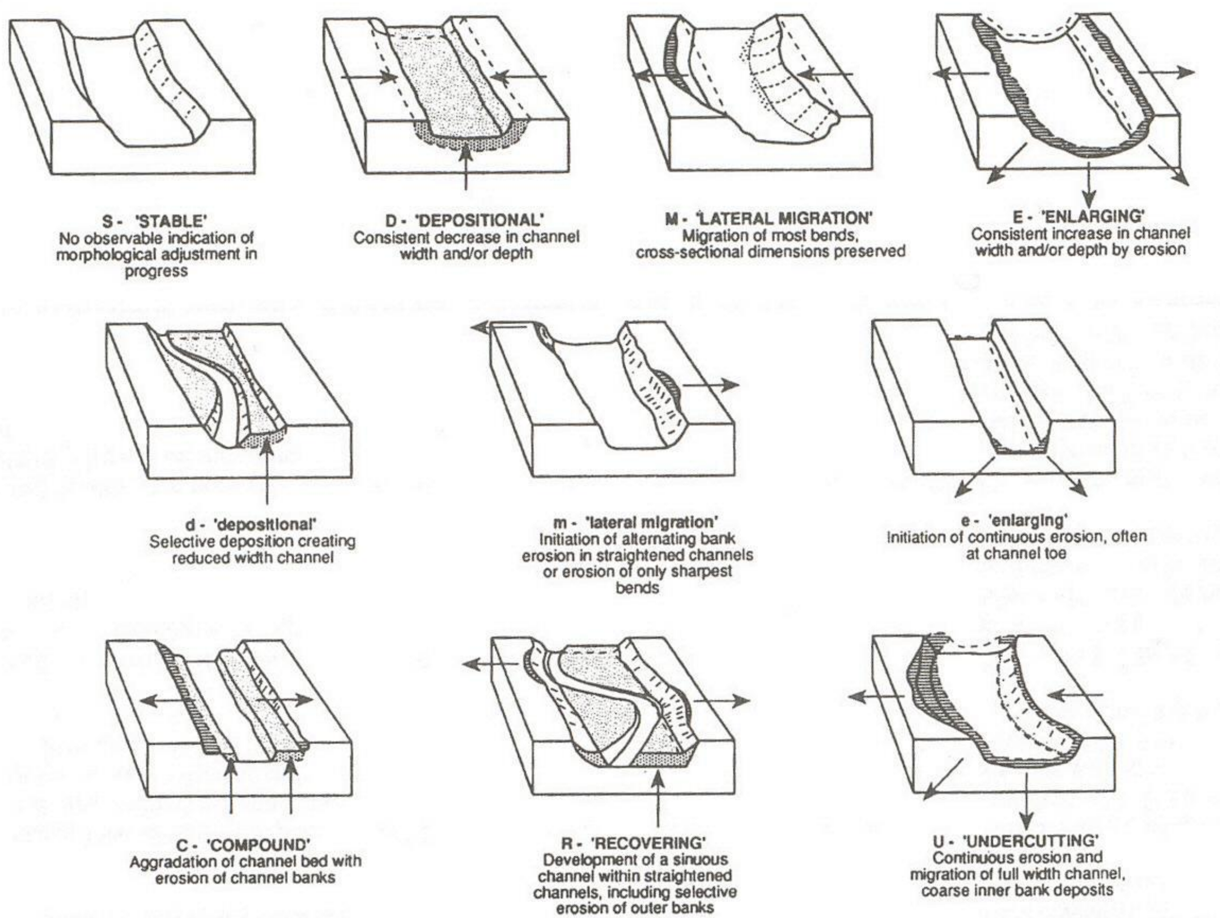
Supply-limited streams have hydraulic capacity beyond supply, and hence scour and erosion may be prevalent.

The steeper channels (step-pool, cascade, and possibly bedrock) transmit high sediment loads and maintain their morphology, while flatter channels (braided, regime, riffle-pool) experience morphological adjustment with increased sediment.

Geomorphic Classification of Channel Reaches

Downs (1995) system *based on* trends and types of morphological change:

- ➢Stable
- ➢Depositional
- ➢Lateral Migration
- ➢Enlarging
- ➢Compound
- ➢Recovering
- ➢Undercutting



(Thorne et al. 1997)

Channel Unit / Bedform Scale

Bar Unit: A hydraulic morphological unit consisting of a pool, riffle, and bar.

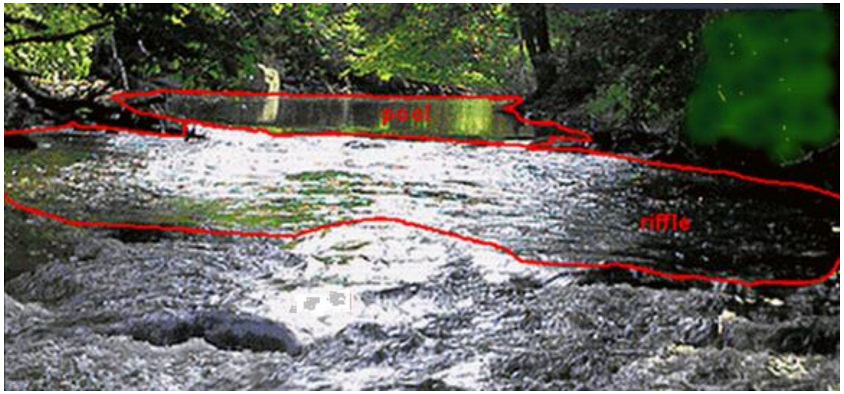
Riffle-Pool and Step-Pool Sequences: A longitudinal profile through the channel thalweg examining riffle-pool or step pool sequences.

Pool: A relatively deep location in the channel with tranquil water surface during baseflows.

Riffle: A relatively shallow location with fast moving water, turbulent water as observed during baseflows.

Bar: A relatively shallow location in the channel from sediment deposition (e.g., point bar).

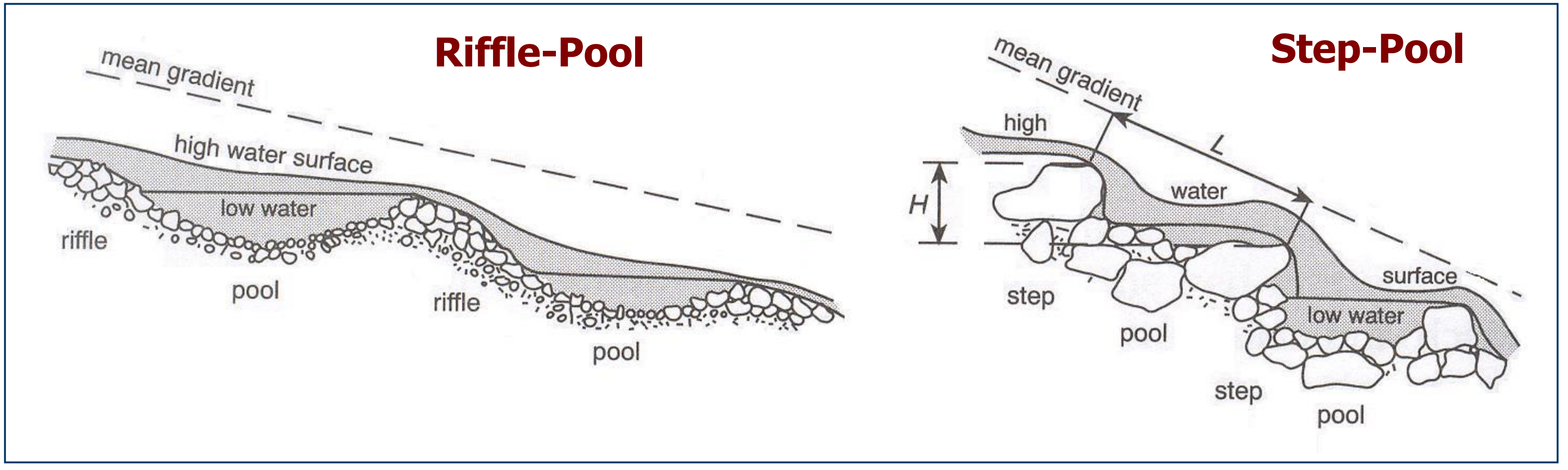
Thalweg: The corridor (pathway) longitudinally through channel with the deepest water depth.



Bedform Configuration: Gravel-bed Rivers

Riffle-Pool Sequence: The development of alternating deeps (pools) and shallows (riffles) is characteristic of both straight and meandering channels with heterogeneous bed materials, containing gravel, in the size range of 2 to 256 mm.

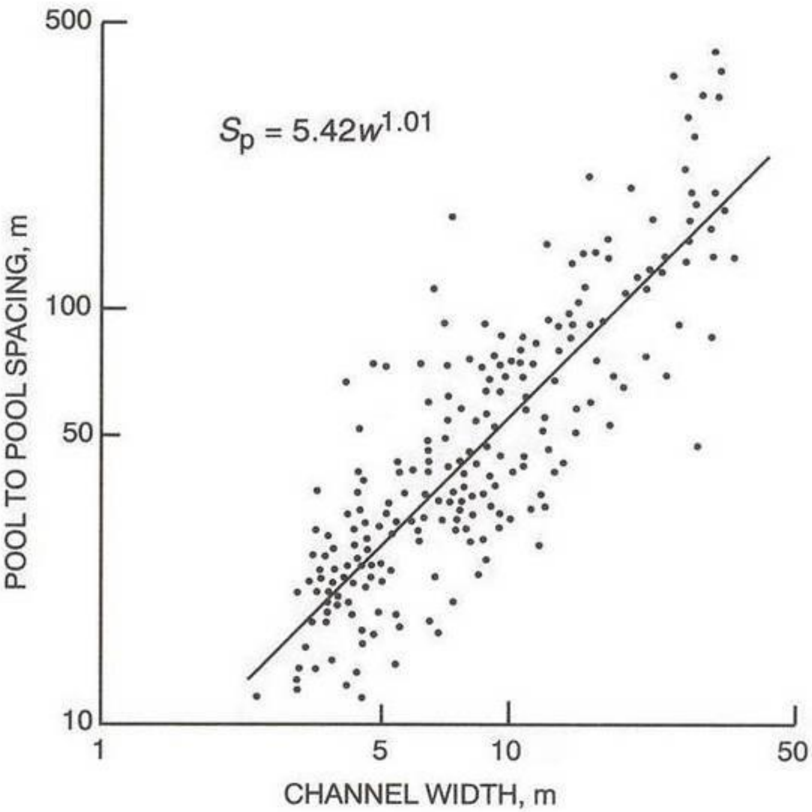
***In general*, riffle-pool sequences occur with bed slopes < 2%, and step-pool sequences occur with bed slopes > 5%.**



Knighton (1998)

Bedform Configuration: Riffle-pool Sequences

Riffle-Pool Spacing:
Average 5-7 channel unit widths from a range of 1.5 to 23.3 channel unit widths.

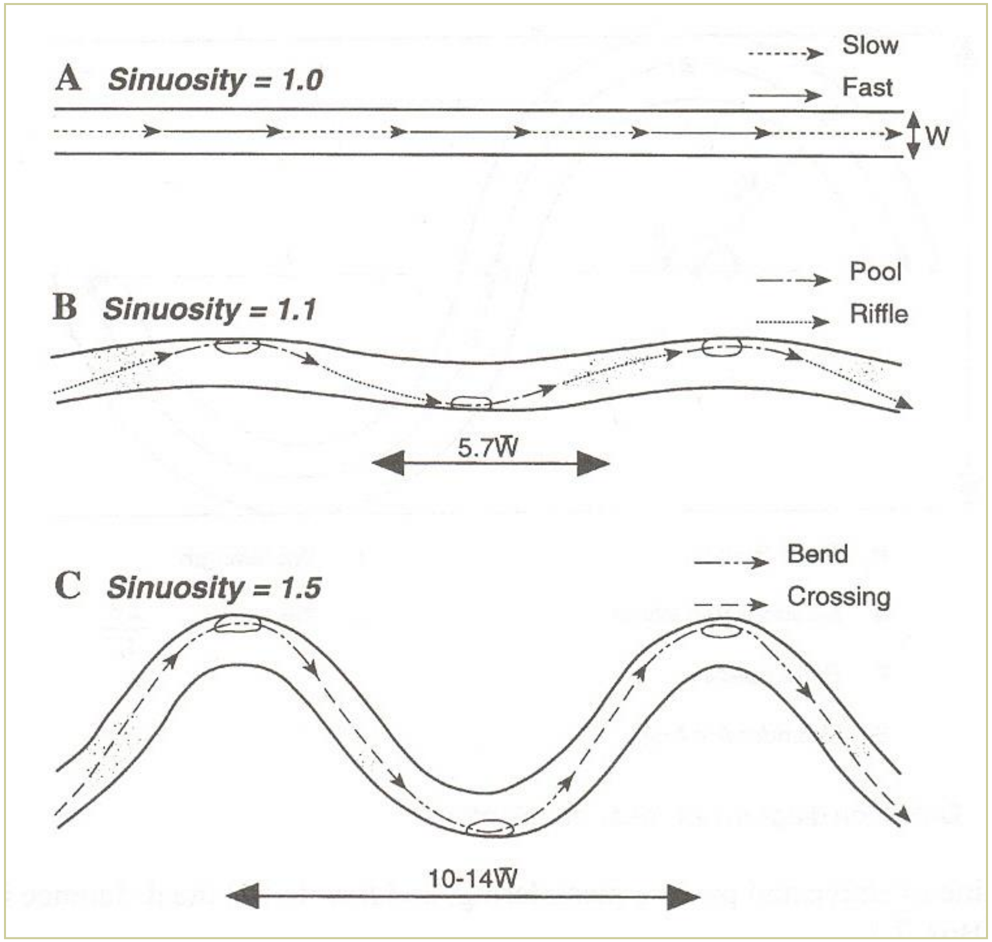


Knighton (1998)

Bedform- Planforms Relationships

Pool-riffle sequences

Relationships with straight-meandering planforms: sinuosity and flow patterns

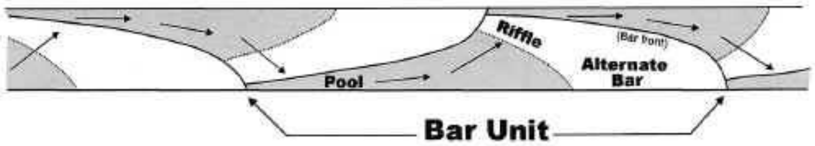


(Chorley et al. 1984)

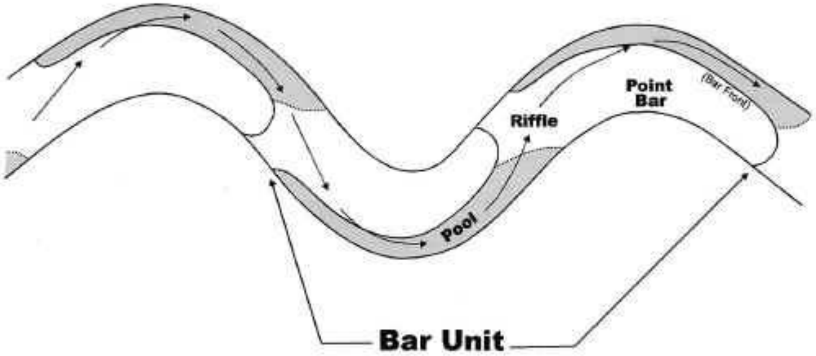
Bedform Configuration – Gravel-bed Rivers

Pools, riffles, and point bars are elements of a morphological structure known as a bar unit (Thompson 1986, Dietrich 1987).

Straight channel: alternative bar



Meandering channel: point bar



Braided channel: mid-channel bar
(multiple bar units - not shown)

Frothingham & Rhoads (2002)

Bedform Configuration: Sand-bed Rivers

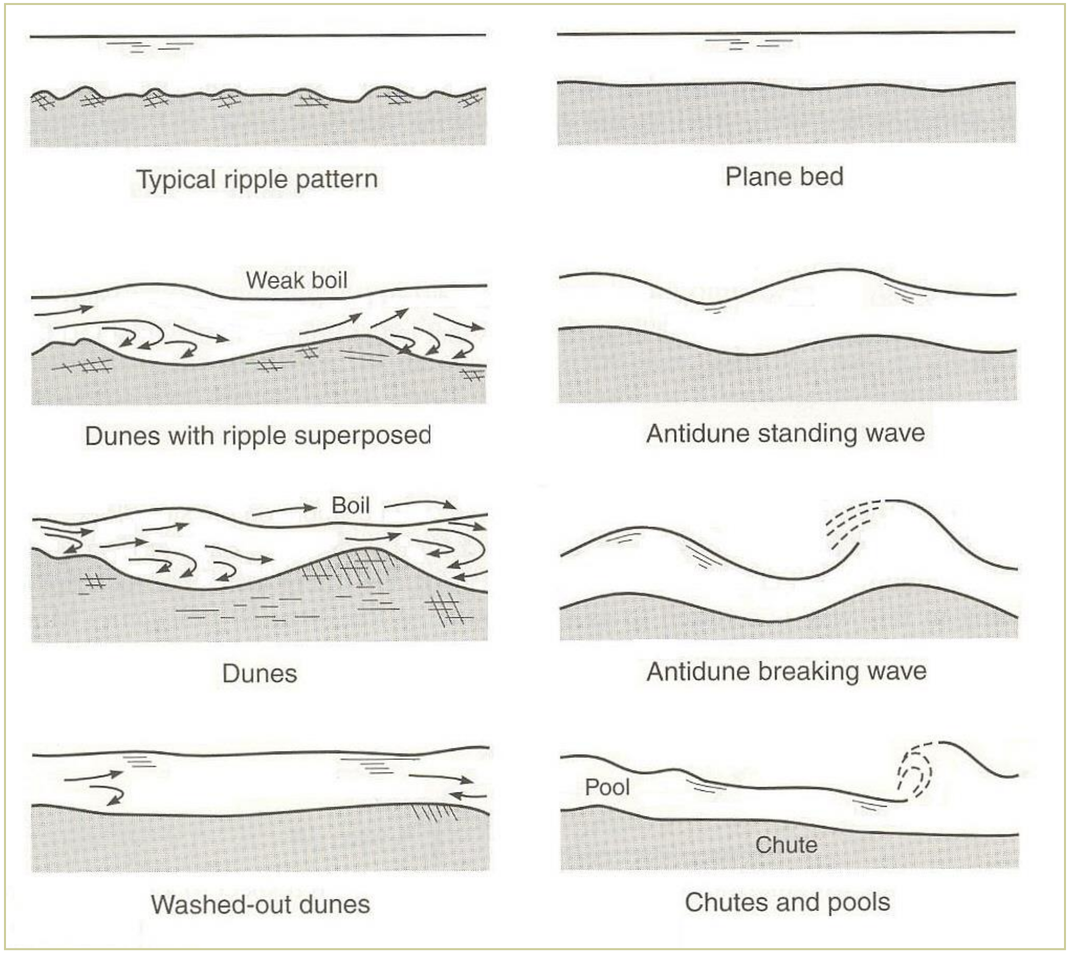
Sand Bedforms:

defined as irregularities in an alluvial channel bed with respect to a flat bed that are higher than the sediment size itself.

Common Types:

Ripple
Dune
Anti-dune
Chute / Bars

(Strum 2001)



Bedform Configuration: Sand-bed Rivers

Bed form	Dimensions	Shape	Behaviour and occurrence		
Bar	Lengths comparable to channel width	Variable	Five main types: (1) Point-bars: form particularly on the inner bank of meanders (2) Alternate bars: distributed periodically along one and then the other bank of a channel (3) Channel junction bars: develop where tributaries enter a main channel (4) Transverse bars (include riffles): may be diagonal to the flow (5) Mid-channel bars: typical of braided reaches		
Ripples	Wavelength less than 0.6 m; height less than 0.04 m	Triangular profile; gentle upstream slope, sharp crest and steep downstream face	Generally restricted to sediment finer than 0.6 mm; discontinuous movement; at velocities much less than that of the flow	Lower regime of roughness; form roughness dominant	Particularly sand-bed streams
Dunes	Wavelength of 4 to 8 times flow depth; height up to $\frac{1}{3}$ flow depth; much larger than ripples	Similar to ripples	Upstream slope may be rippled; discontinuous movement; out of phase with water surface	Lower regime of roughness; form roughness dominant	Particularly sand-bed streams
Plane bed			Bed surface devoid of bed forms; may not occur for some ranges of depth and bed material size	Upper regime of roughness; grain roughness dominant	Particularly sand-bed streams
Antidunes	Relatively low height dependent on flow depth and velocity	Sinusoidal profile; more symmetrical than dunes	Less comon than dunes, occurring in steep steams; in phase with surface water waves; bed form may move upsteam, downstream or remain stationary	Upper regime of roughness; grain roughness dominant	Particularly sand-bed streams

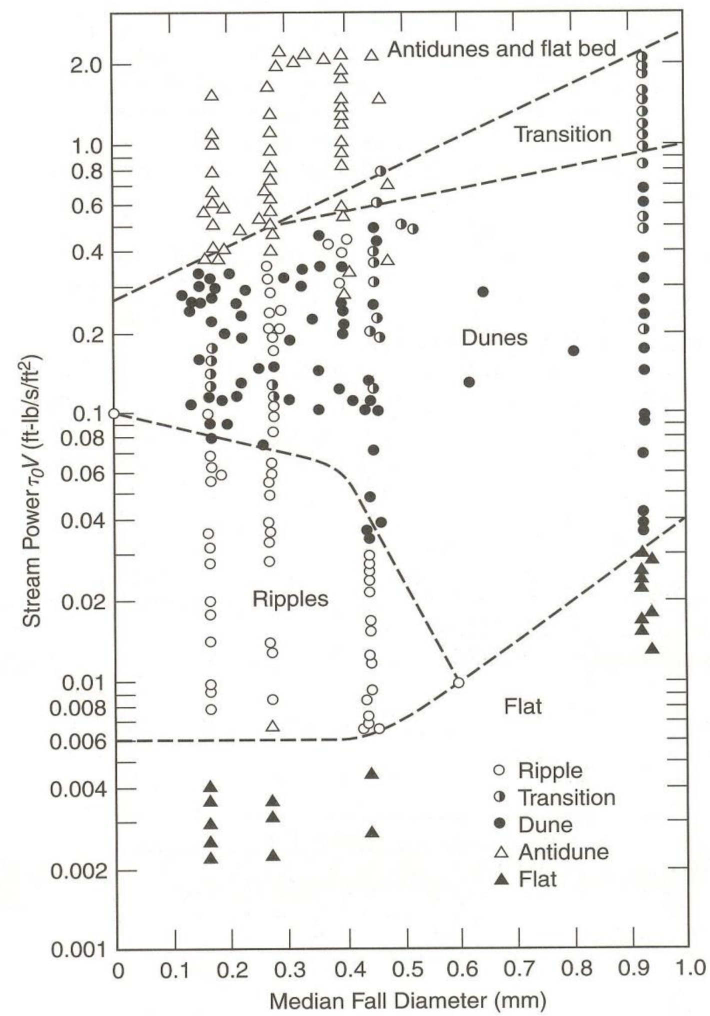
(Knighton 1998)

Bedform Configuration: Sand-bed Rivers

Identifying bedforms as a function of flow and sediment properties:

Simons & Richardson (1966) *plots* **stream power** ($\tau_0 \cdot V$) *versus* **sediment size**.

Note: **($\tau_0 \cdot V$) in ft-lb/s/ft²**



Prediction of bed form type from sediment fall diameter and stream power (Simons and Richardson 1966).

Strum (2001)

Bed Sediment Particles

Bed Sediment Characterization

Particle Size Classes:

Size classification as defined by the American Geophysical Union.

Each size class representing a geometric series, in which the maximum and minimum sizes differ by a factor of 2.

Diameter designated as either d_s or D, depending on text source.

D50 = median particle diameter from sample/survey

Sturm (2001)

TABLE 10-1
Sediment grade scale (AGU)

Class name	Size range, mm
Very large boulders	4,096–2,048
Large boulders	2,048–1,024
Medium boulders	1,024–512
Small boulders	512–256
Large cobbles	256–128
Small cobbles	128–64
Very coarse gravel	64–32
Coarse gravel	32–16
Medium gravel	16–8
Fine gravel	8–4
Very fine gravel	4–2
Very coarse sand	2.0–1.0
Coarse sand	1.0–0.5
Medium sand	0.50–0.25
Fine sand	0.250–0.125
Very fine sand	0.125–0.062
Coarse silt	0.062–0.031
Medium silt	0.031–0.016
Fine silt	0.016–0.008
Very fine silt	0.008–0.004
Coarse clay	0.004–0.002
Medium clay	0.002–0.001
Fine clay	0.0010–0.0005
Very fine clay	0.0005–0.00024

Bed Sediment Particles

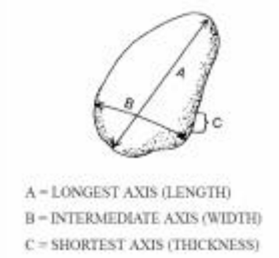
Bed Sediment Characterization

Wolman Pebble Count:

Multiple field methods to collect 100 sediment samples to perform statistics to obtain D50 or other percentile: Uniform grid, cross-sections, zig-zag pattern along the channel, and random- walk end-of-toe approach.

Measure particles along the (B) intermediate axis.

The red line drawn in the image indicates the approximate path the students chose while conducting their pebble count within a 100-meter reach of Skaggs Run.



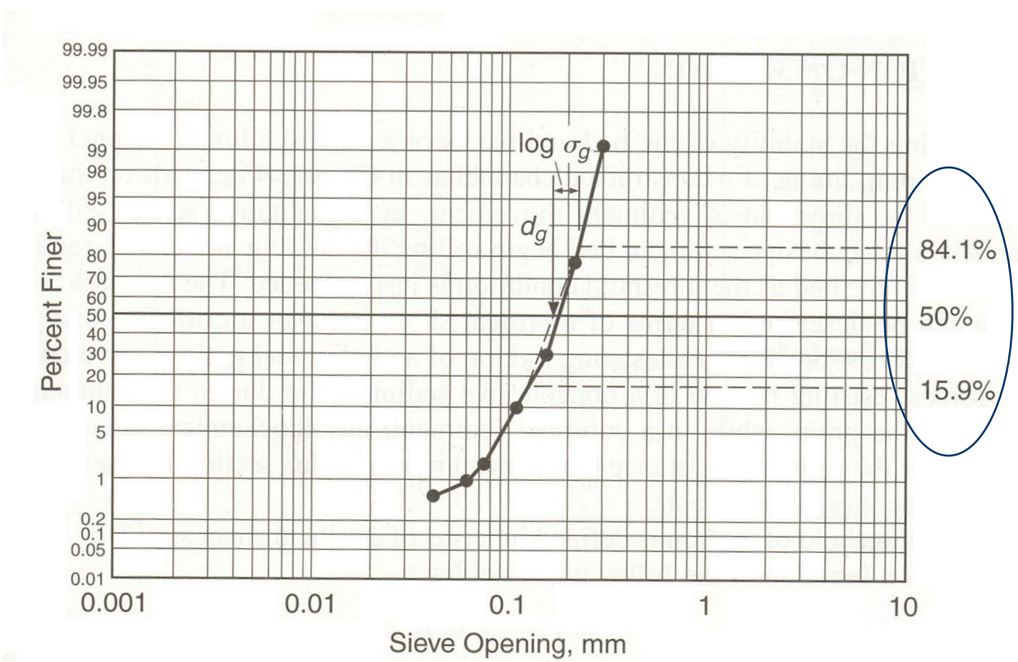
Wolman (1954)

Bed Sedimet Particles

Particle (Grain) Size Distribution

d_{50} = median particle size
d_g = geometric mean size
σ_g = geometric standard deviation

Wolman Pebble Count: Common Collection method of mixed sediment loads.



$$\sigma_g = \frac{d_{84.1}}{d_g} = \frac{d_g}{d_{15.9}} = \left(\frac{d_{84.1}}{d_{15.9}}\right)^{1/2}$$

$$d_g = \left(d_{84.1} d_{15.1}\right)^{1/2}$$

Sturm (2001)