143SRPP
Stream Revitalization: Principles & Practices

LECTURE 5

Fluvial Geomorphology

Fluvial Processes: Equilibrium Concepts

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Channel Form Adjustment

"Gravity is a Constant!!" …….. Andrew Simon

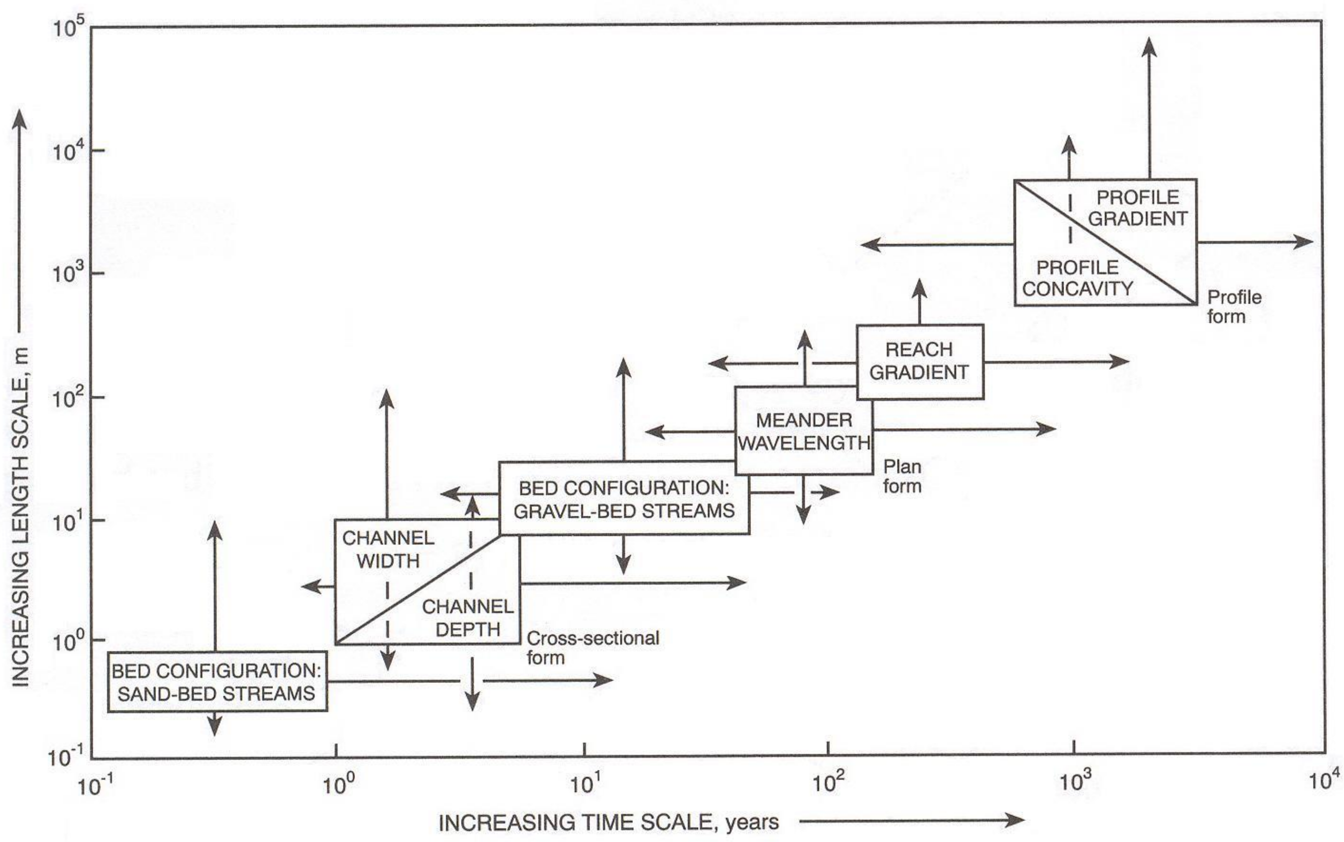
- The physics of erosion and deposition are the same wherever you are…no matter what hydro-physiographic province.
- Channel response of a stream type or river form is a matter of *quantifying available force (stream power), and resistance properties of the channel boundary.*
- **Channel adjustment** is driven by an imbalance between the driving and resisting forces ---- out of a ***dynamic equilibrium*** state.
- Differences in rates and magnitudes of adjustment, sediment transport rates and ultimate channel forms are a matter of defining those forces and resistance characteristics…..deterministically or empirically.

Fluvial Systems: Forms and Processes

Fluvial Process Timescales:

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

Dominant controls of channel form adjustment, independent variables include: climate, geology, soils, vegetation, and basin physiography.



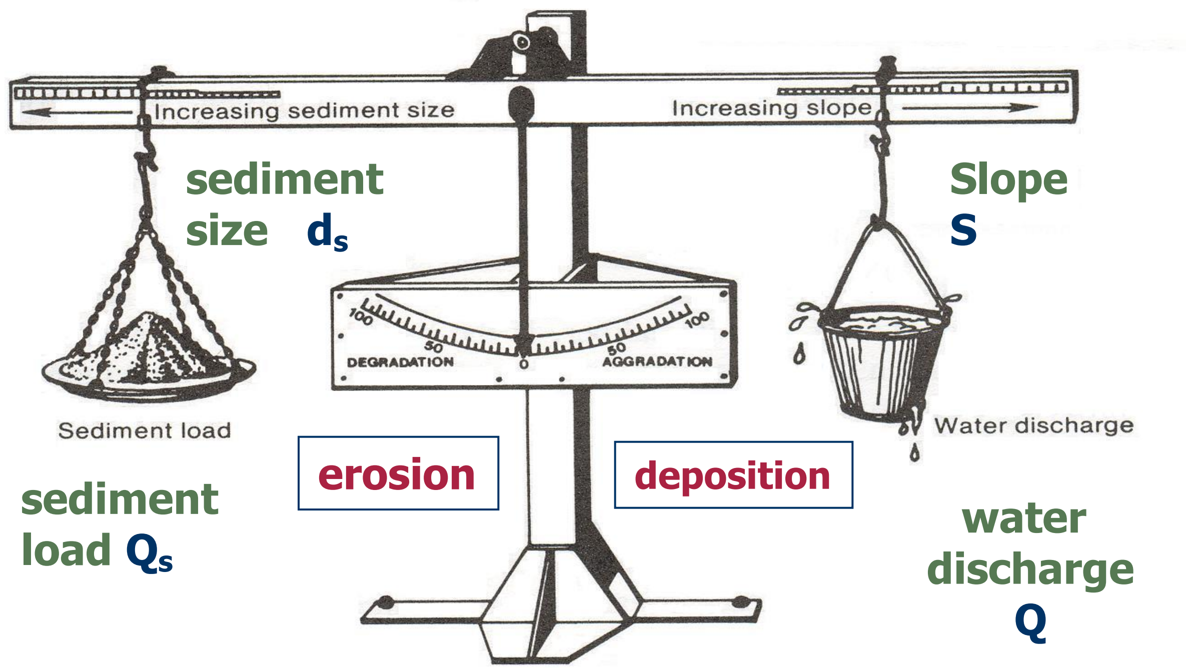
Knighton (1998)

Channel Form Adjustment

Lane's Law stable channel balance: $Q_s \cdot d_s = Q \cdot S$

The dominant controls of channel form adjustment include discharge and sediment load (*notably* bed material load).

Hey (1992) adds bank sediment and vegetation to the above set of independent variables (dominant controls).

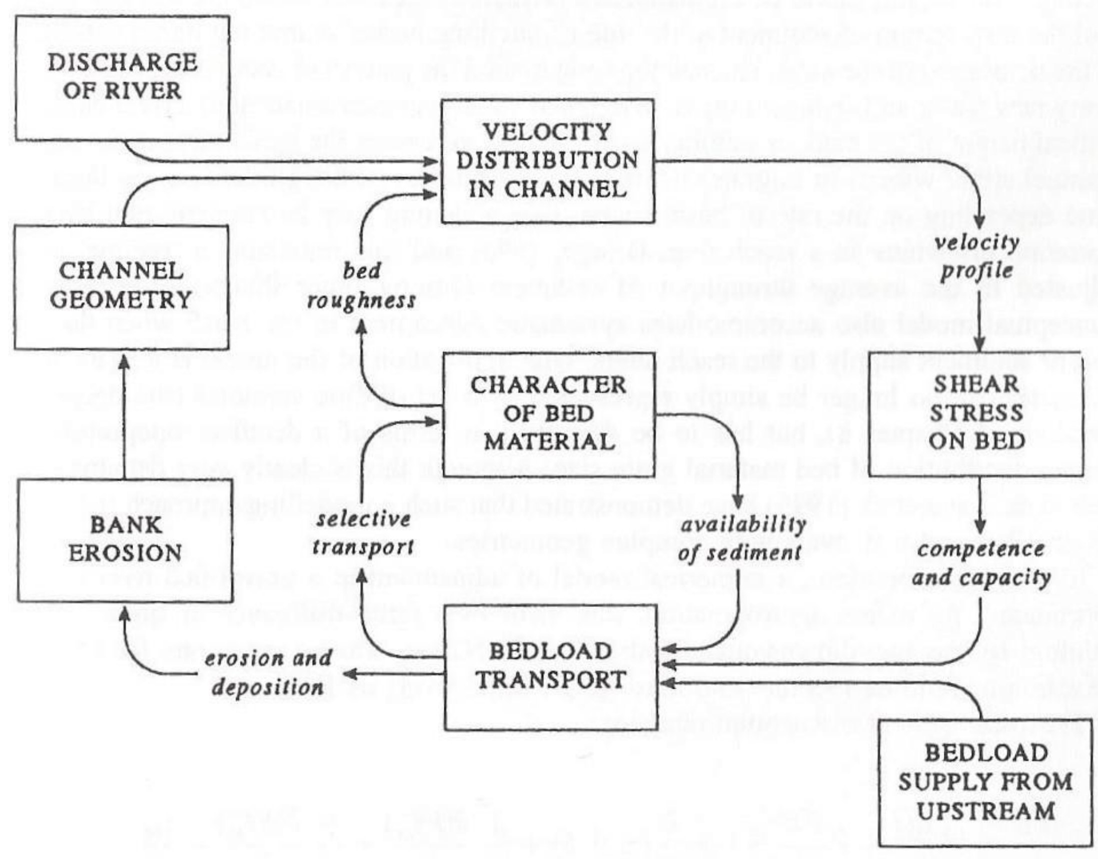


Stable channel balance (after Lane, 1955).

Channel Form Adjustment

Thorne et al. (1997) provides a n qualitative model of form-process interrelationships:

Begins with hydrology: Discharge of River



Channel Form Adjustment

Hey (1997) identifies *nine* degrees of freedom for **adjustment variables** in alluvial channels defining form through erosion and deposition.

The 9 variables are: average bankfull width (W), depth (d), maximum depth (d_m), bedform amplitude (Δ) and wavelength (λ) of bedforms, slope (S), average velocity (V), sinuosity (ρ), and meander arc length (z).

Degrees of freedom and governing process equations* (after Hey 1982a)

Degrees of freedom	Dependent variables	Fixed variables	Independent variables	Type of flow	Governing equations
1	V	$d, S, W, d_m, \lambda, \Delta, p, z$	Q	Fixed bed	1 Continuity
2	V, d	$S, W, d_m, \lambda, \Delta, p, z$	Q, D, D_r, D_l	Fixed bed	+2 Flow resistance
3	V, d, S	$W, d_m, \lambda, \Delta, p, z$	Q, Q_s, D, D_r, D_l	Mobile bed	+3 Sediment transport
5	V, d, S, W, d_m	λ, Δ, p, z	Q, Q_s, D, D_r, D_l	Mobile bed	+4 Bank erosion +5 Bar deposition
7	$V, d, S, W, d_m, \lambda, \Delta$	p, z	Q, Q_s, D, D_r, D_l	Mobile bed	+6 Bedforms +7 Bedforms
9	$V, d, S, W, d_m, \lambda, \Delta, p, z$	–	Q, Q_s, D, D_r, D_l, S_v	Mobile bed	+8 Sinuosity +9 Riffle spacing/meander arc length

*Average flow velocity = V; mean depth = d; channel slope = S; width = W; maximum flow depth = d_m; bedform wavelength = λ; bedform amplitude = Δ; sinuosity = p; meander arc length = z; discharge = Q; sediment discharge = Q_s; characteristic size of bed, right and left bank sediment = D, D_r, D_l; valley slope = S_v.

Channel Form Adjustment: Dynamic Equilibrium

Concept of Dynamic Equilibrium:

True stability in a river system is never possible, a function of discharge and sediment load vary over time and space.

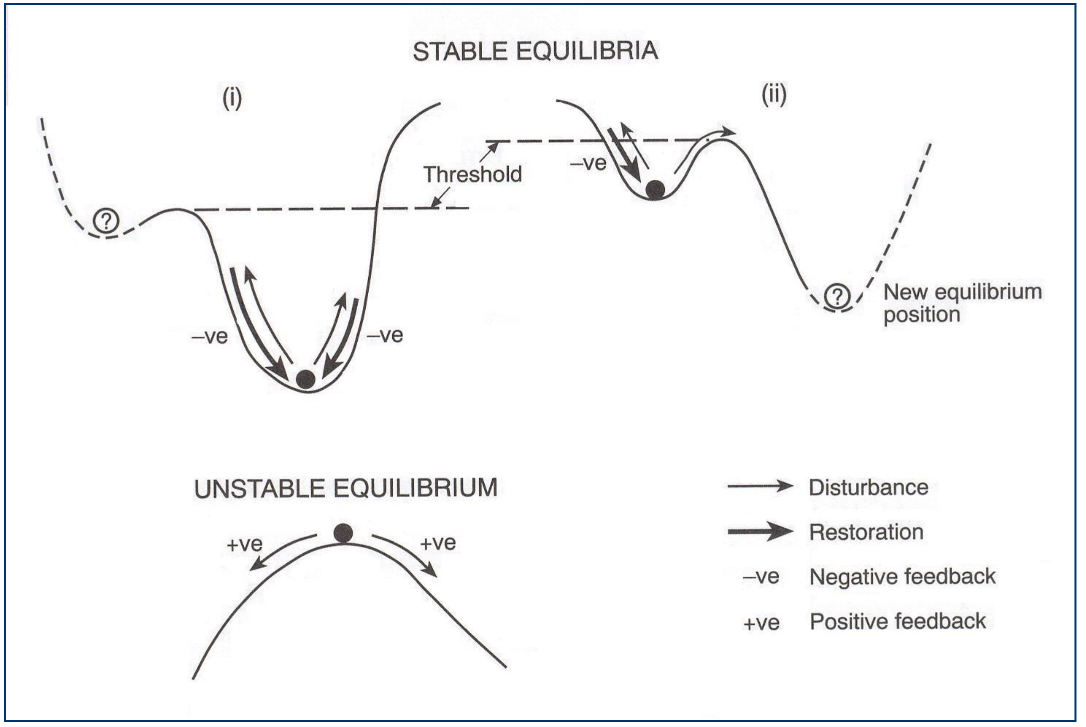
The concept of equilibrium is incorporated into both the hydraulic engineering and fluvial geomorphology literature. Hydraulic engineers refer to **regime theory**, in which stable channel design approaches have been developed based on empirical equations related to bed shear stress and incipient motion of sediment particles. Fluvial geomorphologists refer to it as a **graded river**.

Graded river can be defined as one, in which over a period of years, slope is delicately adjusted to provide, with available discharge and prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin.

Dynamic Equilibrium

Concept of Dynamic Equilibrium:

The important characteristic of open systems is their ability for self-regulation. Negative feedback mechanisms moderate the effects of external factors in such as way that a system can maintain a state of equilibrium, in which a degree of channel stability is established.



Knighton (1998)

Equilibrium: Dominant Discharge Concepts

Dominant Discharge:

The frequent reference made with respect to a mean "equilibrium" state, which reflects the adjustment of channel geometry to imposed conditions suggests that a dominant or channel-forming discharge may be largely responsible for that geometry.

Dominant discharge has been equated with *effective discharge* and *bankfull discharge*, which has been concluded that the these discharges are approximately equal to an 1- to 2-year flood recurrence interval.

Equilibrium: Dominant Discharge Concepts

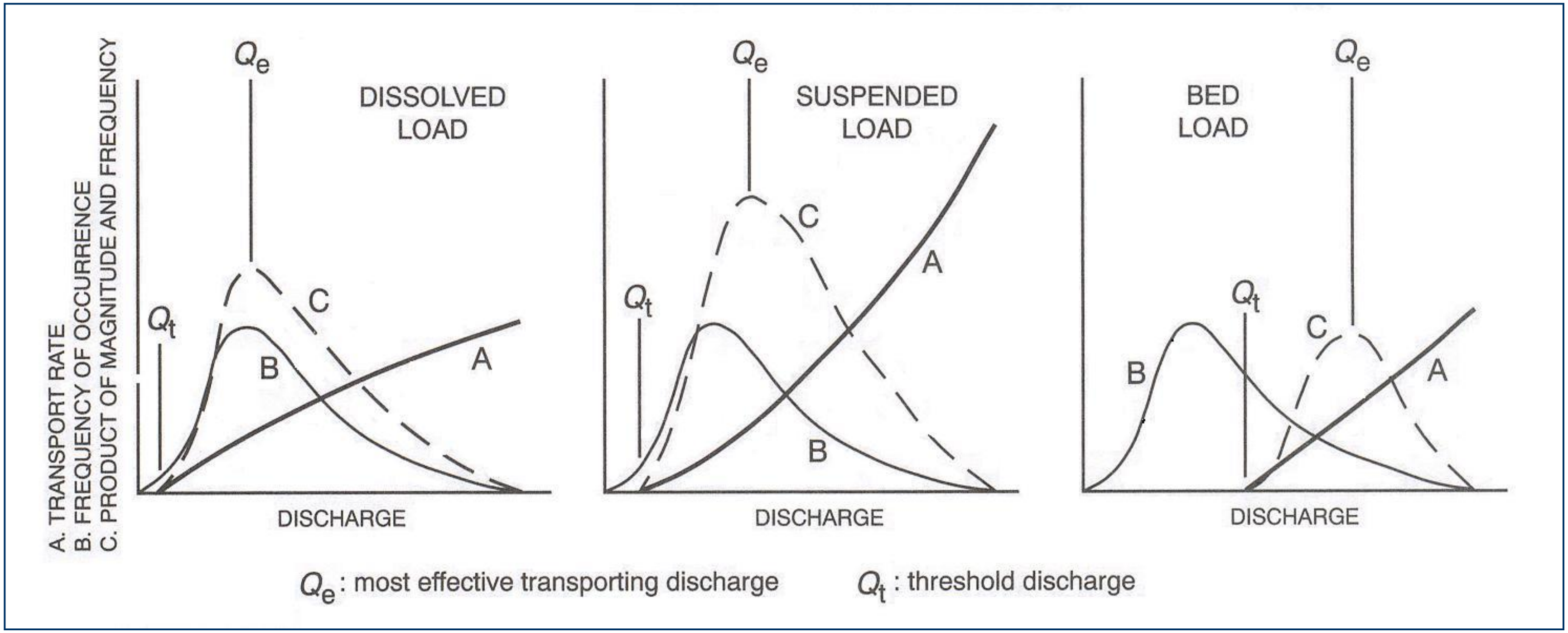
Dominant Discharge: a flow event (single return frequency; stage) that determines the morphological characteristics of a channel representing an "equilibrium" between process and form, i.e., the flow stage that controls the channel form more than any other flow regime.

Effective Discharge: the flow event (return frequency) that performs the most geomorphic work, i.e., that transports the most sediment.

Bankfull Discharge: on an annual flood series, bankfull discharge represents a stage that fills the channel; it can be difficult to identify, but has been suggested as the height to the floodplain level, and/or the height of perennial vegetation, particularly trees.

Equilibrium: Dominant Discharge Concepts

Effective Discharge: Magnitude-Frequency Idea



Wolman and Miller (1960)

Equilibrium: Dominant Discharge Concepts

Bankfull Discharge: Multiple hydrogeomorphic indictors

Bankfull indicator	Reference
Minimum width-to-depth ratio	Wolman (1955) Pickup and Warner (1976)
Highest elevation of channel bars	Wolman and Leopold (1957)
Elevation of middle bench in rivers with several over-flow sections	Woodyer (1968)
Minimum width-to-depth ratio plus a discontinuity (vegetative and or physical) in the channel boundary	Wolman (1955)
Elevation of upper limit of sand-sized particles in boundary sediment	Leopold and Skibitzke (1967)
Elevation of low bench	Schumm (1960); Bray (1972)
Elevation of active flood plain	Wolman and Leopold (1957) Nixon (1959)
Lower limit of perennial vegetation	Schumm (1960)
Change in vegetation (herbs, grass, shrubs)	Leopold (1994)
A combination of: • elevation associated with the highest depositional features • break in bank slope • change in bank material • small benches and other inundation features • staining on rocks • exposed root hairs	Rosgen (1994)

NRCS: Part 654 Nat'l Engr. Handbook
Table 5.1

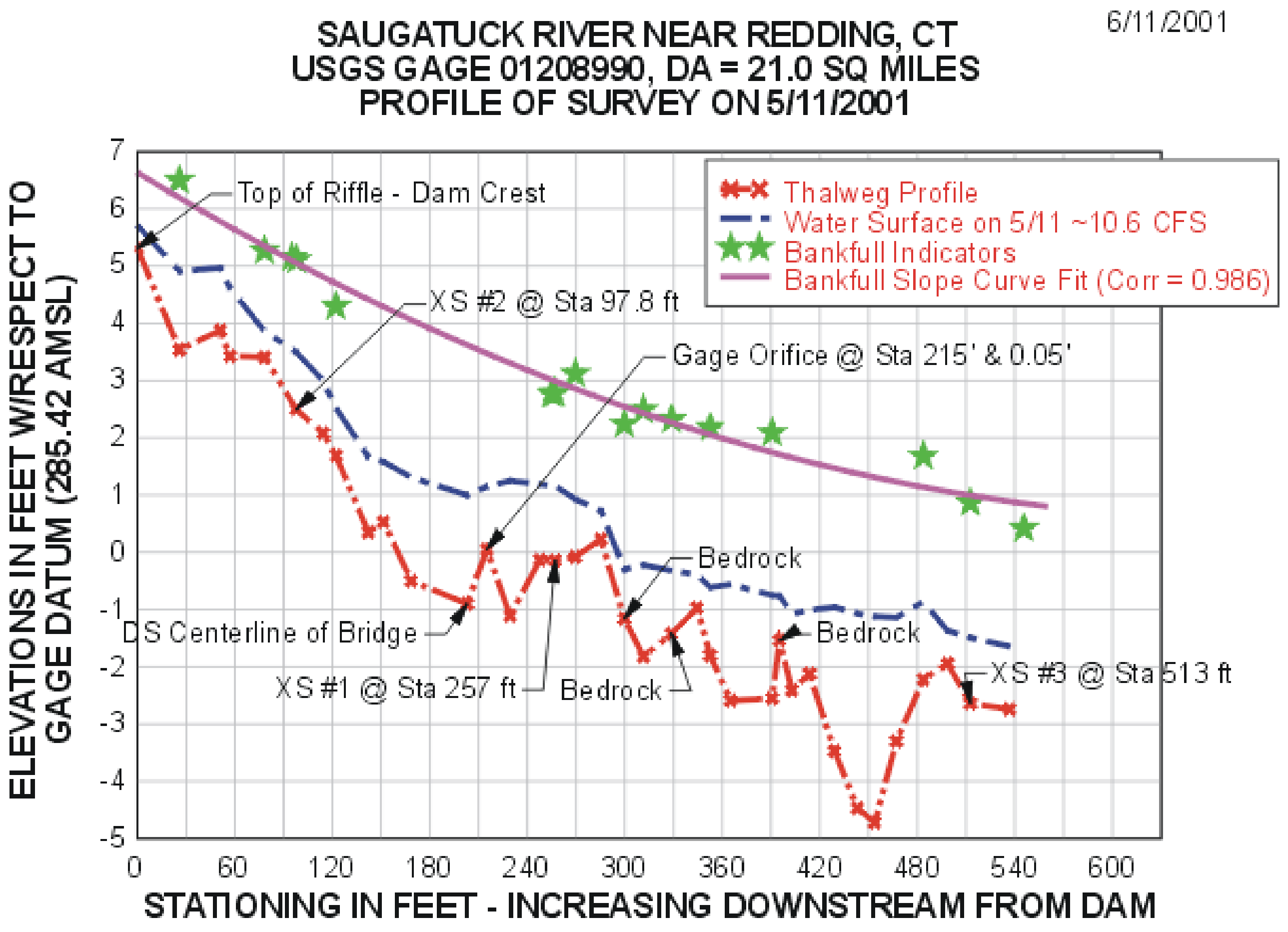
Data Method:
USGS Flow Station, stage at 2-yr return frequency

Bankfull Discharge:

Multiple hydrogeomorphic indictors

NRCS Web-link

Bankfull Discharge:
Multiple hydrogeomorphic indictors



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Equilibrium: Dominant Discharge Concepts

Bankfull Discharge: Summary of stream conditions that affect bankfull stage indicators:

NRCS: Part 654 Nat'l Engr. Handbook

Table 5.11

Reach condition	Process	Effect on bankfull indices
Threshold	Sediment transport capacity of the reach exceeds the sediment supply, but the channel grade is stable	Bankfull indices may be relics of extreme flood events, and may indicate a bankfull flow that is too high
Degrading	The sediment transport capacity of the reach exceeds the sediment supply to the reach, and the channel grade is lowering	The former flood plain is in the process of becoming a terrace. As a result, bankfull indices may indicate a flow that is too high
Aggrading	The sediment transport capacity of the reach is less than the sediment supply	The existing flood plain or in channel deposits may indicate a flow that is too low
Recently experienced a large flow event	Erosion and/or deposition may have occurred on the bed and banks	Bankfull indices may be missing or may reflect the large flow event
Channelized	Sediment transport capacity may not be in balance with sediment supply. The channel may be aggrading or degrading. The reach may be functioning as a threshold channel	Bankfull indices may be relics of previous channel, artifacts of the construction effort, embryonic, or missing altogether

Hydromodification	Stream power exceeding sediment transport capacity over supply	bankfull indicators changing with time.

Channel Form Adjustment:
Sediment Supply/Transport

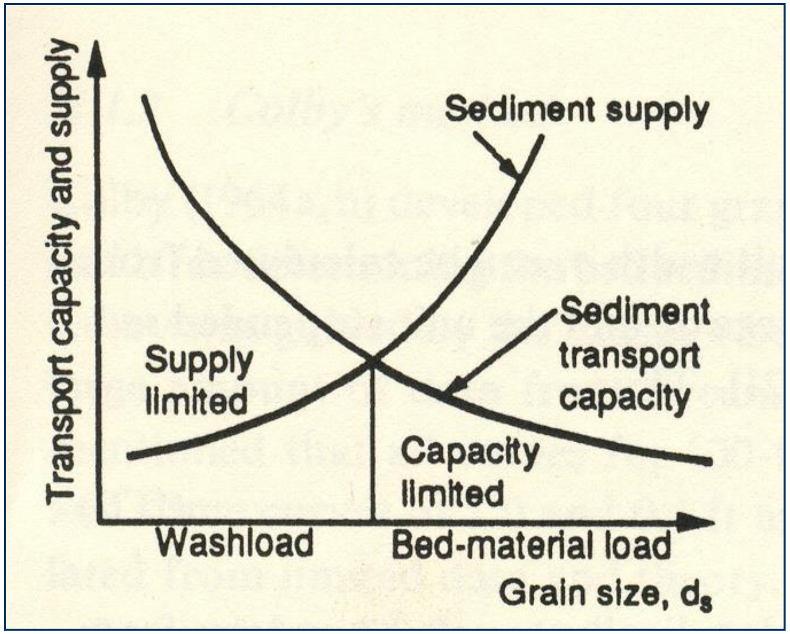
Supply vs. Transport Capacity

Every sediment particle that passes a given stream cross section must satisfy the following two conditions:

1. It must have been eroded somewhere in the watershed above the cross section.
2. It must be transported by the flow from the place of erosion to the cross section.

Limiting the Rate of Sediment Transport

1. The transport capacity of the stream.
2. The availability or supply of the sediment material in the watershed.



Julien (1998)

Channel Form Adjustment:
Catastrophic Geomorphology

Catastrophic geomorphology is chiefly about catastrophic events that affect regional landscapes, including riverine corridors.

Processes that fashion the landscape act continually and gradually over thousands of years. On rare occasions, they act briefly with great force and suddenness.

Hancock and Skinner (2003)

Major flood events: Channel forming events

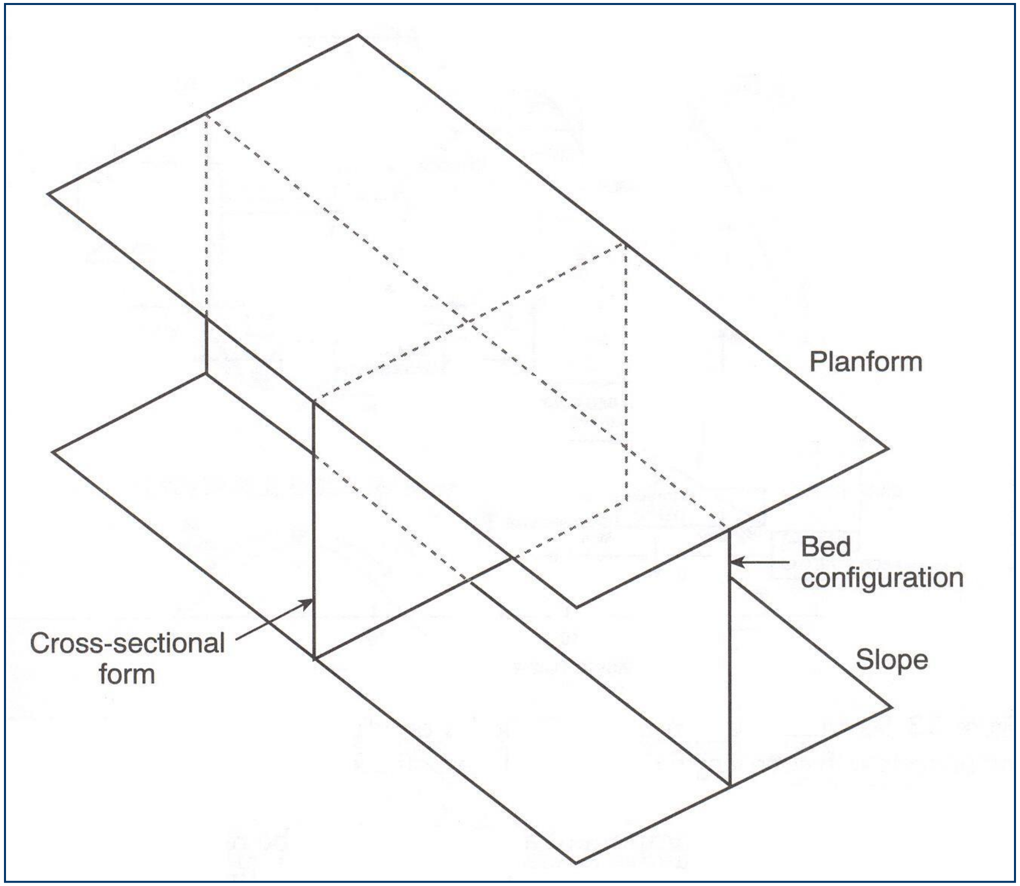



USGS Mt. St. Helens, WA (1980)

Channel Form Adjustment

The major components of channel form at ***different planes*** **of channel adjustment**:

1. planform (e.g., straight meanders),
2. longitudinal profile, slope,
3. cross-sectional area,
4. bed configuration (e.g., pool-riffle sequence),



Knighton (1998)

Channel Form Adjustment

The major components of channel form at ***different planes* of channel adjustment**:

1. Channel planform (planimetric geometry): the form of the channel when viewed above, e.g., straight, meandering, and braided.
2. Longitudinal profile (slope): the gradient of a stream at the reach and the longitudinal scales.
3. Cross-sectional area: the size and shape of a channel in the cross-profile either at a point or as a reach average.
4. Bed configuration: the distinct sequence of forms molded in the bed of particularly sand- and gravel-bed streams (e.g., pool-riffle sequence).

Slope and channel pattern occur in the same plane indicating that, in the short term at least, adjustment of the latter is one way on modifying slope.
Slope <=> planform.

Knighton (1998)

Equilibrium Cross-section

Equilibrium Cross-Section:

Rivers with erodible boundaries flow in self-formed channels which, when subject to relatively uniform controlling conditions, are expected to show a consistency in form, or average geometry, adjusted to transmit the imposed water and sediment discharges. Average geometry is defined by hydraulic geometry variables.

Hydraulic Geometry *Main Variables* :

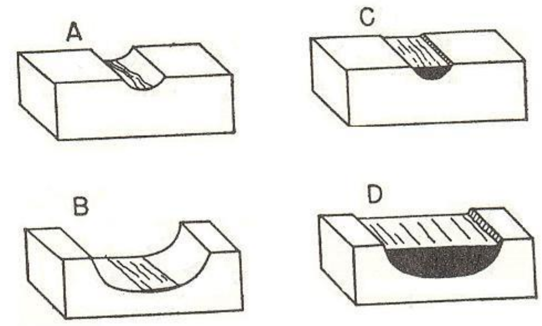
Width: $W = aQ^b$ Depth: $D = cQ^f$ Velocity: $V = kQ^m$

Because of Continuity: $Q = W \cdot D \cdot V$; $a \cdot c \cdot k = 1$ and $b+f+m = 1$

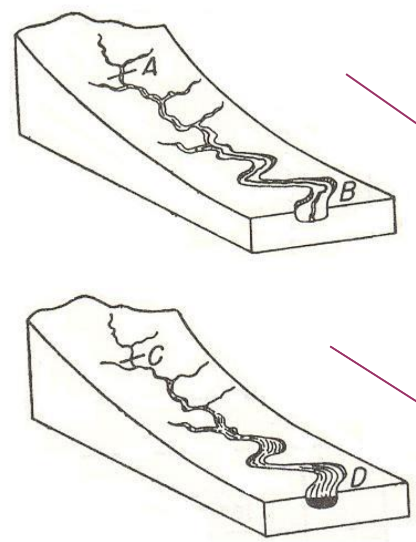
Equilibrium Cross-section

Hydraulic Geometry relationships have been developed for cross-sectional characteristics and flow discharge include:

1. **Downstream** Hydraulic Geometry
   A → B and C → D
2. **At-a-Station** Hydraulic Geometry
   A → C and B → D



At-a-station



Downstream

Knighton (1998)

Equilibrium Cross-section

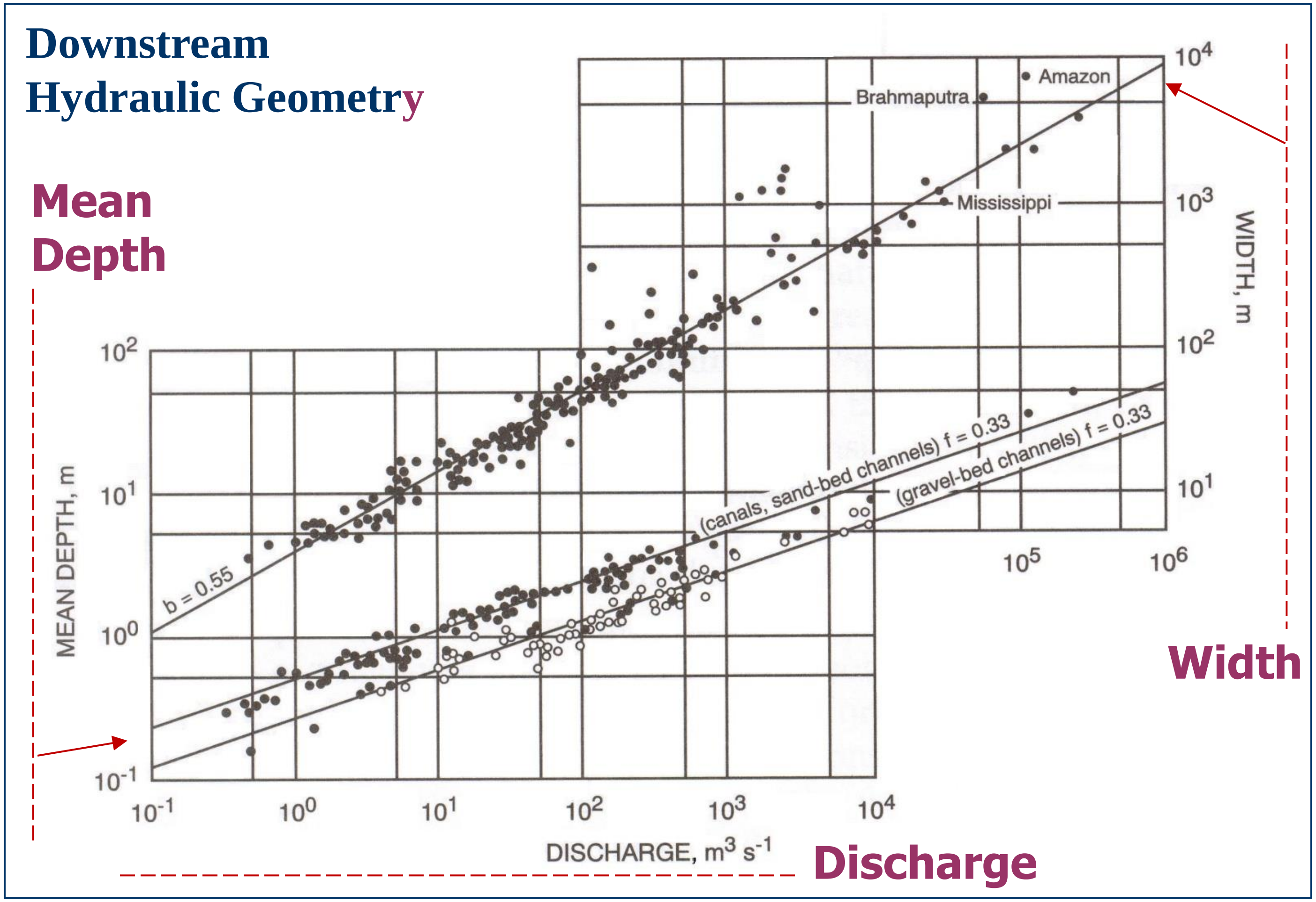
Downstream Hydraulic Geometry:

Relate downstream changes in flow geometry to a discharge with constant flow frequency, *usually bankfull*, dominant discharge, or mean annual discharge.

Cross-sectional form adjusts to accommodate the discharge and sediment load supplied from the drainage basin, within the additional constraints imposed by boundary composition, bank vegetation, and valley slope.

Channel dimensions are not arbitrary adjusted, but are adjusted through the processes of erosion and deposition, to the quantity of water moving through the cross-section so the channel contains all but the highest flows.

Equilibrium Cross-Section

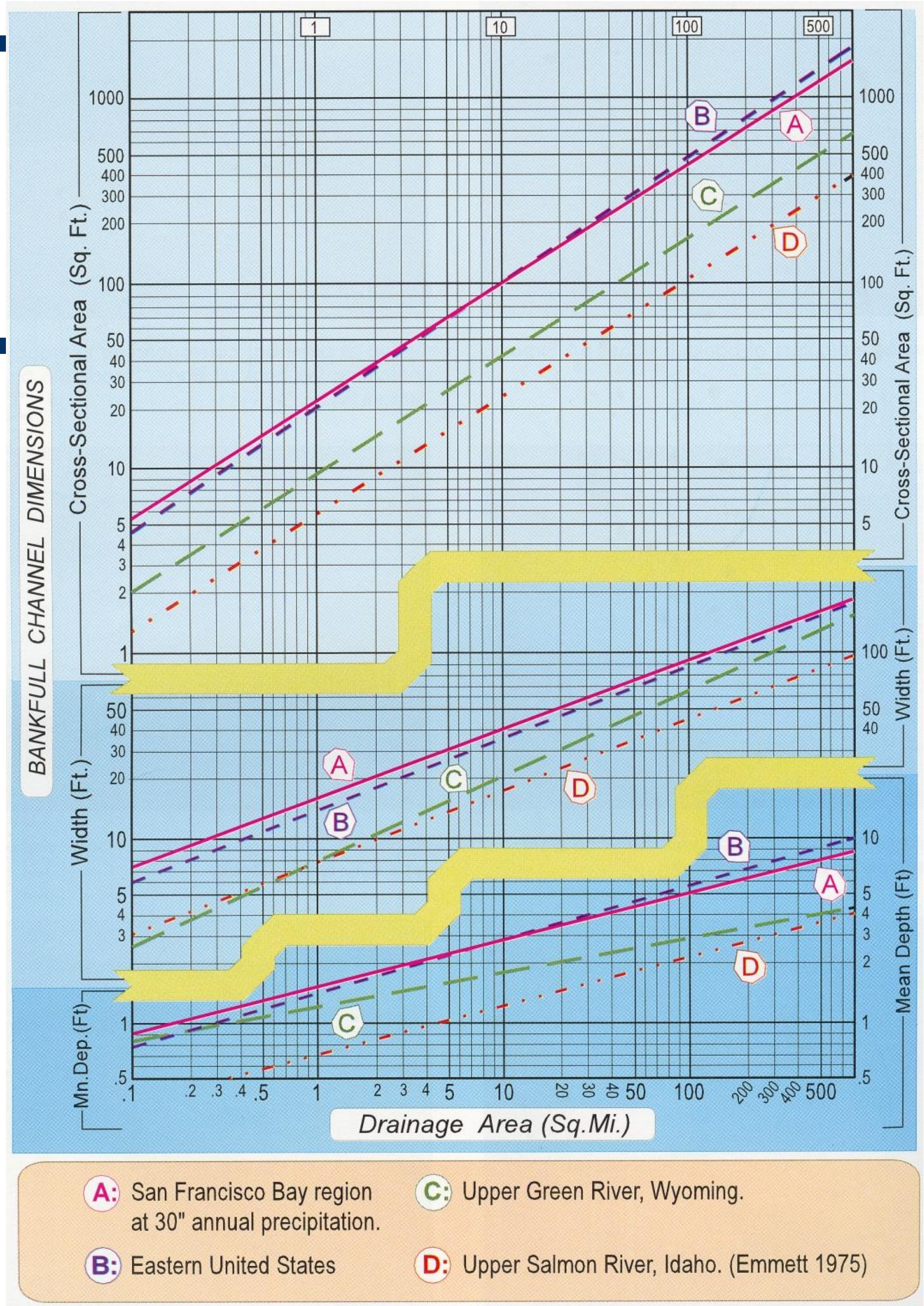


Knighton (1998)

Equilibrium Cross-section

Downstream Hydraulic Geometry:

Application of downstream hydraulic geometry principles as applied by Rosgen (1996) for river restoration – this information is commonly referred to as a **"regional curve"** by designers.



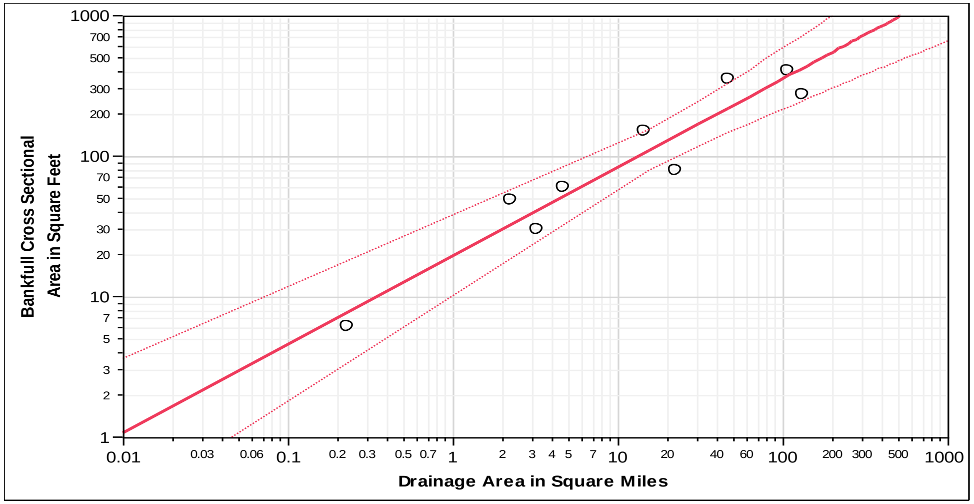
Rosgen (1996)

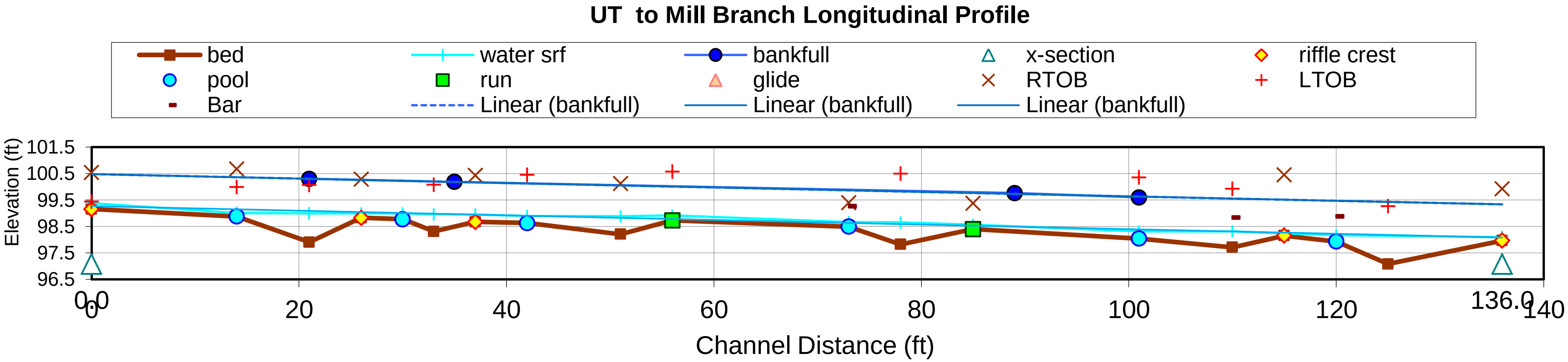
Equilibrium Cross-section

Downstream Hydraulic Geometry:
Regional Curve for the Ridge and Valley Physiographic Province

Bankfull Cross-sectional area vs drainage area

Brady McPherson (2011)





Equilibrium Cross-section

Downstream Hydraulic Geometry: Hey and Thorne (1986) use the empirical approach and extends the original Leopold and Maddock (1953) formulas as:

Width Type I - Grassy Banks: $$w = 4.33Q_b^{0.50}$$

Type II - 1-5% Tree/Scrub Cover: $$w = 3.33Q_b^{0.50}$$

Type III – 5-50% Tree/Scrub Cover: $$w = 2.73Q_b^{0.50}$$

Type IV - > 50% Tree/Scrub Cover: $$w = 2.34Q_b^{0.50}$$

Depth Average $$d = 0.22Q_b^{0.37}D_{50}^{-0.11}$$

Maximum $$d_{\max} = 0.20Q_b^{0.36}D_{50}^{-0.56}D_{84}^{0.35}$$

Slope $$s = 0.087Q_b^{-0.43}D_{50}^{-0.09}D_{84}^{0.84}Q_{sbl}^{0.10}$$

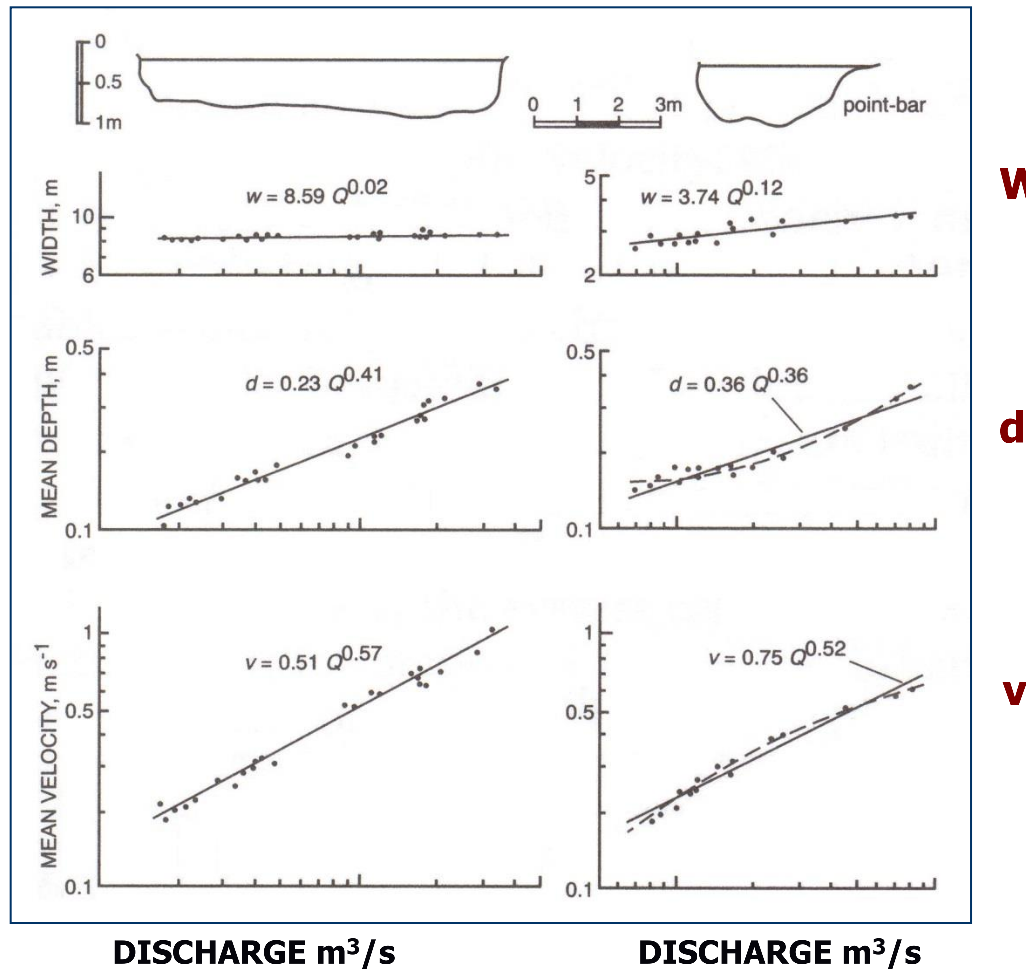
Q_b = bankfull discharge

D = bed material size (mm)

Q_{sbl} = bedload discharge

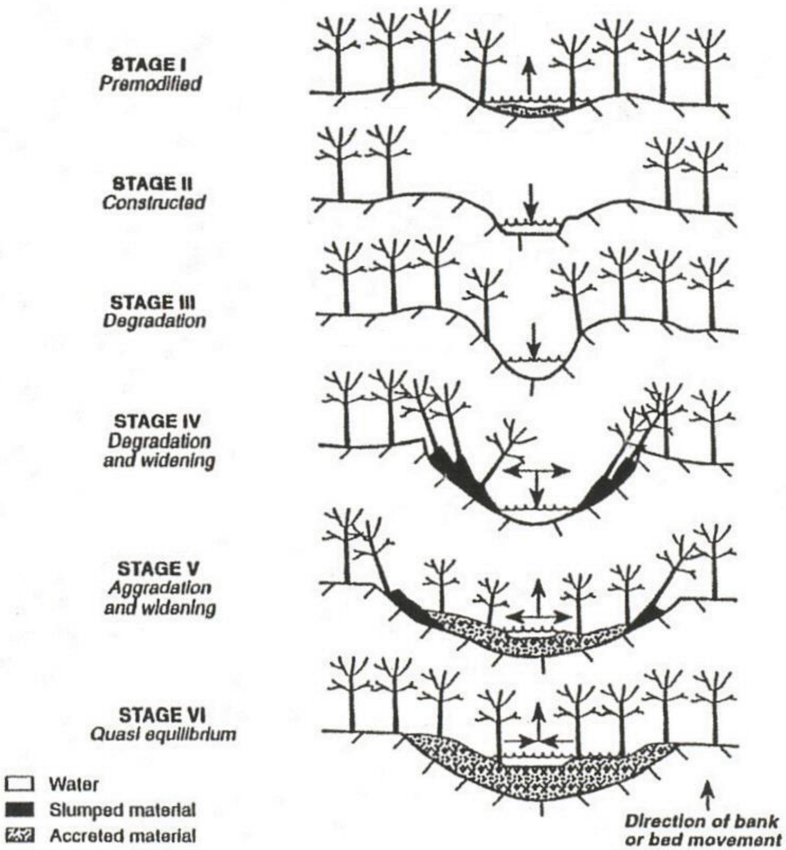
Equilibrium Cross-section

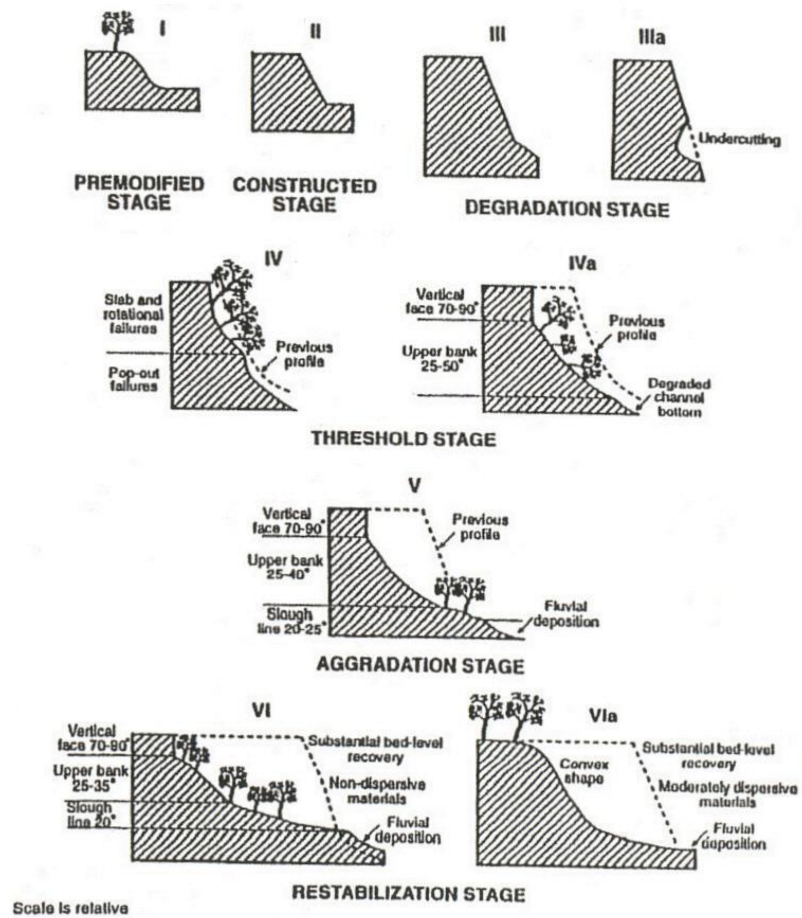
At-a-Station Hydraulic Geometry: Unlike downstream hydraulic geometry, which deals with spatial variation in channel properties at some reference discharge, at-a-station hydraulic geometry deals with *temporal variations* in flow variables as discharges fluctuates at a cross-section, usually for a range of discharges up to bankfull.



Channel and Bank Stability: Channel Evolution Model

Simon (1995)





Channel and Bank Stability: Channel Evolution Model

Six stages of channel evolution identified starting with a premodified state, then disturbed, and followed by channel adjustment reaching a new equilibrium state.

Six stages are as follow:

1. Premodified – stable channel, lateral aggradation
2. Constructed – disturbed channel
3. Degradation – channel incision, basal erosion on banks
4. Threshold – basal erosion on banks; bank failure
5. Aggradation – sediment aggradation, meander development
6. Restabilization – sediment aggradation; stable channel

Channel and Bank Stability: Channel Evolution Model

Six Stages of Channel Evolution from pre-disturbed, disturbed, to natural recovery

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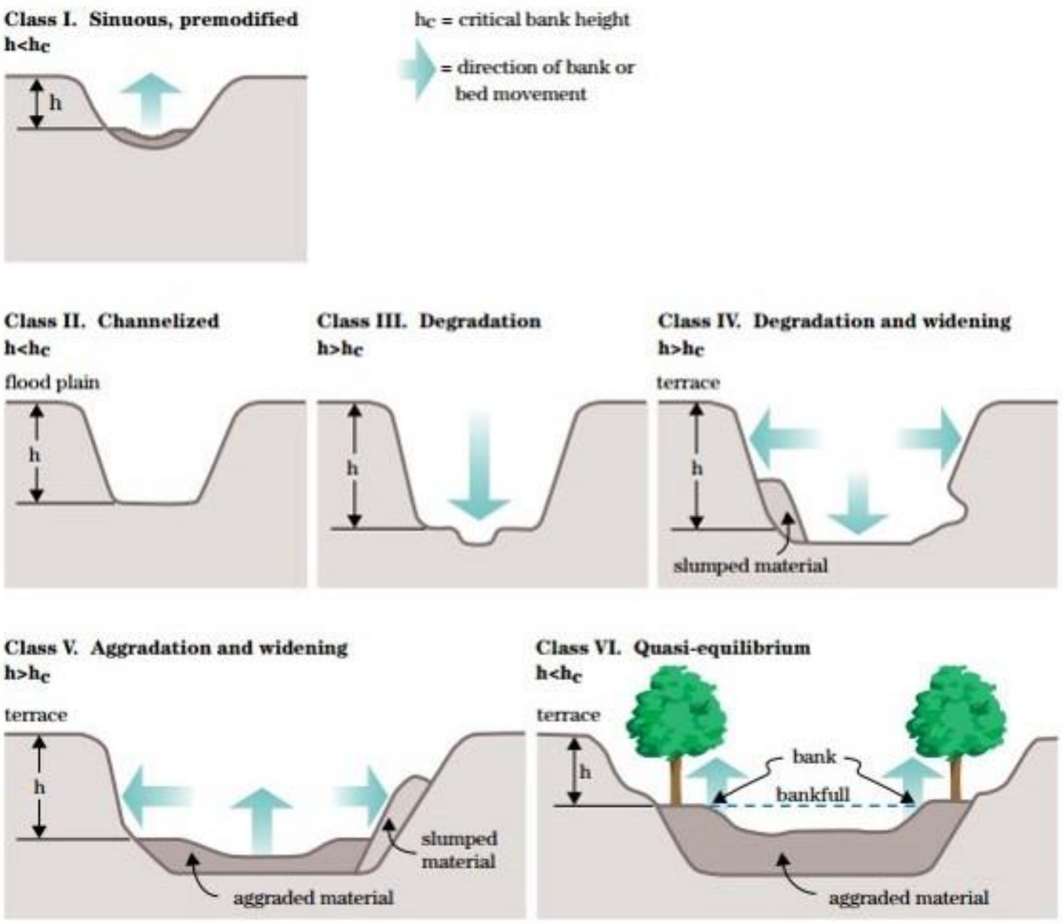
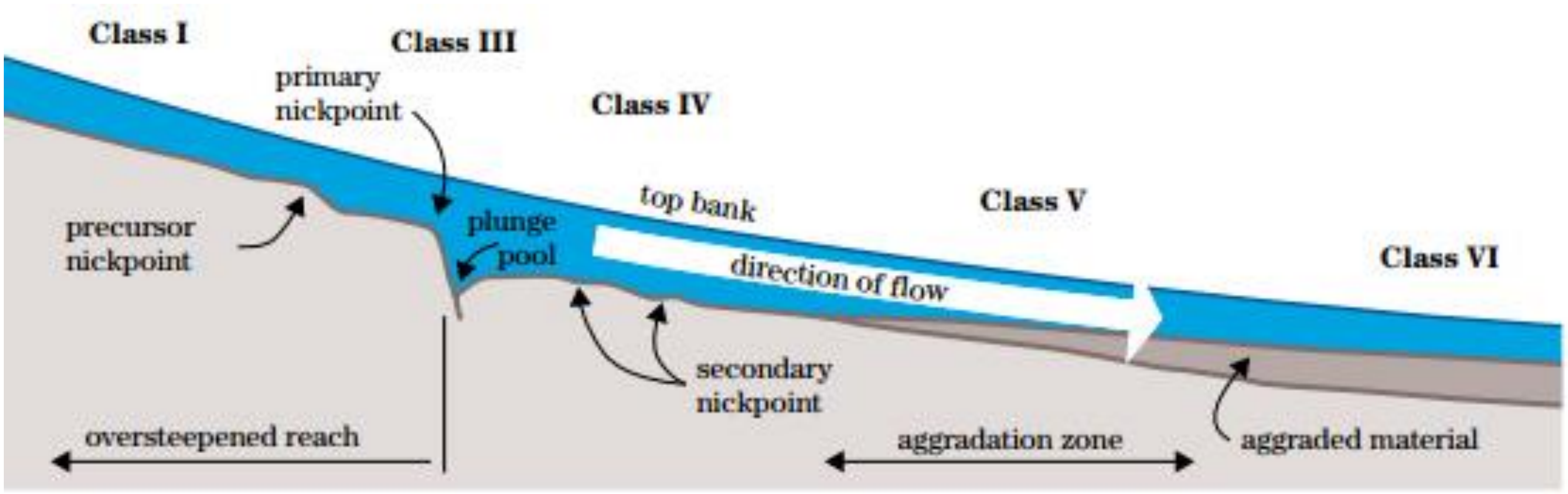
Figure 3.4b



Channel and Bank Stability: Channel Evolution Model

Six Stages of Channel Evolution Model: Knickpoint/ Head-cut Migation



NRCS: Part 654 Nat'l Engr. Handbook

Figure 3.4b

Channel and Bank Stability: Channel Evolution Model

Modified CEM version

Cluer & Thorne (2014)