# 2022 Fish Passage and Stream Restoration Design Training

## Module 8: Geomorphic Assessment for Stream Crossings

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Geomorphologist
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# Cygnia Rapp, LG

**Geomorphologist**
**HQ Hydraulics, Hydrology Team**
**WSDOT**

***Current duties:*** Provides technical support on fish passage and CED projects, leads research for supporting the design of more resilient infrastructure near gravel-bed streams.

***Background & Experience:*** Cygnia Rapp is a Fluvial Geomorphologist of 20+ years and lead author of state guidelines for assessing channel migration and delineating the channel migration zone. Her current research interest is developing state-of-science guidance and methodology in assessing sediment transport to support the design of resilient infrastructure along and near gravel-bed streams. This research includes the potential for emerging technologies in data collection to enhance the calibration of modern sediment transport models. Cygnia specializes in the evaluation of geomorphic processes as they relate to flooding, channel migration, and the creation and restoration of aquatic habitats.

***Education:*** University of Chicago, BA in Physical Geography, Special Honors, 1994; Arizona State University, MS in Geomorphology, 1997

***Personal interests:*** Cygnia lives in Bellingham and enjoys skate skiing, mountain biking, and elk hunting.

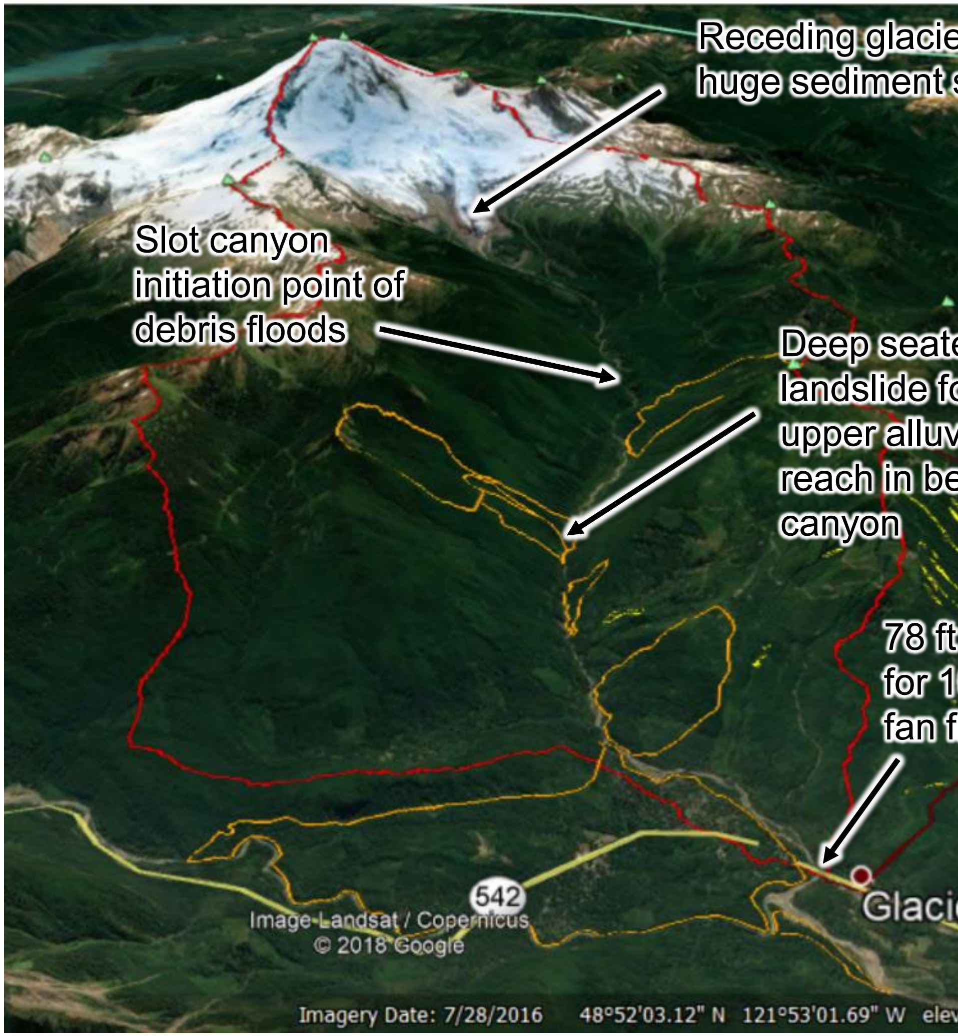
# Agenda

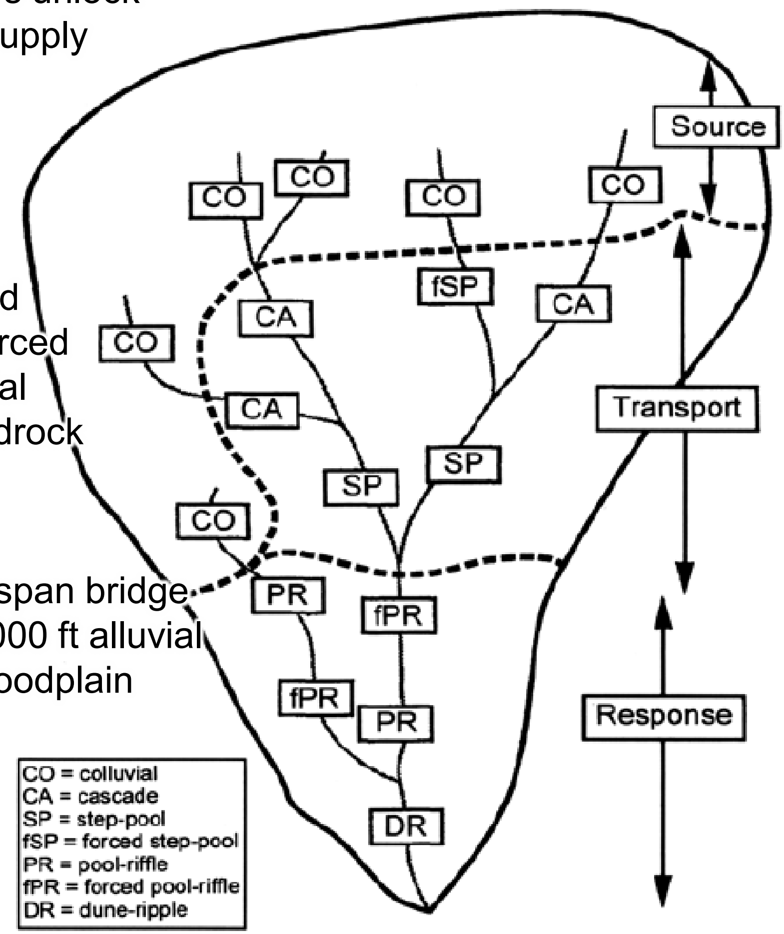
- Terms, Basic Concepts
- Assessment of Vertical Channel Stability

What this presentation is NOT: 101 Fluvial Processes Course

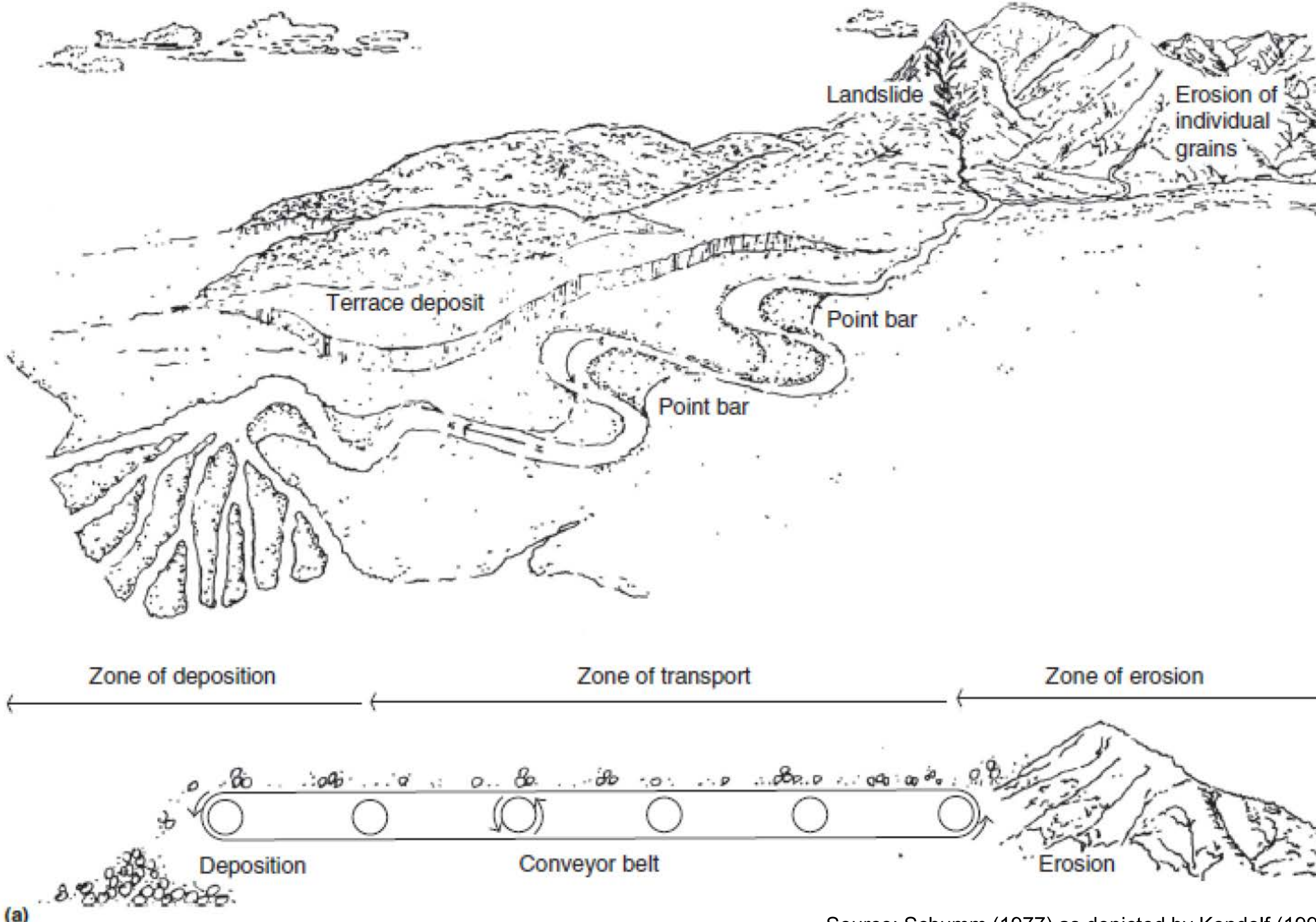
# Terms, Basic Concepts

# Channel Network, Process Domains

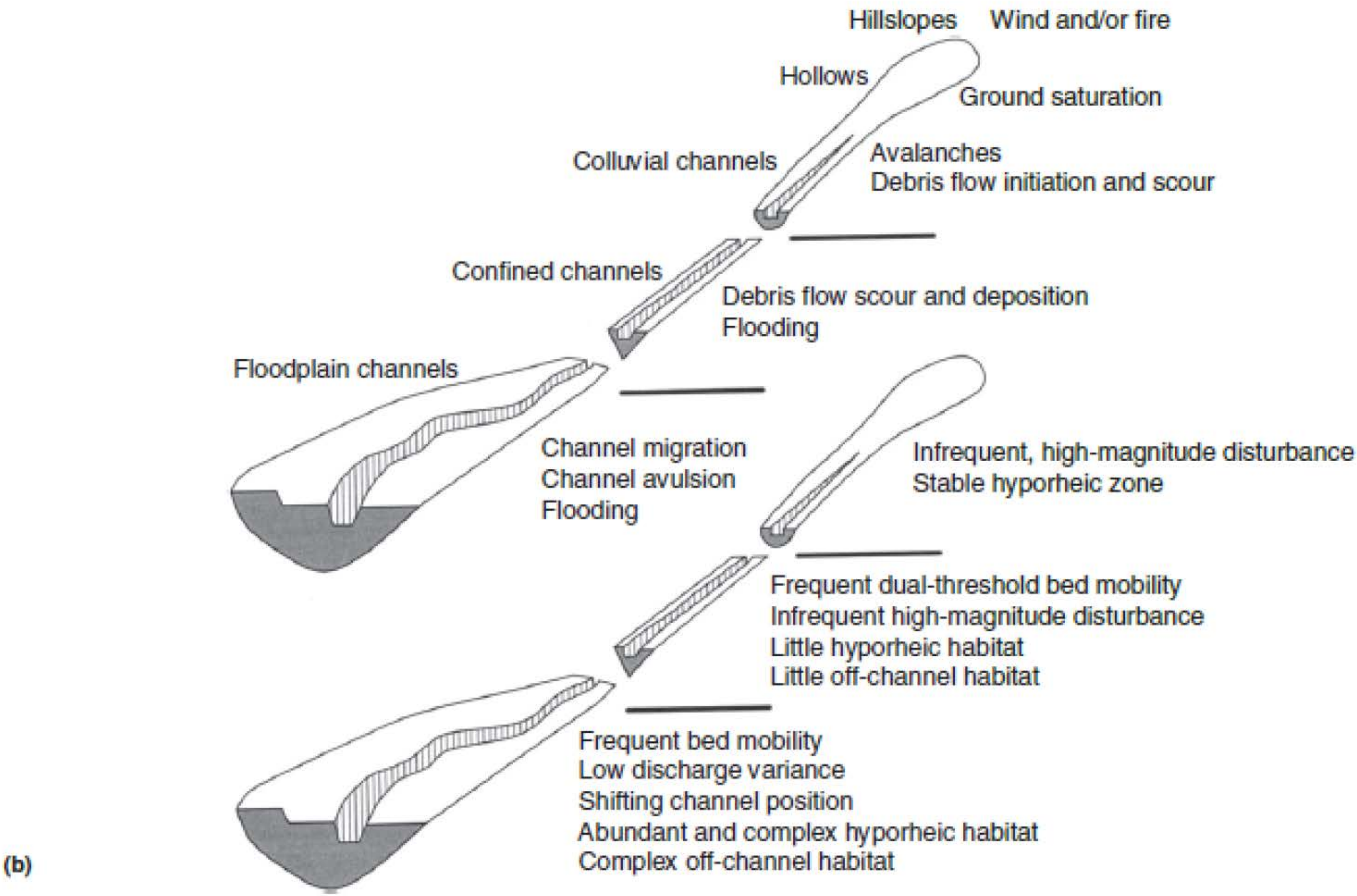



Source: Montgomery and Buffington (1998)

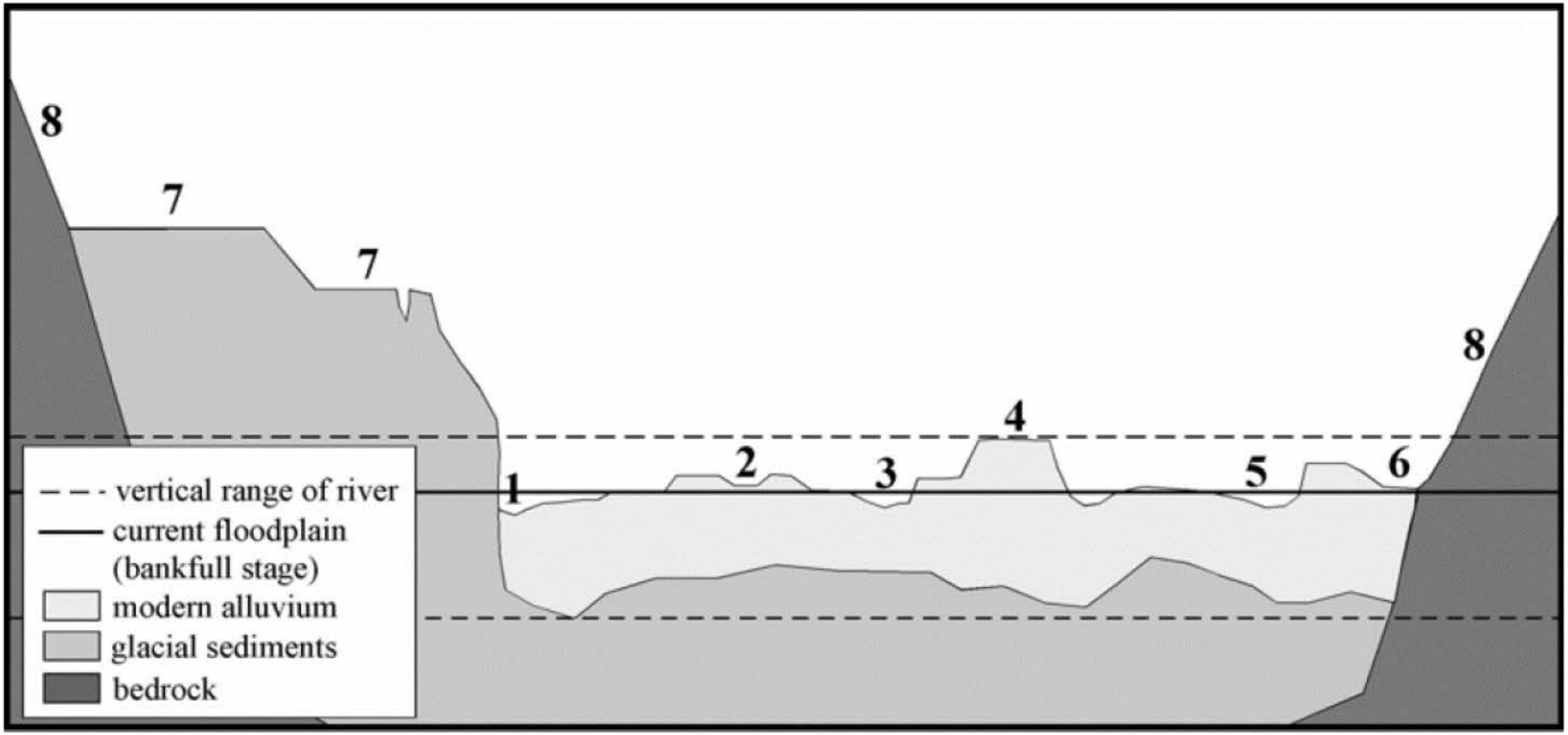



Source: Schumm (1977) as depicted by Kondolf (1994)

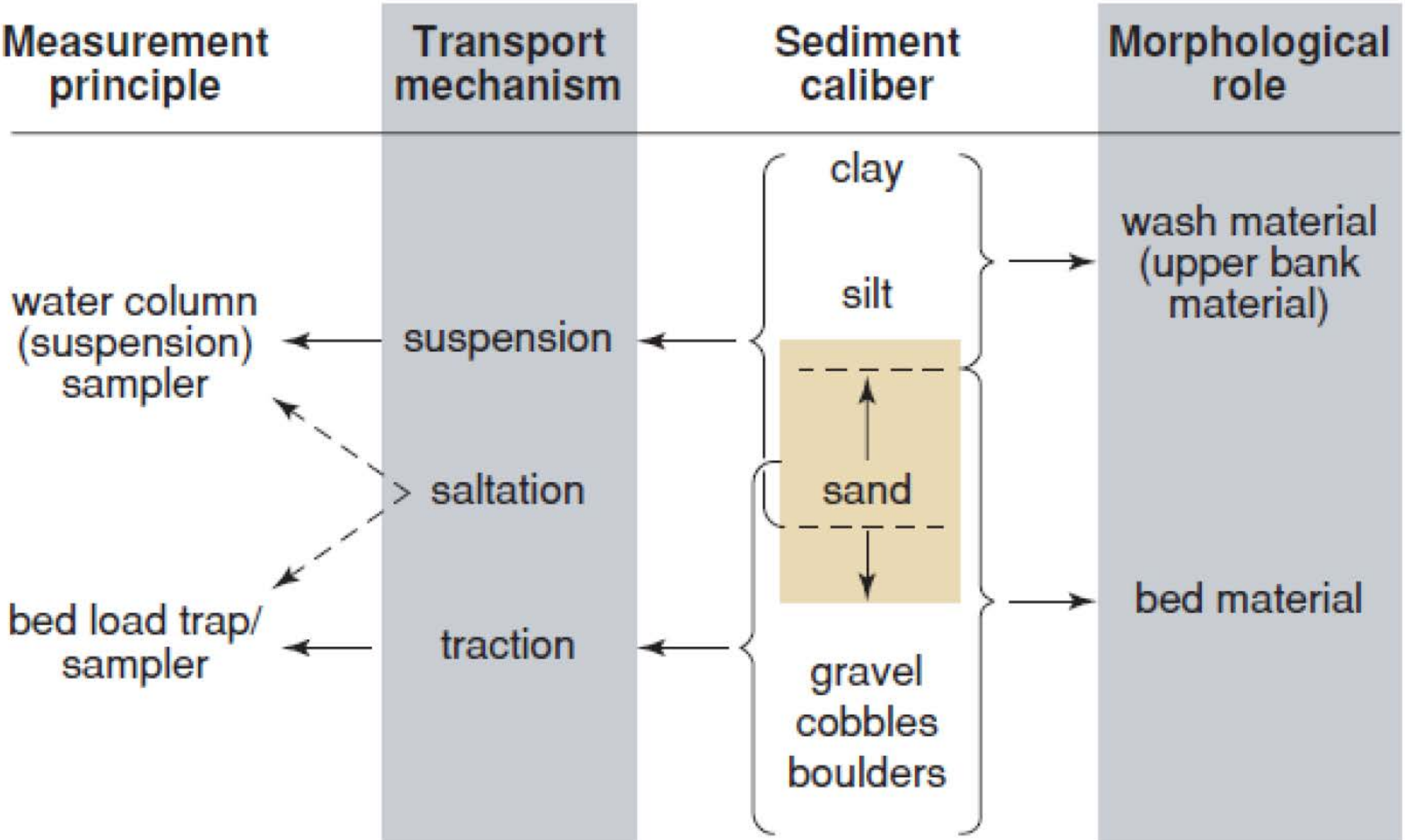



Source: Montgomery (1999)

# Alluvial River Valley Landforms




Source: Rapp and Abbe (2003)




Source: Church (2006)

# Definitions

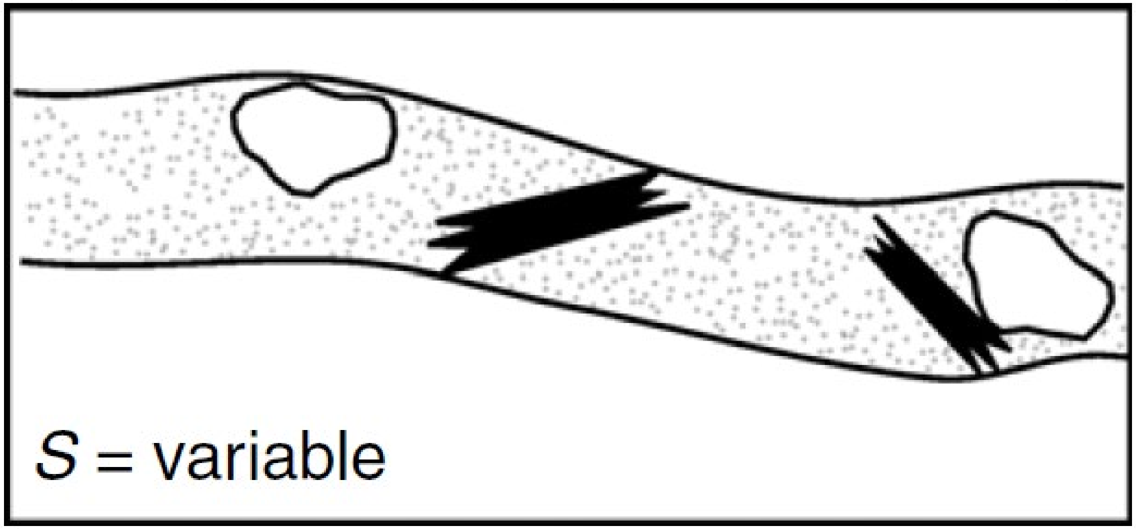
- Bed Material
  - Material that forms the bed, lower banks of the river
  - Chiefly determines morphology of the channel
  - In alluvial channels, corresponds with coarser part of the sediment load
  - May move either as bedload or as intermittently suspended load

- Wash material:
  - Material that, once entrained, is transported for long distance in suspension
  - Found only in minor quantities (interstitial trapping) in streambed
  - May form significant fraction of upper bank and floodplain deposits from deposition in overbank flows
  - Wash material one reach may become bed material in another reach with lower sediment transporting power

Source: Church (2006)

# Colluvial Stream Type

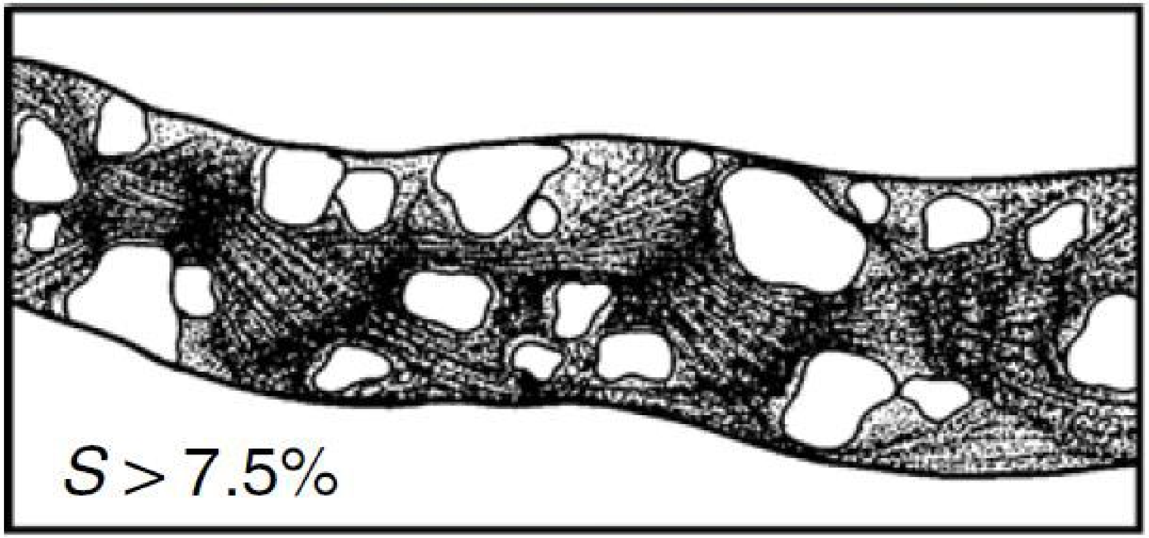
- First-order channels
- Perennial or ephemeral
- Streambed poorly sorted sand- to boulder-sized sediment
- Stochastically occurring obstructions
- Steep channel gradients
- Little scouring energy, shallow stream flows, in-channel obstructions large relative to channel size
- Directly coupled to confining hillslopes
- Prone to mass wasting, bulking debris flows




Source: Montgomery and Buffington (1997)
Buffington and Montgomery (2013)

# Cascade Stream Type

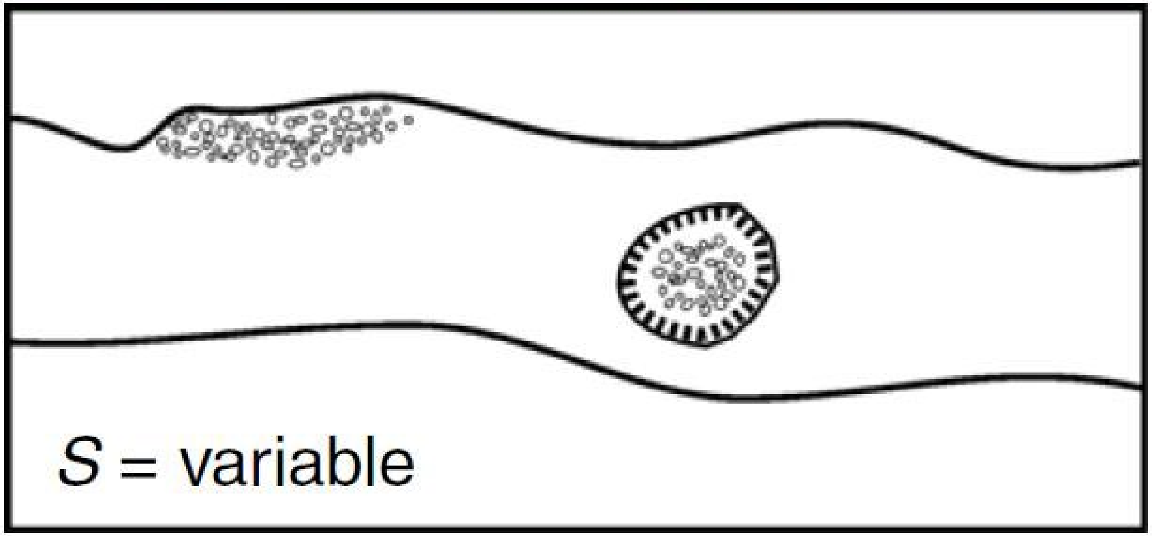
- Chaotic arrangement of boulder-sized bed material
- Continuous macroscale turbulence
- Confined by valley walls
- Directly coupled to hillslopes
- Boulders are lag deposits
- Steep gradients
- Concentrated flow, efficient transport of cobble- to sand-sized sediment during annual floods
- Movement of channel forming boulders requires infrequent large floods
- High mobility of D50 during bankfull flow
- Little sediment storage
- Infrequent, turbulent pools of low volume
- May be prone to debris flow passage




Source: Montgomery and Buffington (1997)
Buffington and Montgomery (2013)

## Bedrock Stream Type

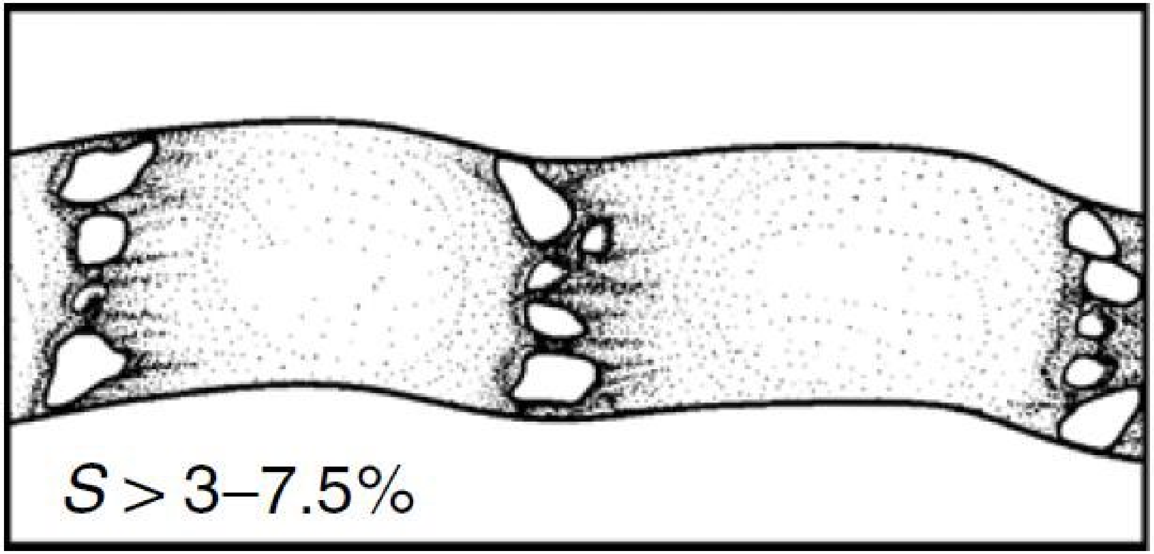
- Typically confined
- Bedrock or clay bed
- Bedrock reaches lack persistent or continuous alluvial bed
- Bedload transport rate greater than sediment supply
- Recent debris-flow scour
- Legacy from land disturbance (e.g., log jam removal, splash dams)
- Pools, flow obstructions may retain alluvial pockets
- Incision into till can behave similarly




Source: Montgomery and Buffington (1997)
Buffington and Montgomery (2013)

## Free-Formed Step Pool Stream Type

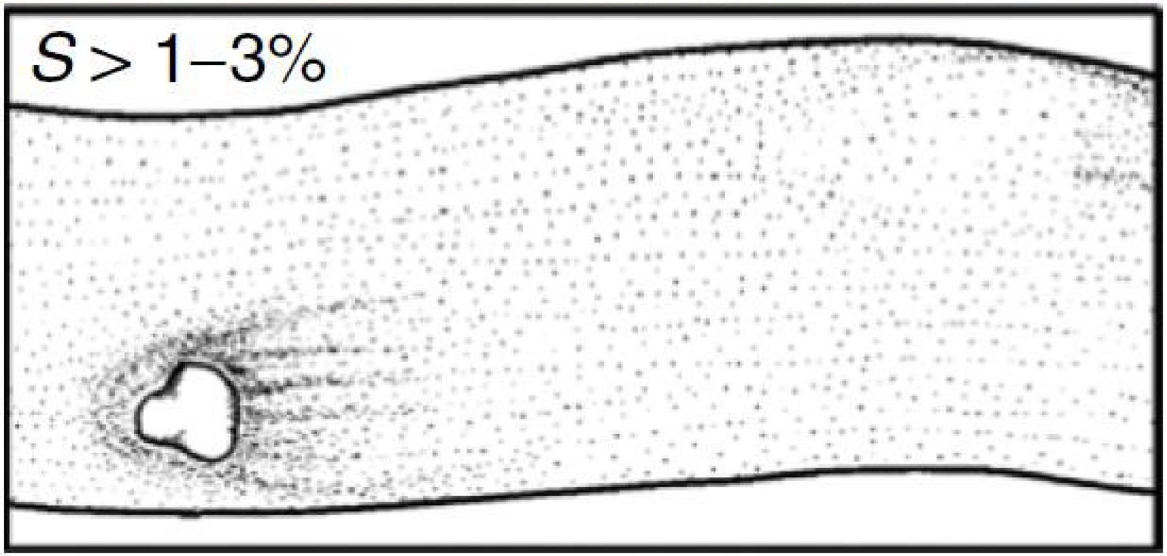
- Repeating sequences of steps, plunge pools
- Steep-gradient, confined channels, little floodplain development
- Directly coupled to hillslopes
- High transport capacities
- Moderate to high mobility of D50 during bankfull flow
- Supply, mobility of boulders same as cascade channels
- Amplitude and wavelength of steps and pools may adjust
- Significant roughness due to low W:D ratios, low relative submergence
- May be prone to debris-flow passage




Source: Montgomery and Buffington (1997)
Buffington and Montgomery (2013)

# Plane Bed Stream Type

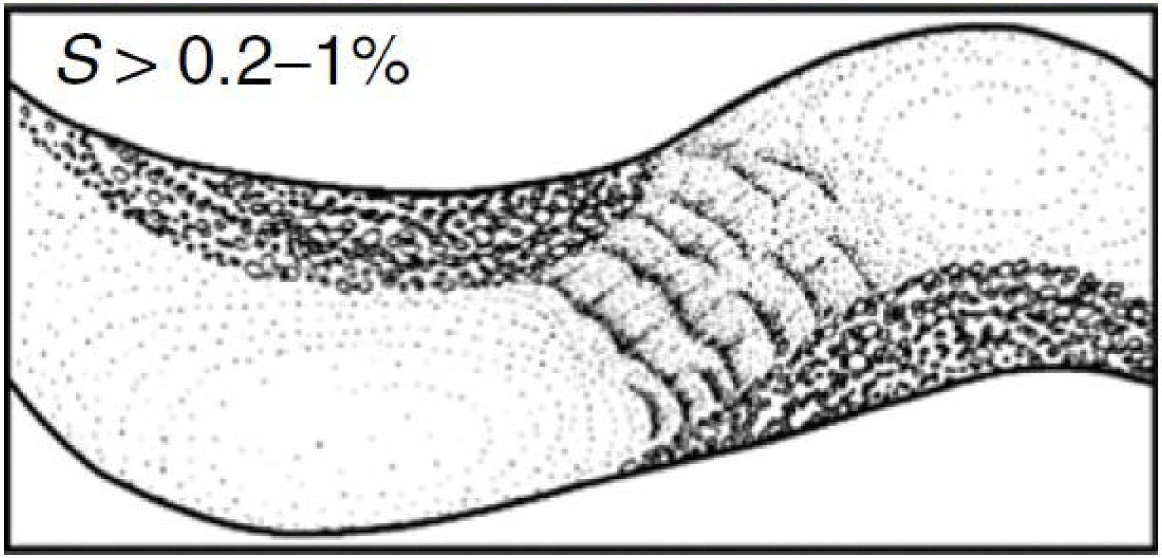
- Long reaches of glide, run, or riffle morphology
- Lacks significant pool, bar topography
- Moderate-gradient channels dominated by gravel/ cobble bed material
- Some sand, occasional boulders
- Variable confinement, floodplain extent, hillslope coupling
- Low W:D ratios, low relative submergence, damp lateral flow oscillations
- Typically armored bed surface
- Two-phase bed load transport
- Bankfull discharge typically effective discharge
- Susceptible to obstruction-forced pool formation




Source: Montgomery and Buffington (1997)
Buffington and Montgomery (2013)

# Free-Formed Pool-Riffle Stream Type

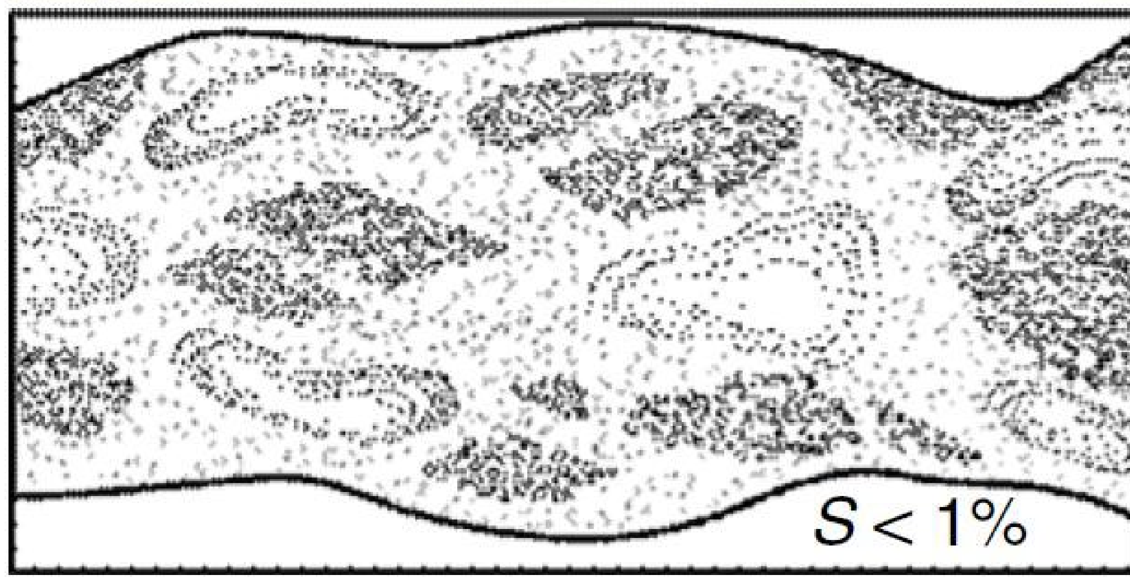
- Alternating pool and bar topography
- Spatial variation of flow and bed form deposition
- Moderate W:D ratios, large relative submergence
- Typically moderate- to low-gradient, unconfined channels
- Gravel/cobble/sand bed material, extensive floodplains
- Decoupled from hillslopes, lateral sediment inputs
- Except where channel migrates against valley wall, terrace
- Extensive sediment storage in floodplains, bar forms
- Typically armored bed
- Two-phase bedload transport
- Unless high sediment supply reduces armoring and effective discharge
- Susceptible to obstruction-forced pool formation




Source: Montgomery and Buffington (1997)
Buffington and Montgomery (2013)

## Braided Stream Type

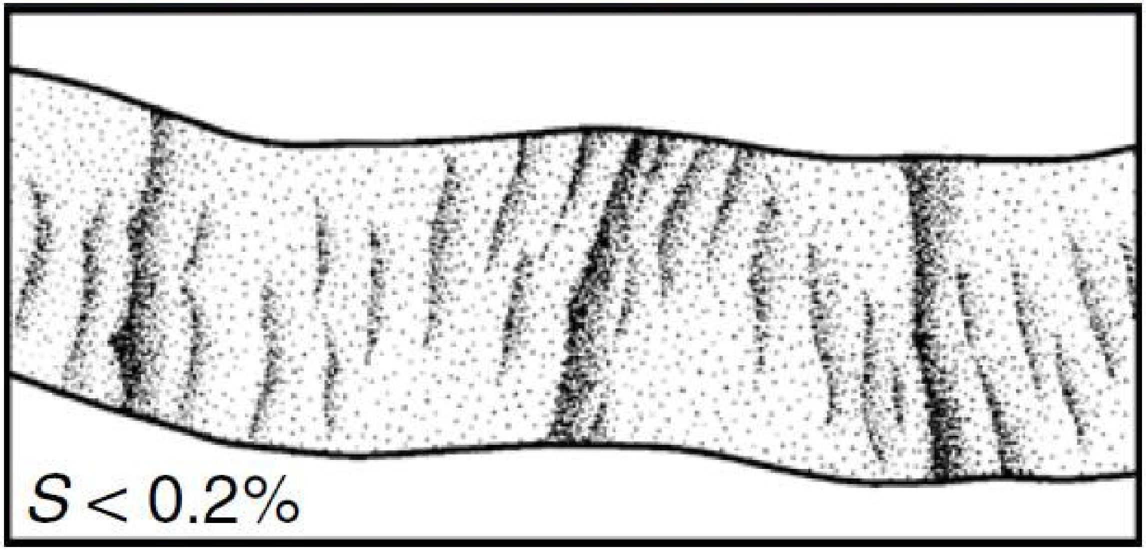
- Multithread rivers, large W:D ratios, wide range of slopes
- Bed material may be sand or gravel/cobble
- Correspondingly different values of relative submergence, bed mobility at bankfull flow
- Individual braid threads may have pool-riffle morphology or bar-riffle morphology lacking pools
- Pool scour commonly occurs where braid threads converge
- Braiding frequently results from high sediment loads, channel widening caused by bank destabilization
- Extensive sediment storage in bed forms




Source: Montgomery and Buffington (1997)
Buffington and Montgomery (2013)

# Dune-Ripple Stream Type

- Low-gradient, unconfined, sand-bed rivers occupying large alluviated valleys
- Typically decoupled from hillslopes
- Variety of mobile bed forms that depend on stage, Froude number, transport intensity
- Transport-limited, low threshold for bed load transport, very high bankfull mobility
- Low roughness due large W:D ratios, large relative submergence
- Bed form roughness may be significant
- Extensive sediment storage in bed forms, floodplain

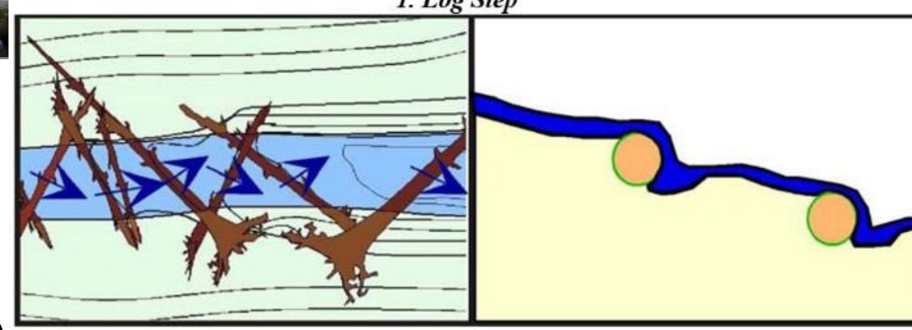


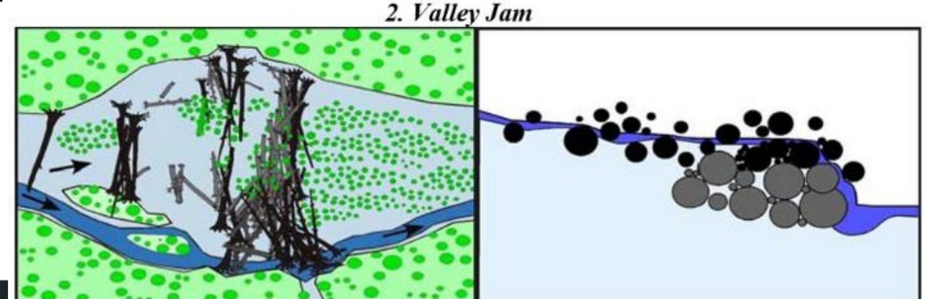

Source: Montgomery and Buffington (1997)
Buffington and Montgomery (2013)

# Forced Step Pool Stream Type

- Log steps form when a tree bole spans the channel
- Each end is locked in place along the channel margins by rock boulders, woody debris, or sediments
- Valley jams are large, complex grade control structures
- Slopes from 2% to 20%
- Force morphologies reduce channel gradient and redistribute energy loss through the reach
- Loss of large wood may transform channel to step-pool, cascade, or bedrock channel

Photo by Tim Abbe

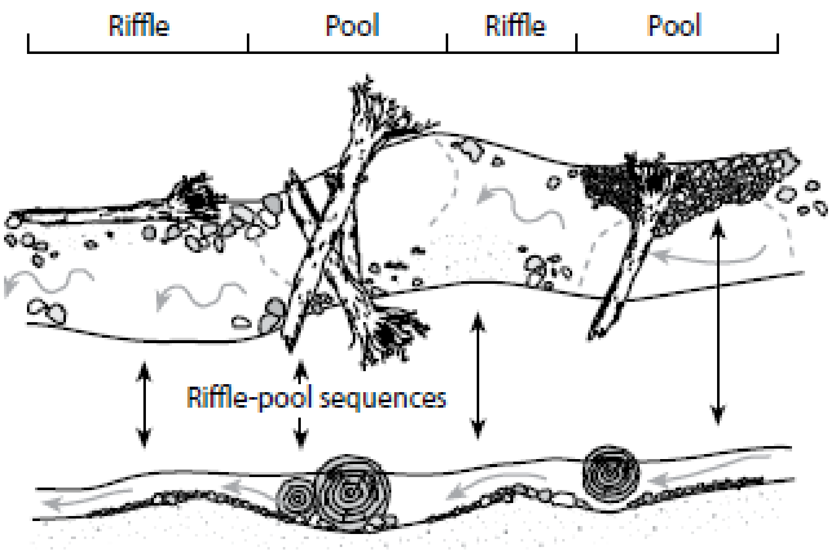


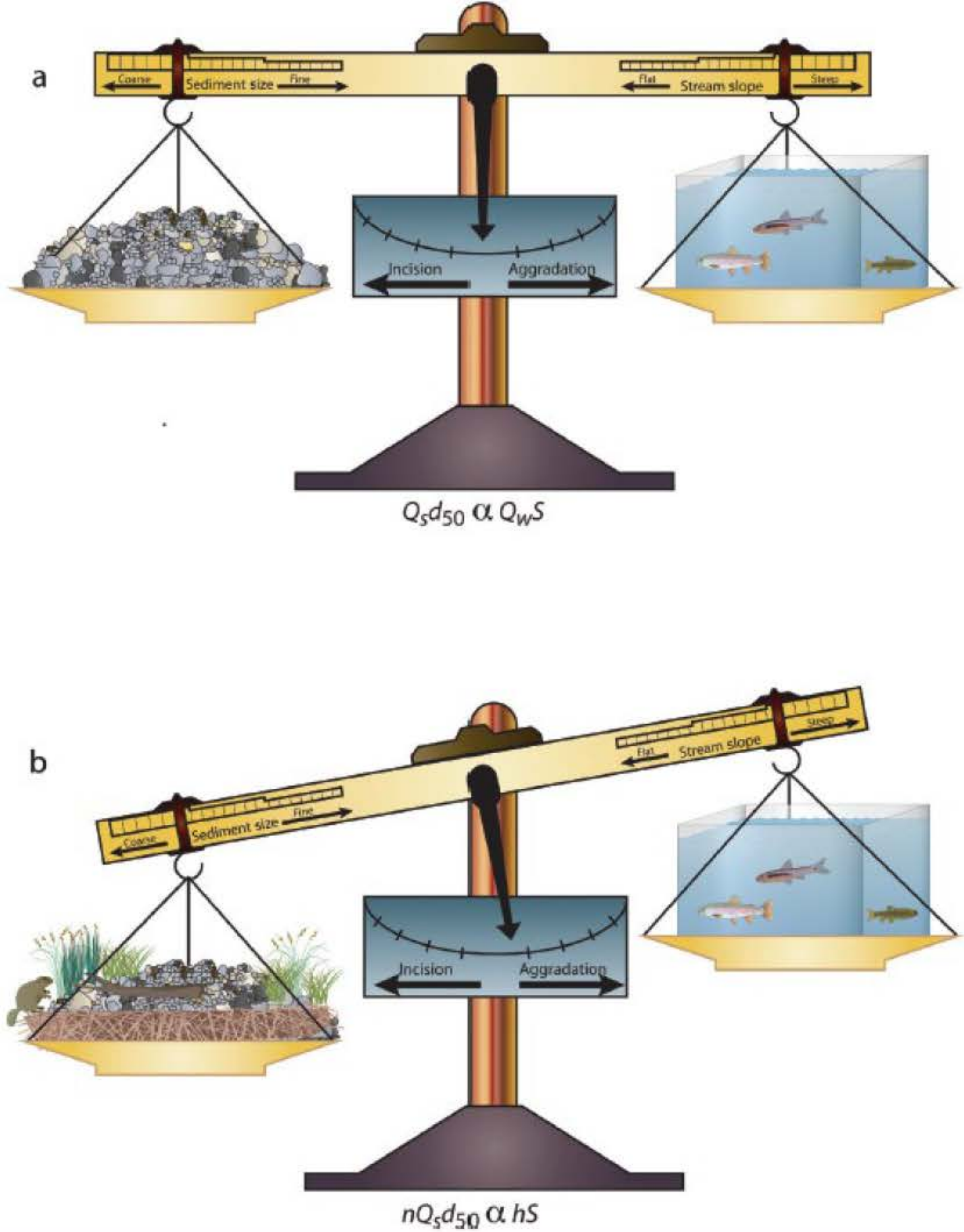




Source: Rapp and Abbe (2003)

## Forced Pool Riffle Stream Type

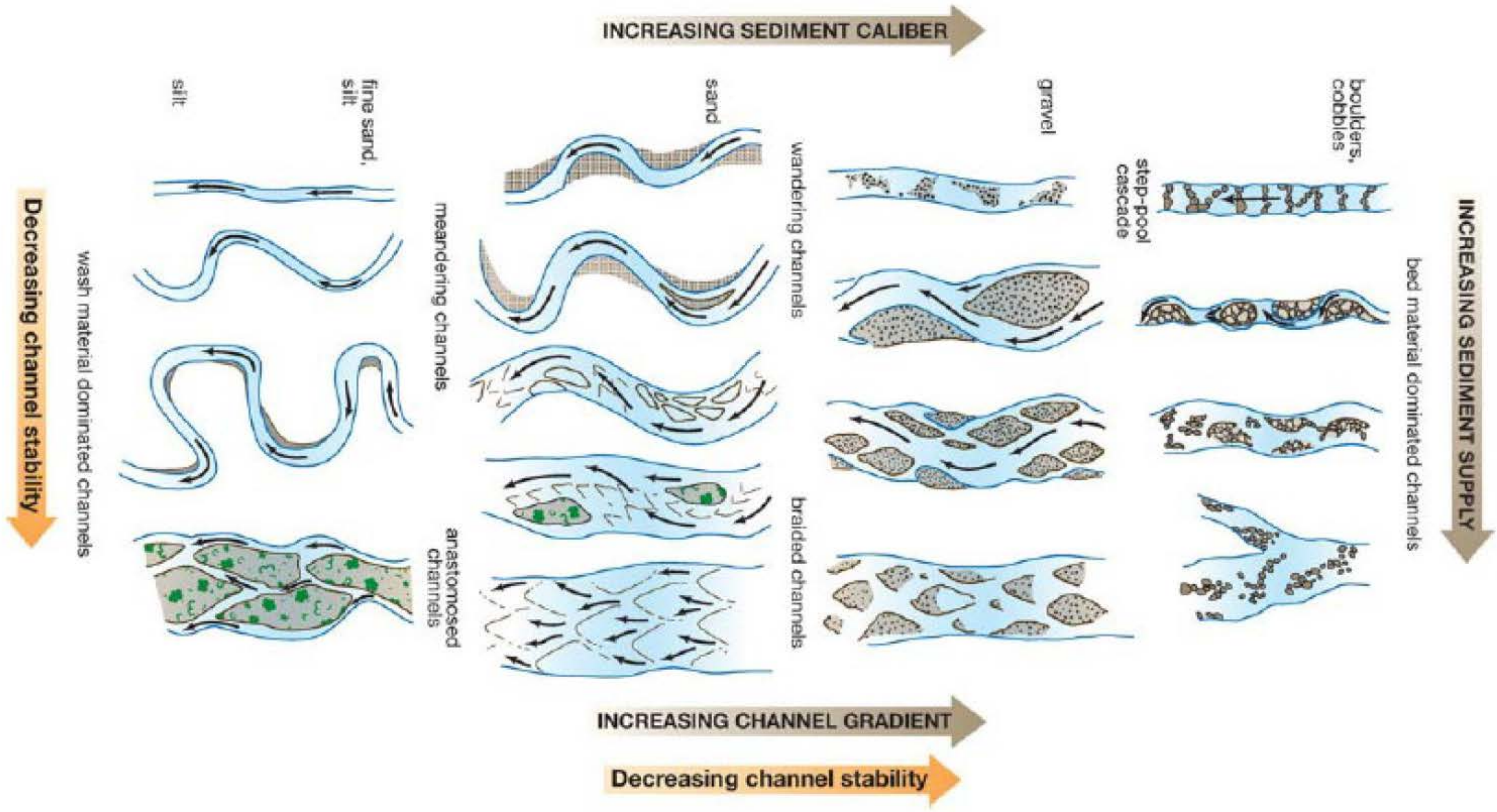
- Slopes overlap range of free-formed pool riffle and plane bed channel types
- Pool spacing depends on wood loading, channel type, slope, width
- Mean pool spacing decreases from >13 channel widths per pool to <1 channel width with increasing wood loading
- Pool spacing for free-formed pool-riffle 2 – 4 channel widths, forced pool-riffle <2 channel widths
- Loss of large wood may transform channel to free-formed pool-riffle, plane bed

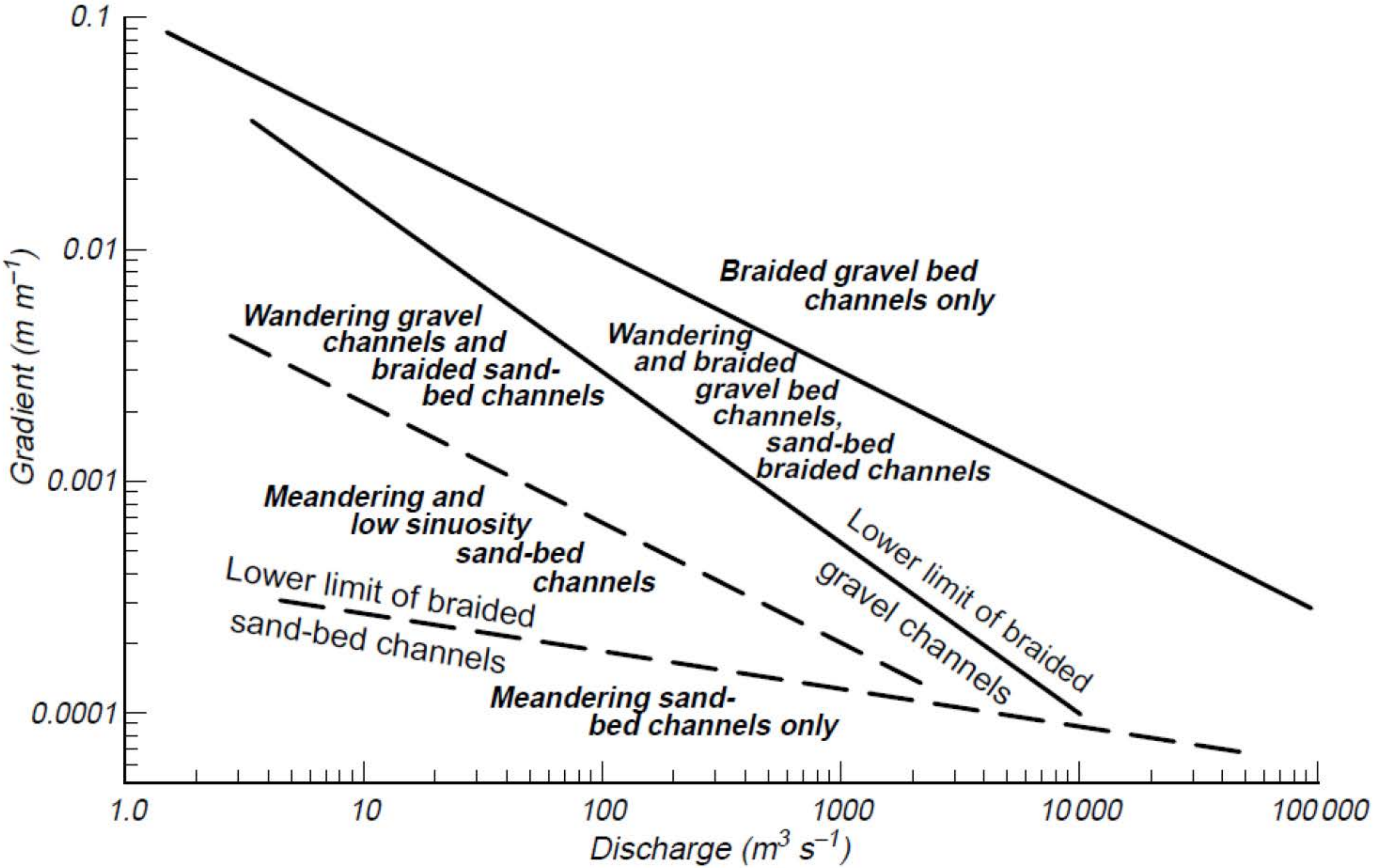



Source: Pollock et al (2014),
Adapted from Lane (1955)

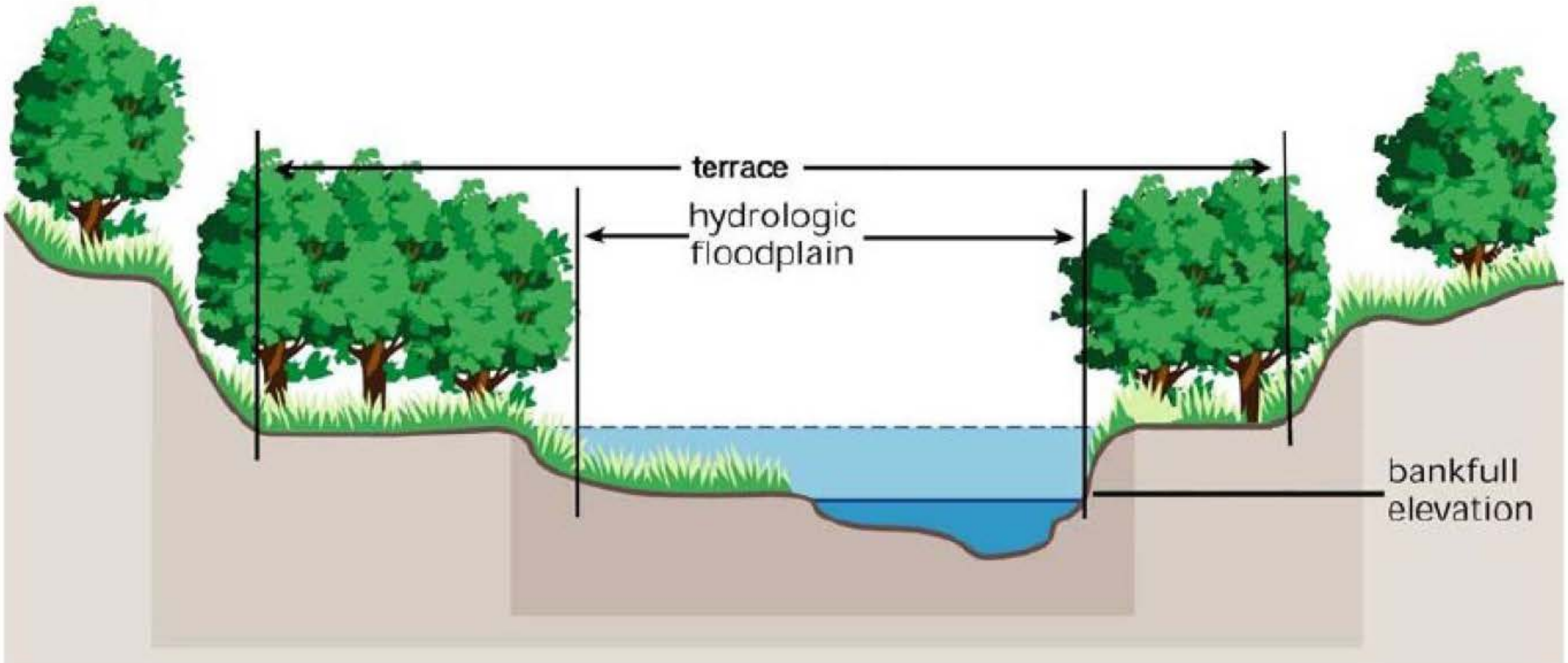
# Channel Patterns: Process Drives Form

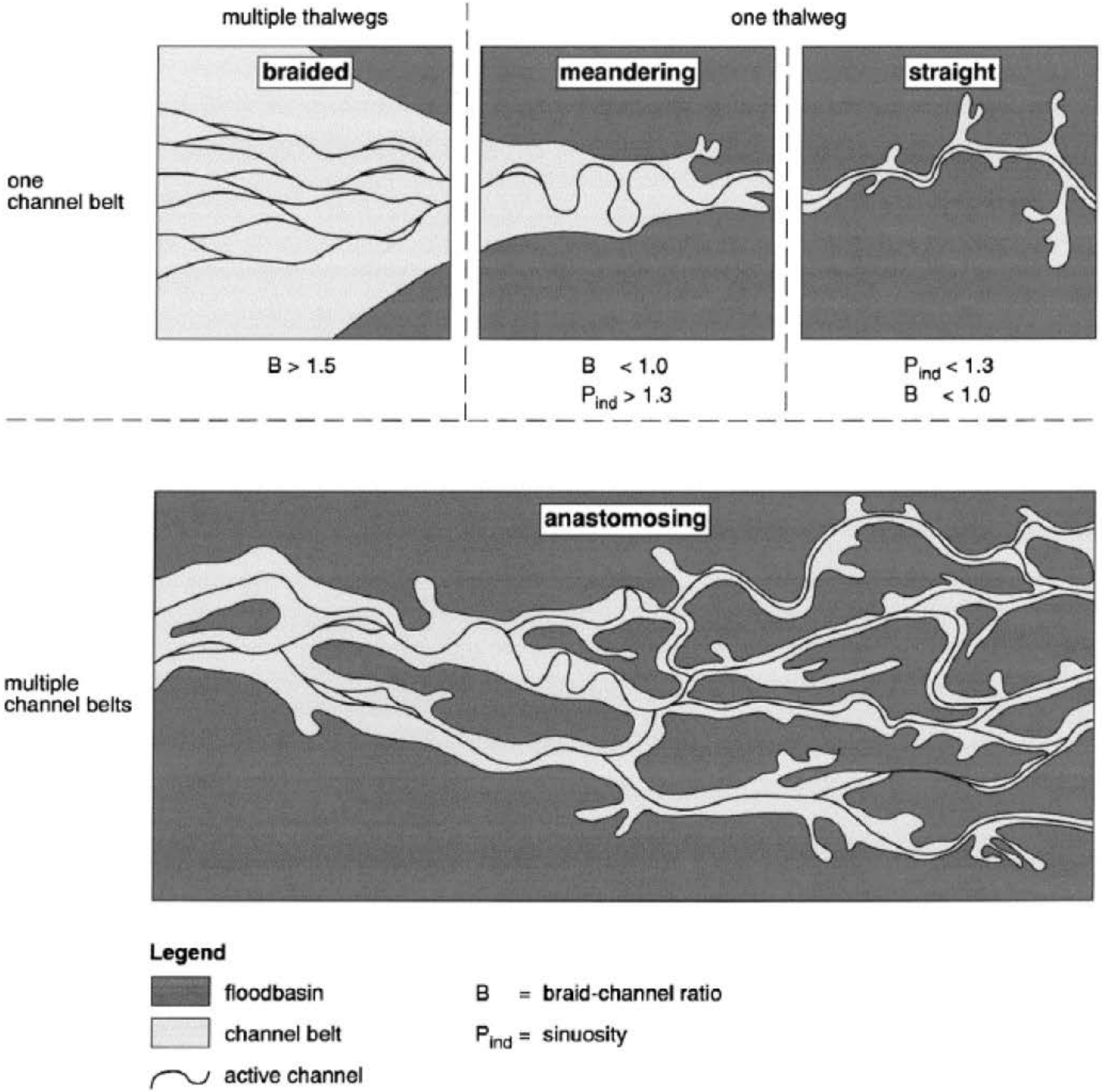



Source: Church (2006)




Source: Church (2002)


terrace
hydrologic
floodplain
bankfull
elevation

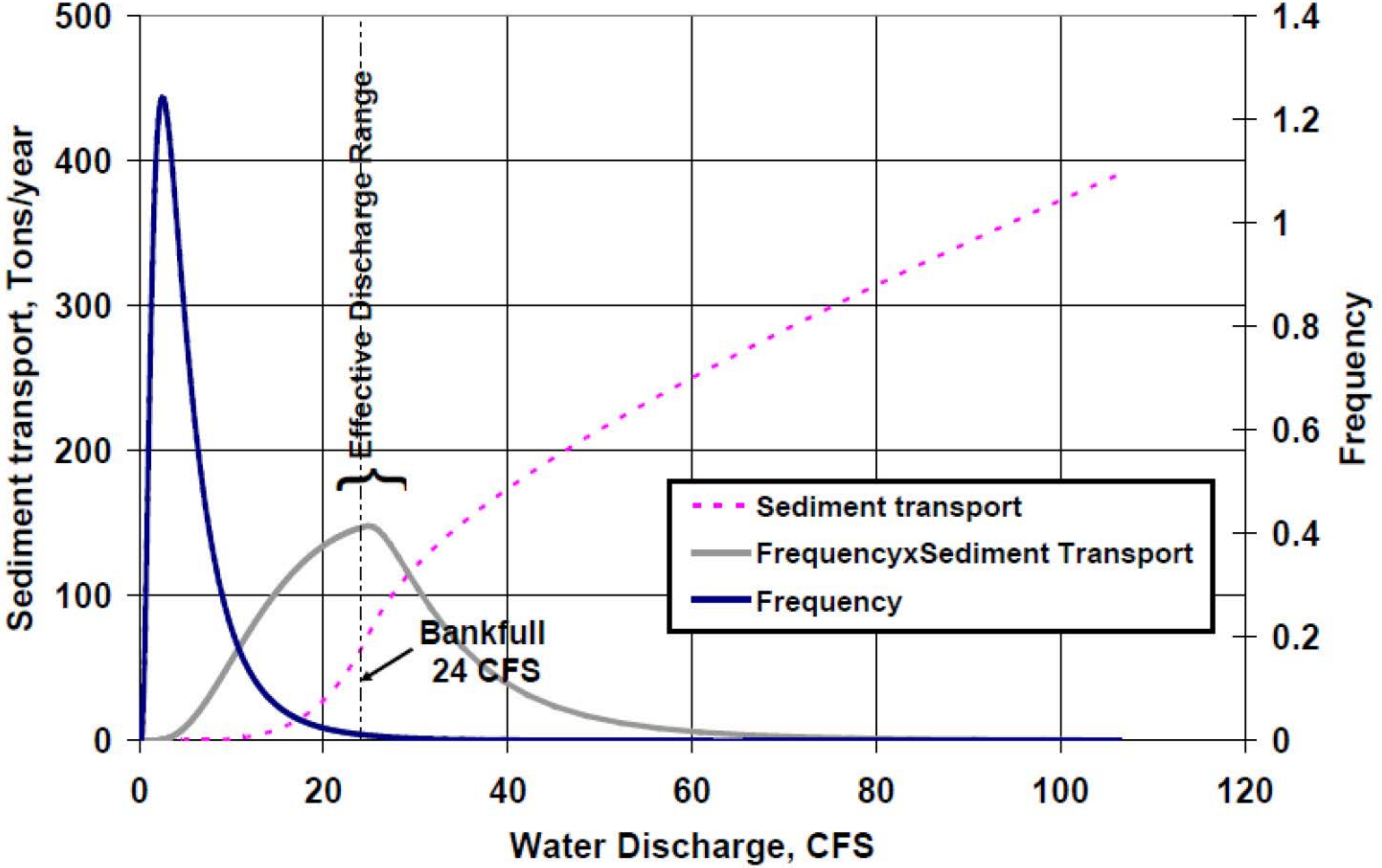



Source: Makaske (2001)


Hoh River


Carbon River

# Bankfull and Effective Discharge



# Bankfull Discharge: Process Drives Form

- The bankfull discharge is the discharge that is most efficient at doing work within the stream channel
- Bankfull discharge—optimum combination of stream power and frequency
- Bankfull discharge usually the focus of stream restoration designs, sediment transport analyses
- Varies by region (Castro and Jackson, 2001):
  - Western WA: 1.2 year
  - Eastern WA: 1.4 to 1.5 year
- Castro and Jackson (2001) can be used to approximate bankfull width and depth when they cannot be determined defensibly in the field
  - Appropriate for single meandering systems
  - Does not apply to braided channels, multithread systems

# Suggested Resources


- Buffington, J.M. and D.R. Montgomery. 2013. Geomorphic classification of rivers. In: Shroder, J.; Wohl, E., ed. Treatise on Geomorphology; Fluvial Geomorphology, Vol. 9. San Diego, CA: Academic Press. p. 730-767

- Castro, J.M. and P.L. Jackson. 2001. Bankfull Discharge Recurrence Intervals and Regional Hydraulic Geometry Relationships: Patterns in the Pacific Northwest, USA. Journal of the American Water Resources Association 37(5):1249-1262.

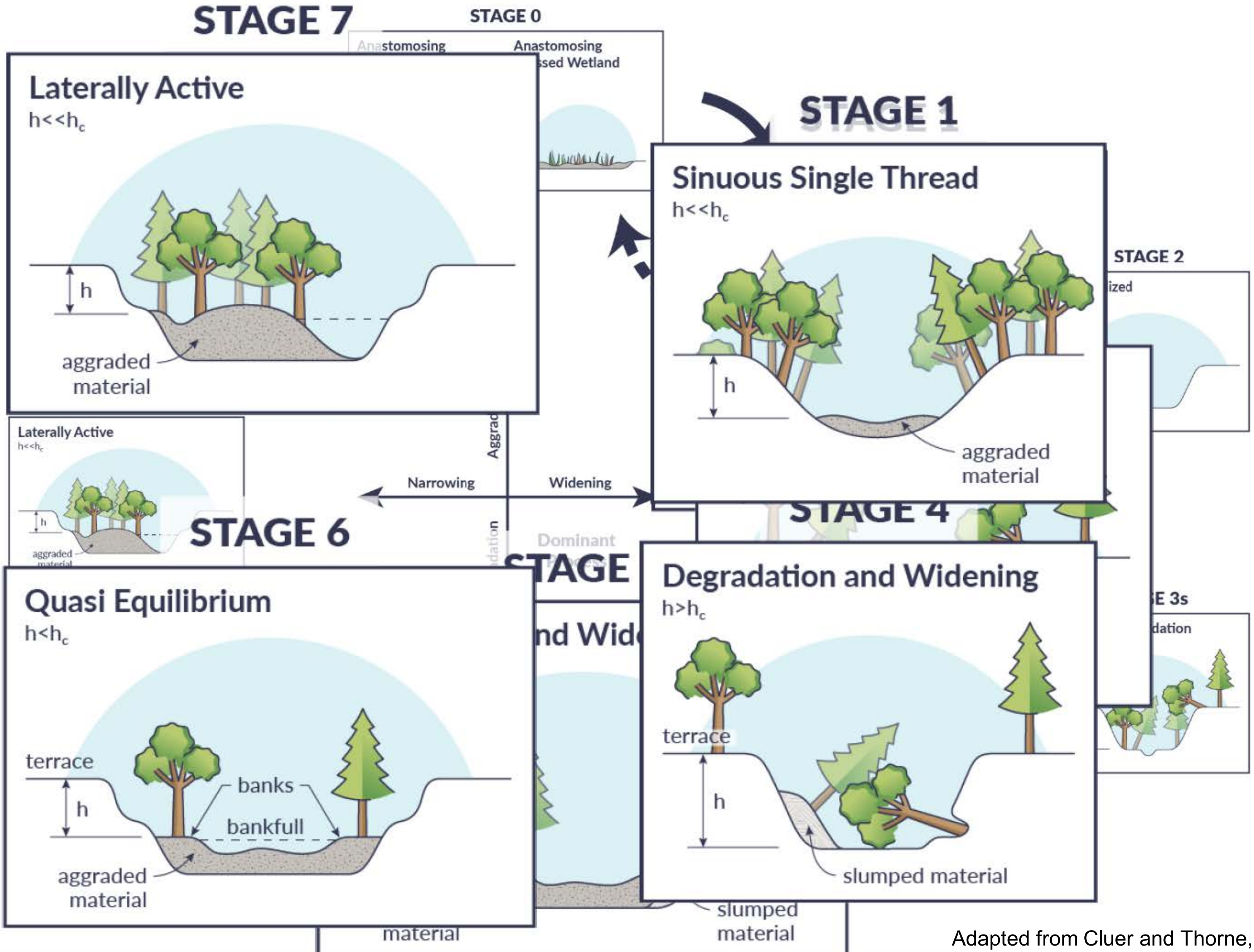
- Church, M. 2002. Geomorphic thresholds in riverine landscapes. Freshwater Biology 47:541-557.

- Church, M. 2006. Bed Material Transport and the Morphology of Alluvial River Channels. Annual Review of Earth and Planetary Science 34:325-54.

- Montgomery, D.R. and J.M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109, 596–611.


Source: Montgomery and Buffington (1997, 2013)

# Assessing Vertical Channel Change




Adapted from Cluer and Thorne, 2014

# Causes of Channel Incision

- Decreased erosional resistance
  - Decreased, modified riparian vegetation cover, rooting strength
  - Removal of instream structural elements
  - Loss of bed roughness, complexity
  - Increased bed mobility, disrupted armor layer
- Increase erosional forces
  - Watershed surface disturbance
  - Increased confinement of flows
  - Constriction of flow
  - Concentration of flow
  - Increased of gradient, energy slope
  - Increase of sediment-transporting flows
  - Decrease of sediment load

# Stream Impacts from Channel Incision

- Upstream migrating channel incision, channel deepening
- Increased bank height, if critical height exceeded, bank erosion
- Increased sediment supply due to erosion of channel boundary
- Disconnection of floodplains
- Prematurely dewatered, disconnected backwater habitat
- Locally increased channel slope, loss of pool habitat
- Drainage of shallow aquifers, affects riparian vegetation, wetlands, baseflows
- Increased meander cut-offs due to knickpoint migration
- Downstream channel aggradation, localized braiding

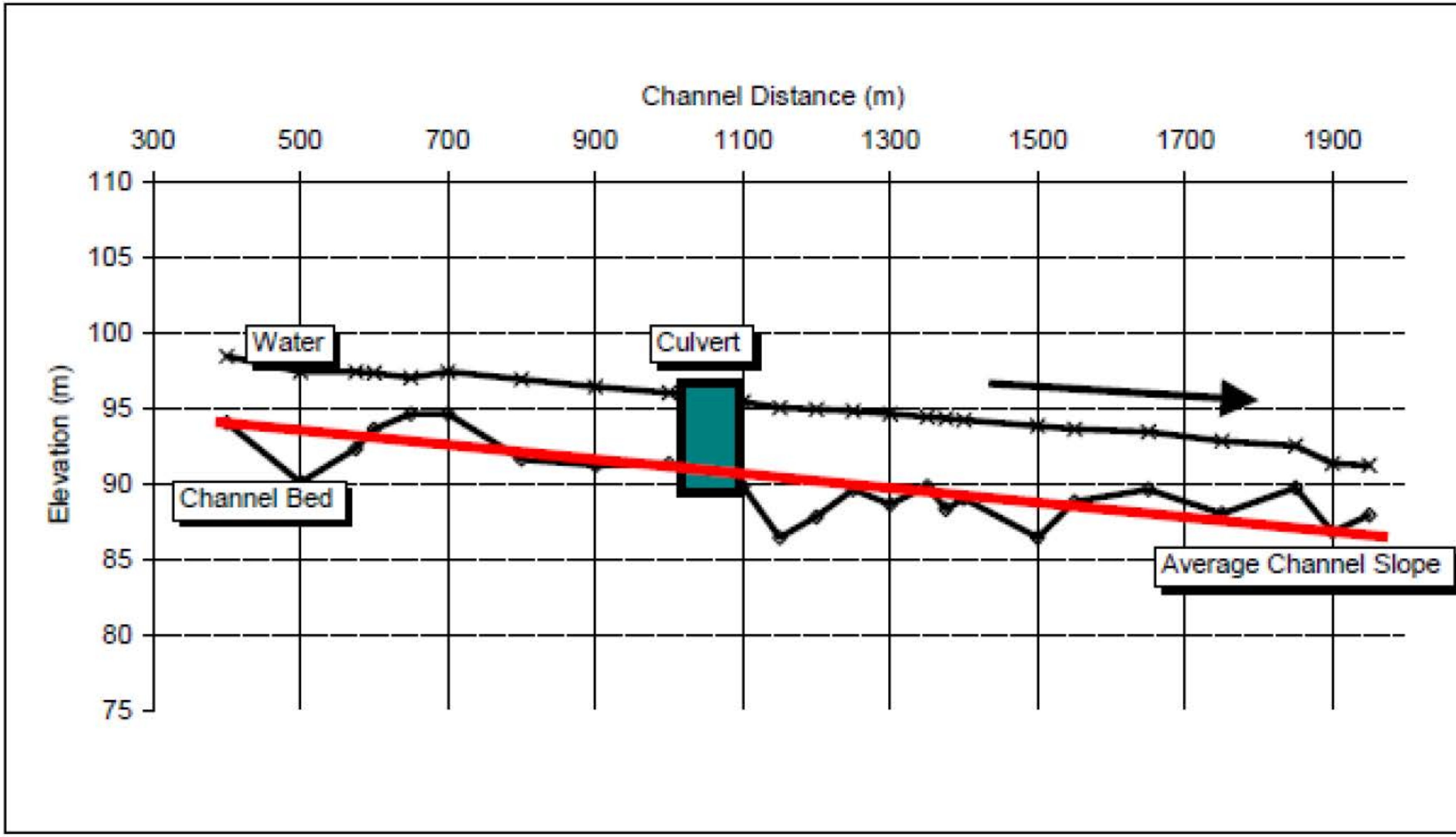
# Indicators of Channel Degradation

- Headcuts in the stream bed
- Lack of pool habitat in low gradient streams
- No sediment deposits on the channel bed
- Dead or dying riparian vegetation
- Vertical streambanks on both banks that extend down to the toe of the slope
- Bank seepage due to dewatering of aquifers
- Exposed cultural features
- Upland vegetation encroaching into floodplains and riparian areas

# Stream Profile Analysis

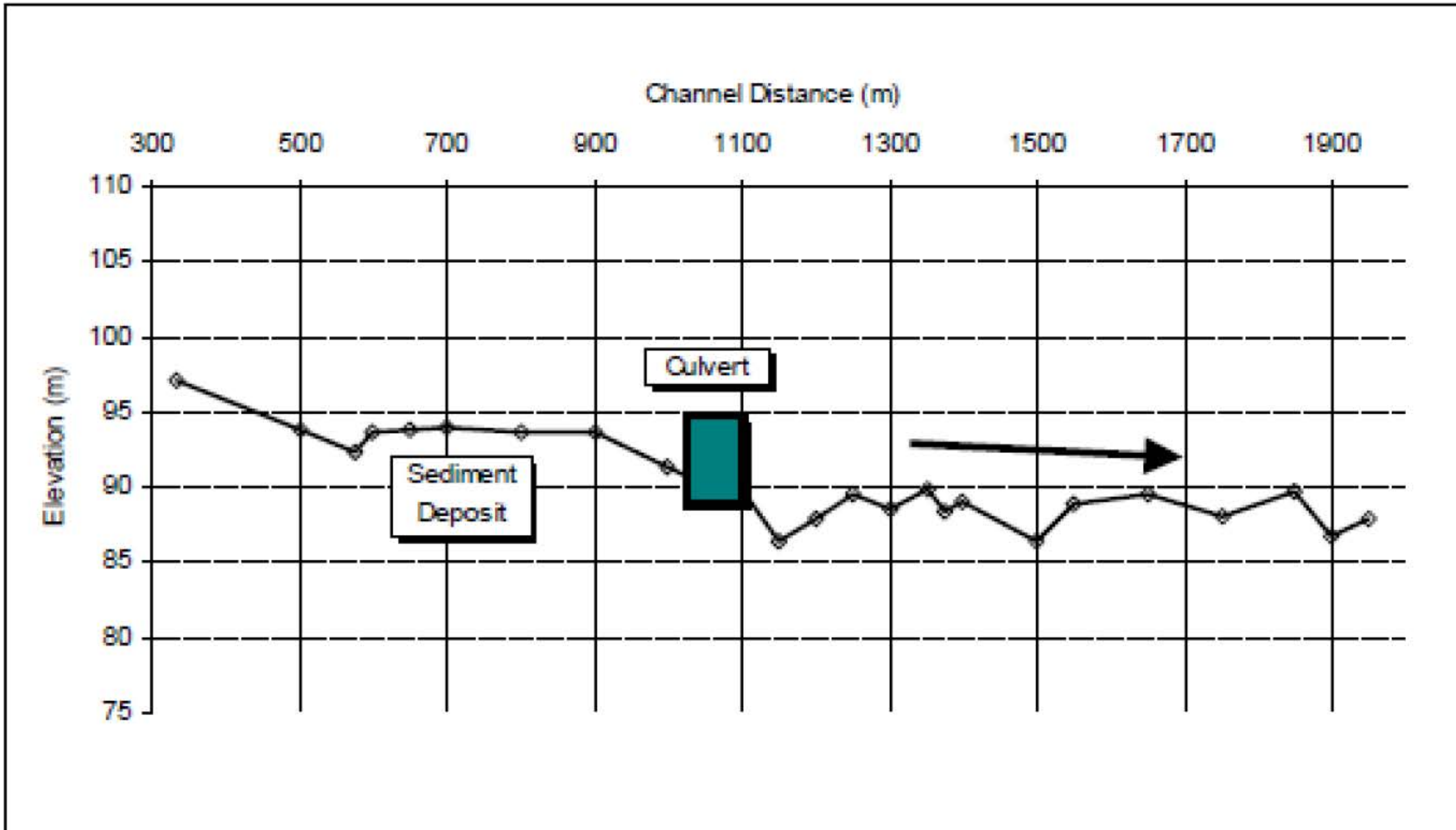
- Field recon, survey of longitudinal profile
- Constructed, naturally occurring bed controls
- Extend survey beyond influence of culvert, Minimum 20 channel widths
- May need to extend survey to capture potential headcut, calculate average slopes up-, downstream

# No Channel Offset



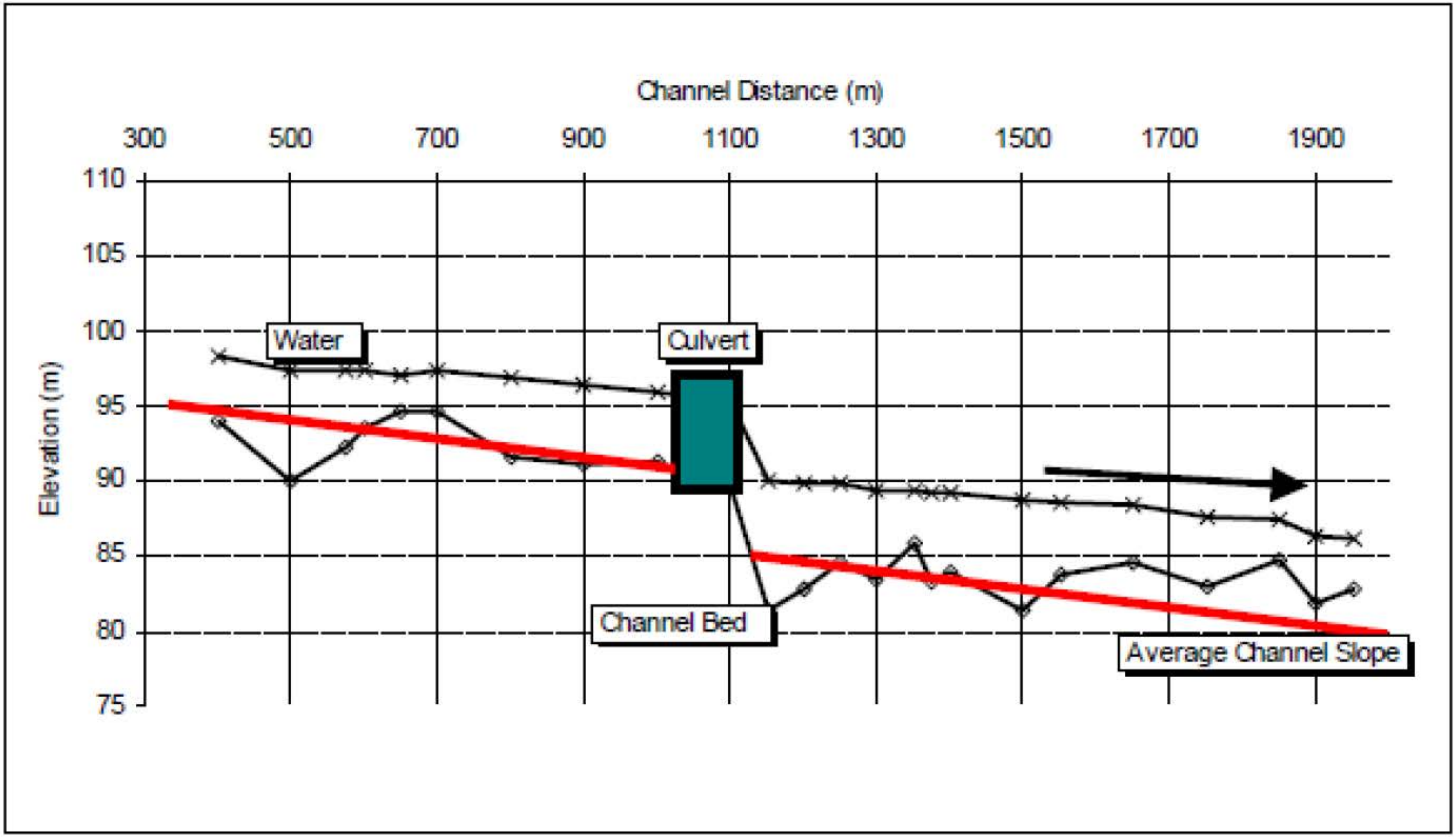

Source: Castro and Beavers (2016)

# Upstream Sediment Deposit




Source: Castro and Beavers (2016)

# Systemic Downstream Incision




Source: Castro and Beavers (2016)

# Suggested Resources


- Castro, J., Beavers, A. 2016. Providing Aquatic Organism Passage in Vertically Unstable Streams. Water, 8, 133; doi:10.3390/w8040133.

- Cluer, B., Thorne, C.R. 2014. A stream evolution model integrating habitat and ecosystem benefits. River Res. Appl., 30, 135–154.

- Harrelson, C.C.; Rawlins, C.L.; Potyondy, J.P. 1994. *Stream Channel Reference Sites: An Illustrated Guide to Field Technique*; General Technical Report RM-245; U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: Fort Collins, CO, USA.

- Schumm, S.A., Harvey, M.; Watson, C. Incised Channels: Morphology, Dynamics, and Control; Water Resources Publications: Littleton, CO, USA, 1984.

# Questions?