Integrating Stream Mechanics into Design

Agenda

How streams work
What to look for and what it means
Break
Working with your streams; infrastructure and other needs

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Principal Scientist
Intuition & Logic

How are natural streams different from designed canals and why must they be managed using different criteria?

Streams are Self-Forming

- Streams trend toward dynamic equilibrium
- Channel changes are driven by:
  - channel geometry, slope, vegetation, strength of boundaries, Qwater, Qsediment,
- The stream will respond to reestablish that equilibrium by adjusting its channel geometry or slope

Balancing Act

- Driving forces – Quantity and shear stress of water and sediment
- Resisting forces – Channel geometry, roughness and the strength of bed and bank materials

Lane's Relationship

$$Q_w * S \propto Q_s * D_{50}$$

where

Q_w = rate of water delivery

S = energy slope

Q_s = rate of sediment delivery

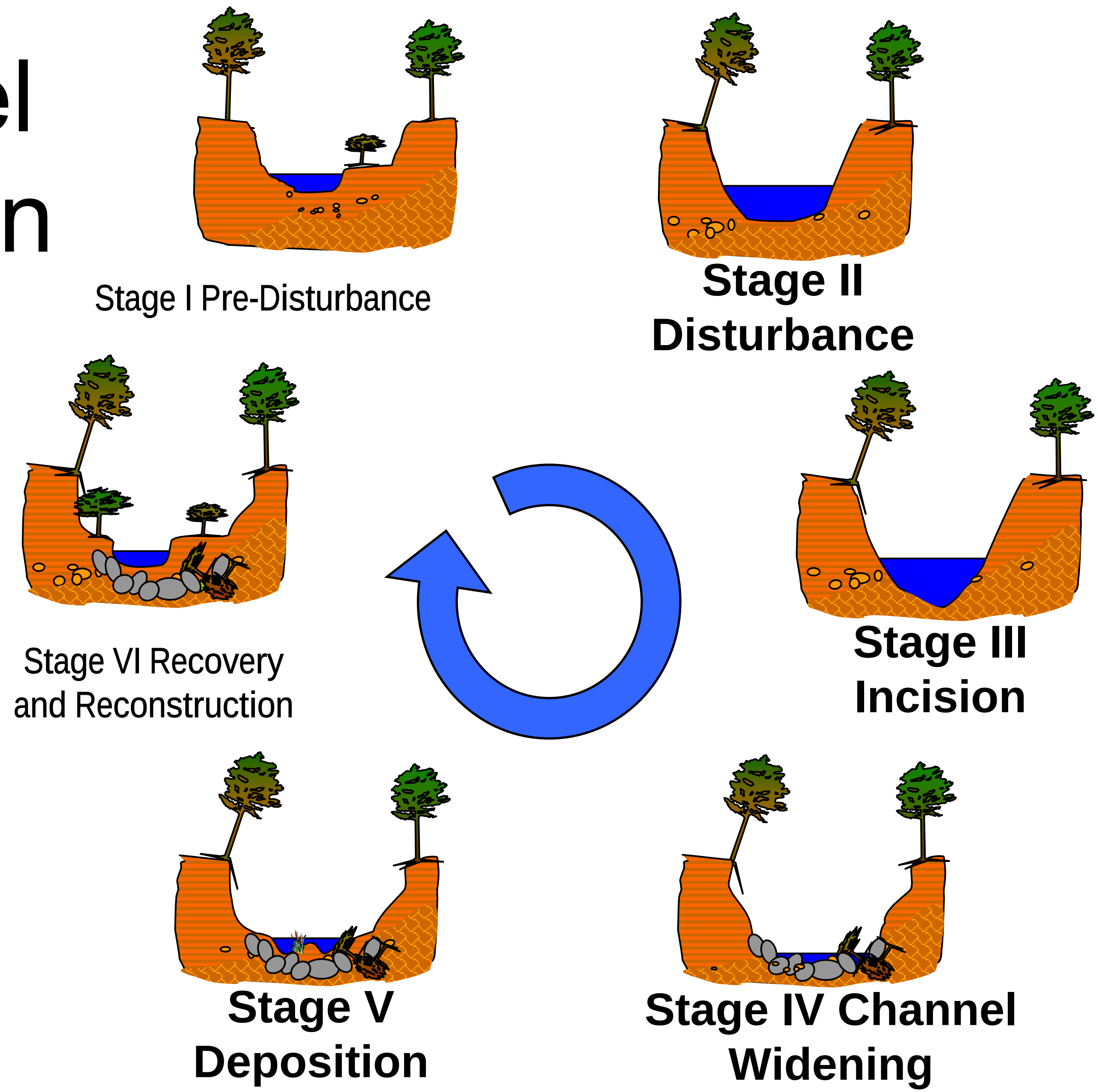
D_{50} = median size of mobile particles

This is not an equation, it is a general relationship !!

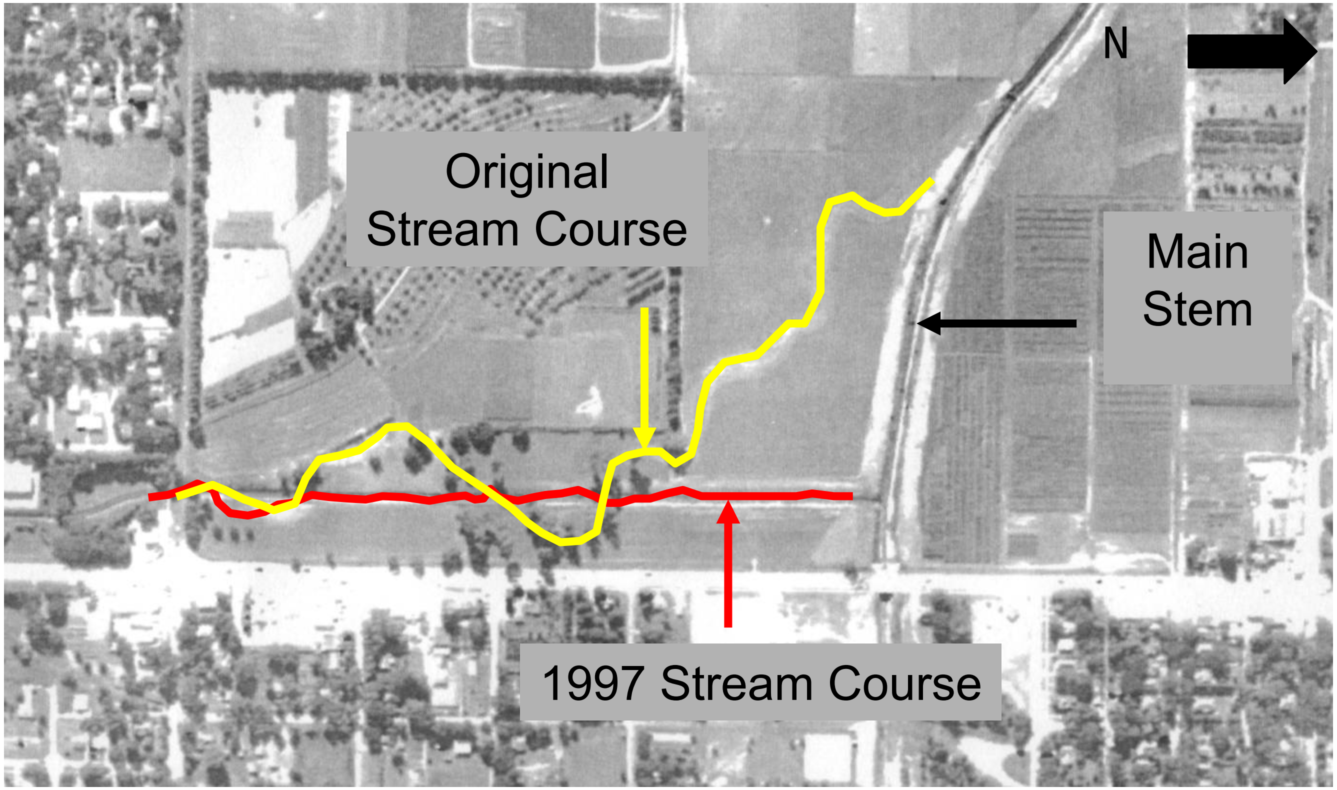
Channel Evolution

When the forces maintaining equilibrium are disturbed, a predictable set of events is set in motion

Channel Evolution Model



Disturbance – Channel Straightening



Channel evolution from other perspectives

- Plan Form
  - Re-established meanders
  - Meander migration
- Profile
  - Headcuts and knick zones (degradation)
  - Silted in channels (aggradation)

Meander Formation and Migration

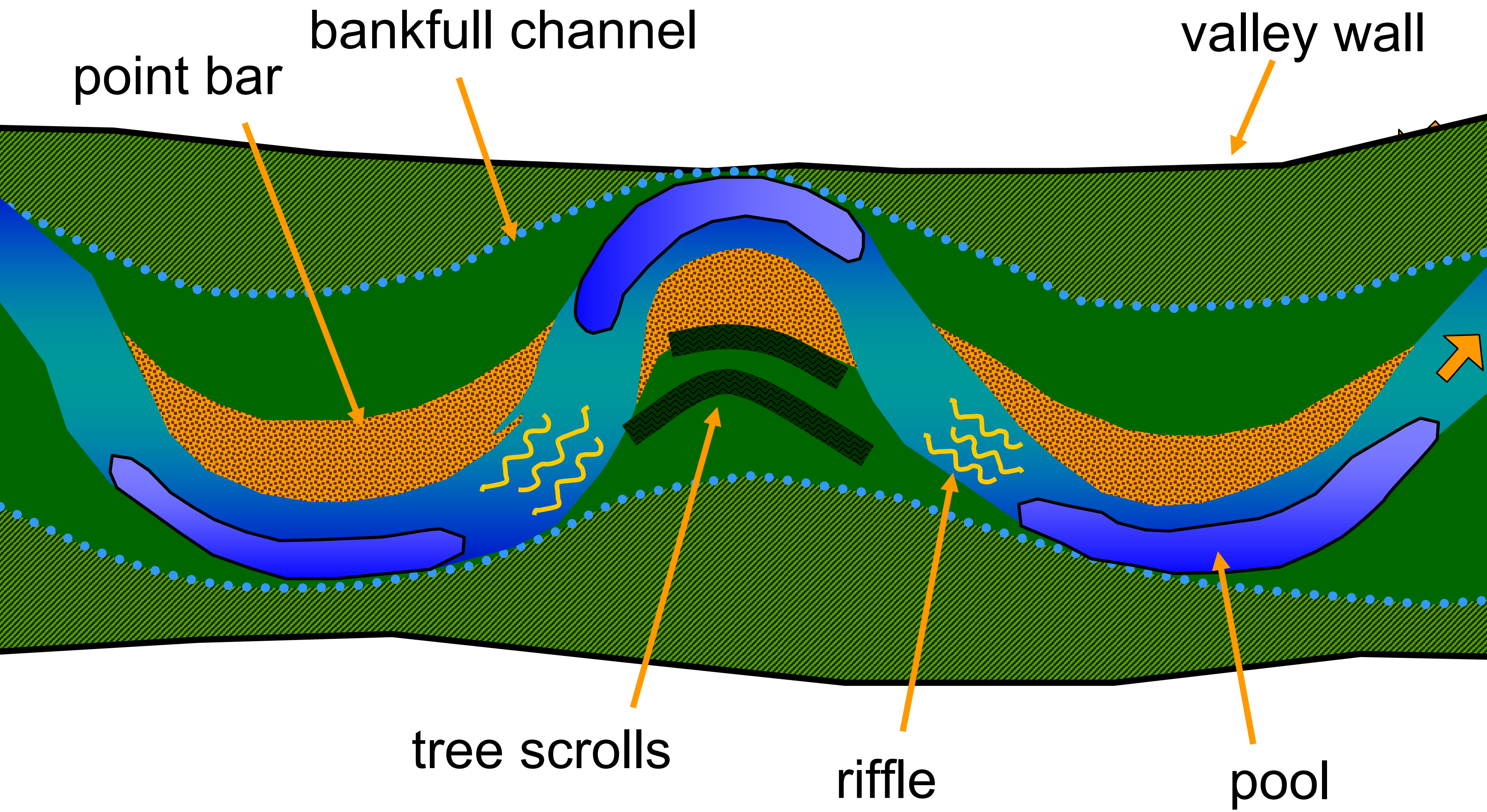
"Meanders appear to be the form in which a river does the least work in turning; hence they are the most probable form a river can take."

Luna Leopold

Plan Form Responses

- Straight streams are very rare in nature
- The meander pattern is a consequence of secondary flows and the shape of meanders are generally predictable
- When equilibrium is disrupted, changes in plan form such as meander advance, change in meander amplitude or reversal of meander pattern may occur

Channel Form

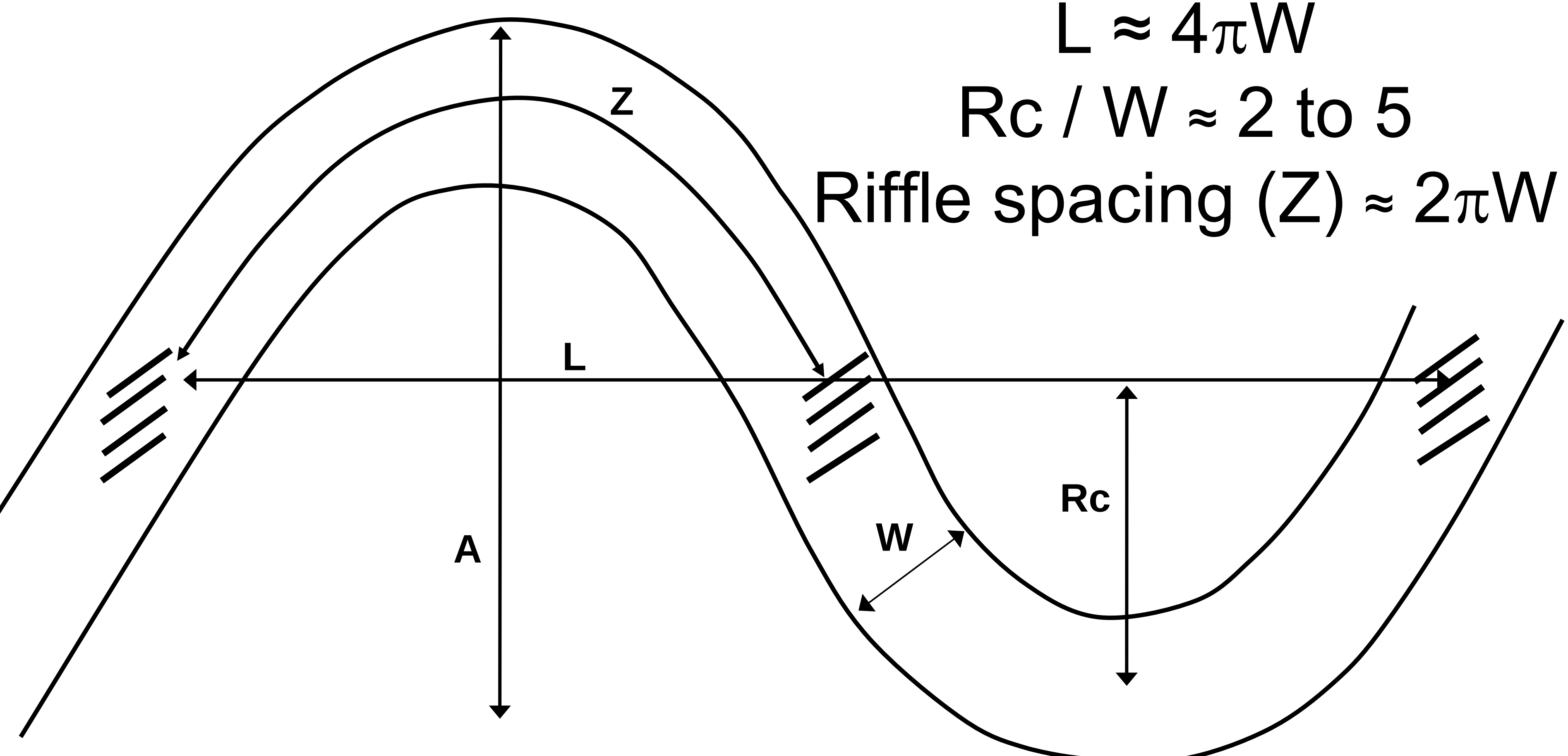


Plan Form

$L \approx 4\pi W$

$Rc / W \approx 2 \text{ to } 5$

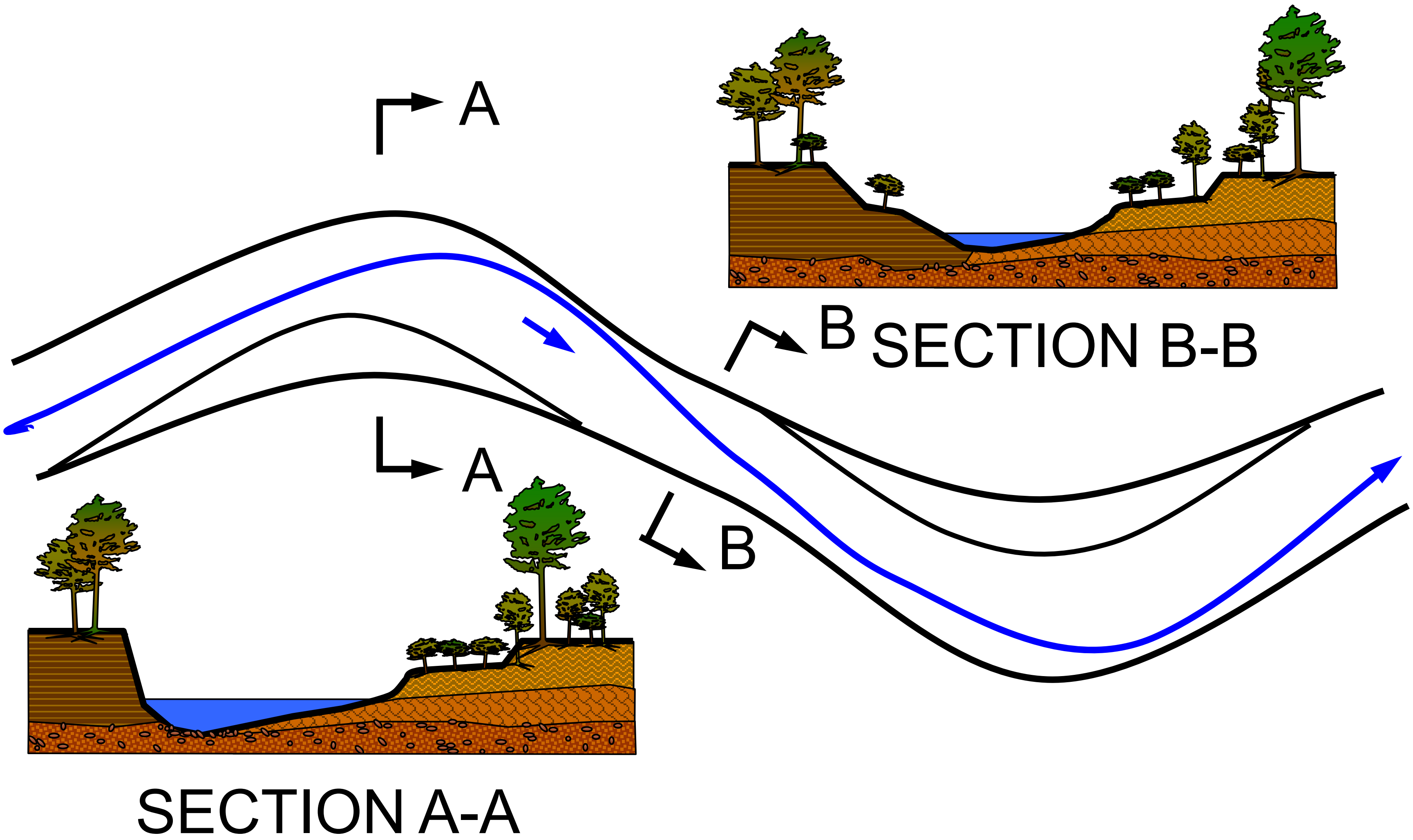
Riffle spacing (Z) $\approx 2\pi W$



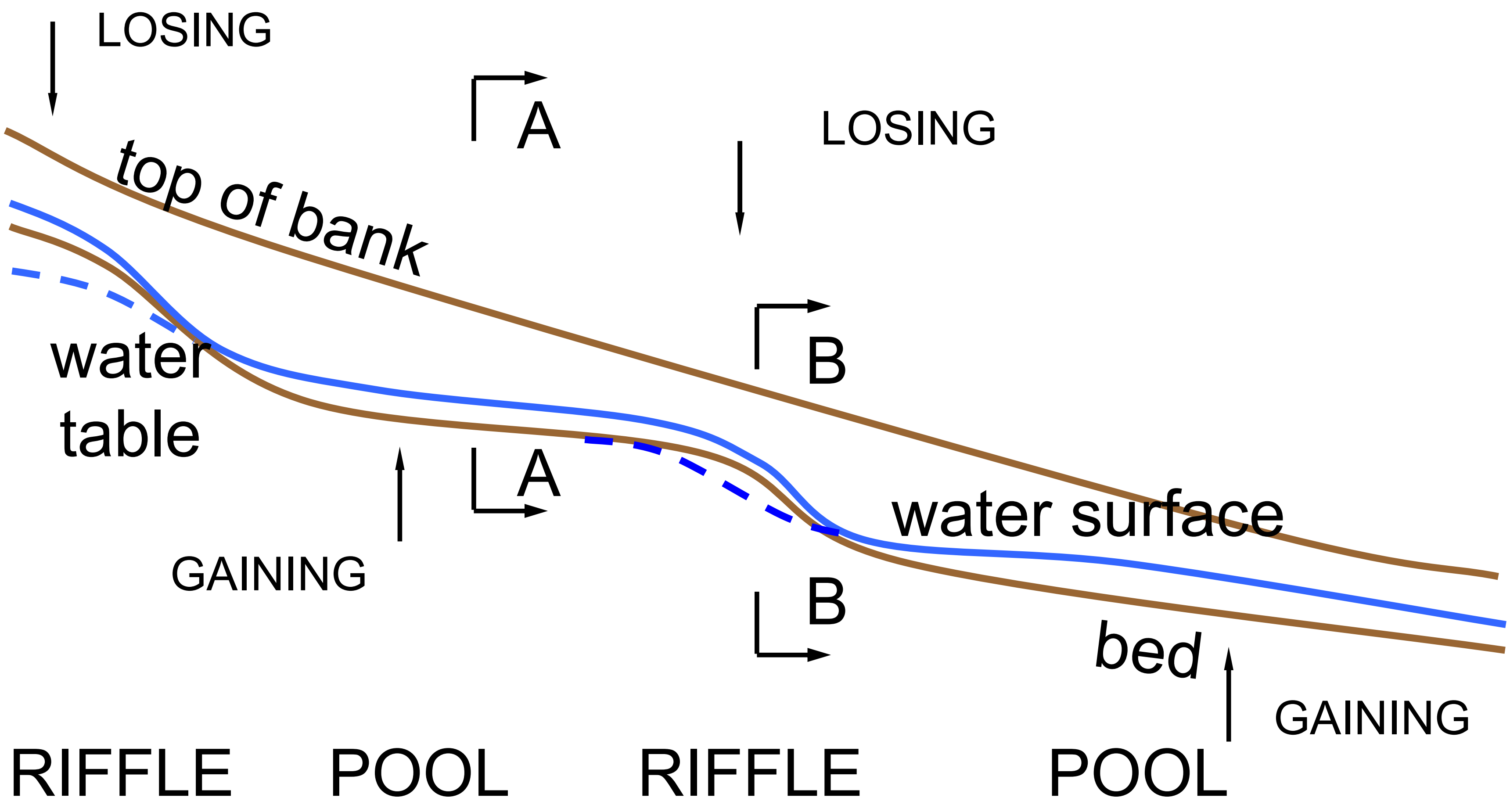
L = wavelength   Rc = radius of curvature

A = amplitude   W = width at bankfull discharge

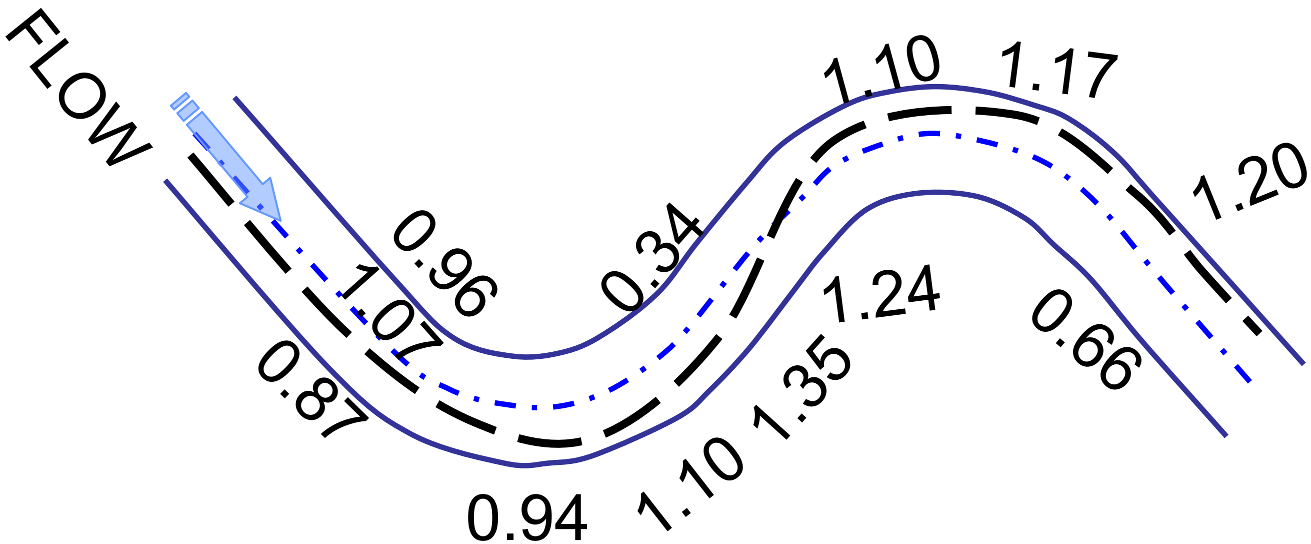
Plan & Sections



Profile


LOSING
A
LOSING
top of bank
B
water
table
A
water surface
GAINING
B
bed
GAINING
RIFFLE
POOL
RIFFLE
POOL

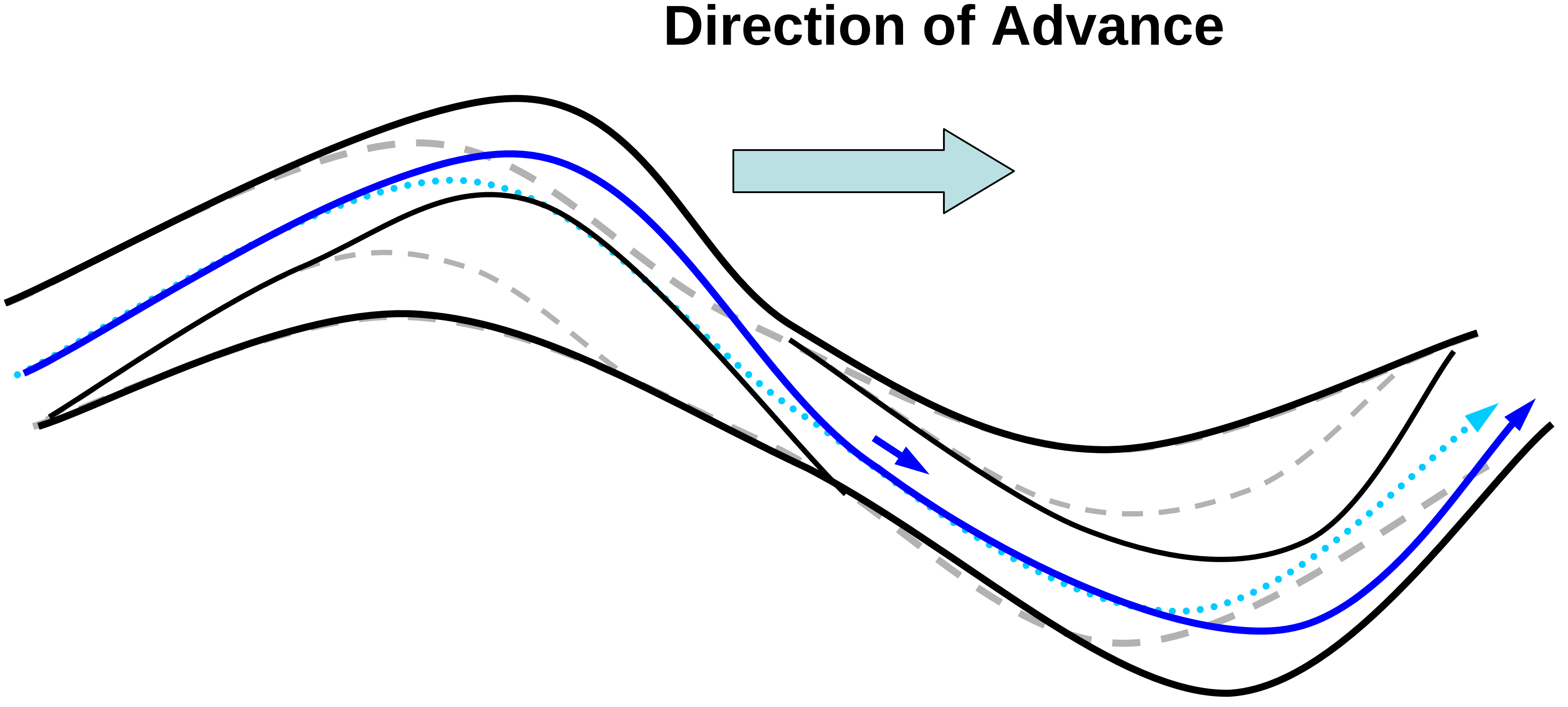
Peak Velocity in Channel



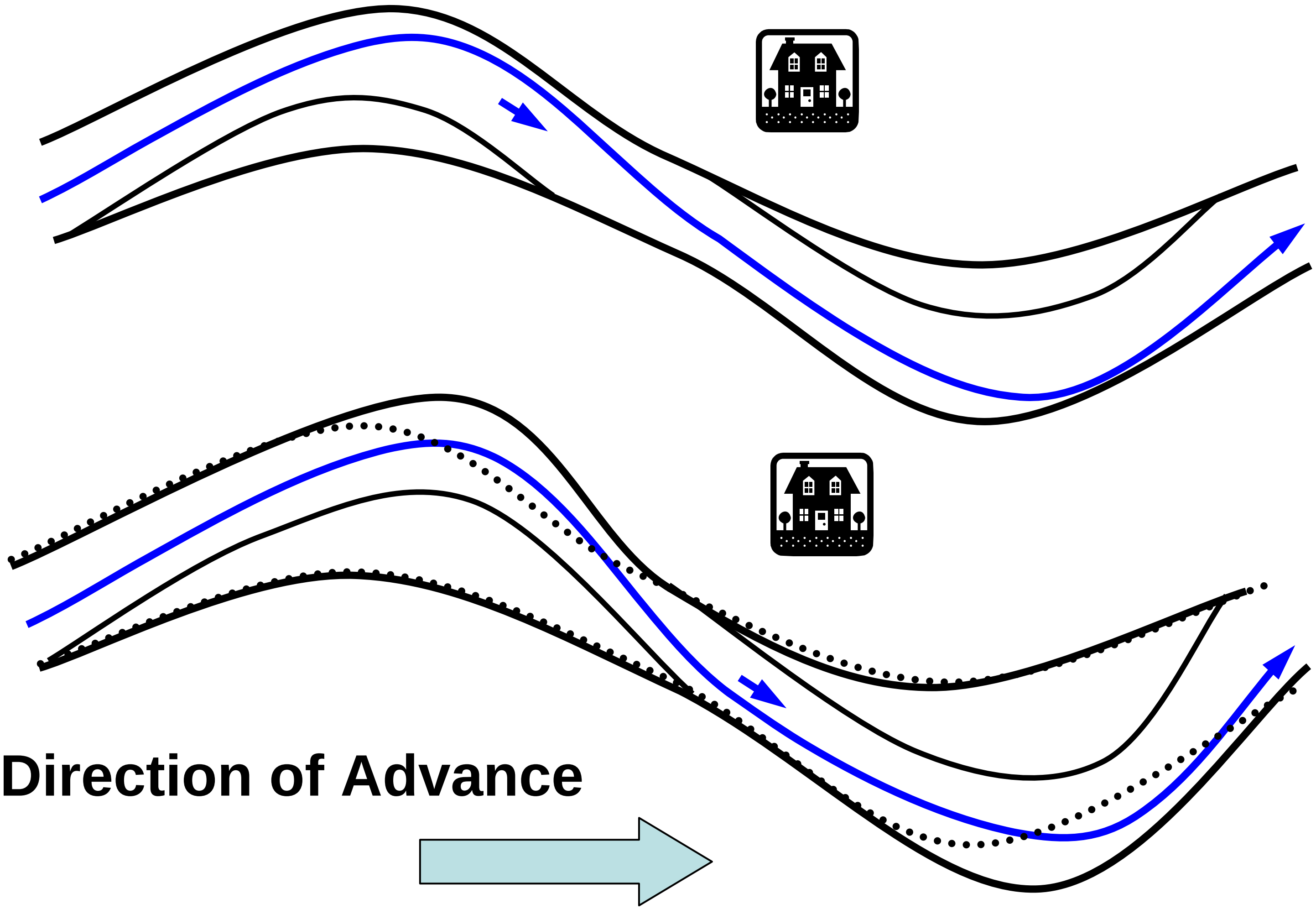
Values represents the ratio of velocity at a location to average velocity

Adapted from Hydraulic Design of Flood Control Channels, US Army Corps of Engineers, Plate B-35
EM 1110-2-1601, 1 JUL 91

Meander Advance

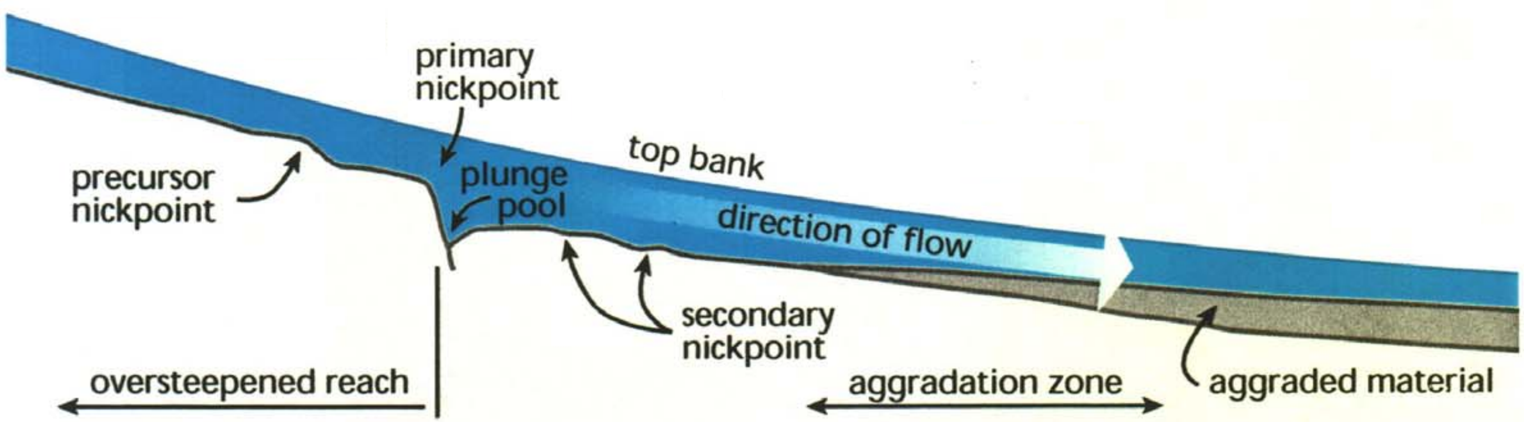


Meander Advance



Direction of Advance

Profile Changes
Headcut Migration and Aggradation



Natural Stream Structure

- Meandering Paths Typical
- 2 Stage Section - Channel and Floodplain
- Spiral Flow
- Sequence of Pools and Riffles (not always)
- Plan and Profile Ties: Pools at Bends, Riffles at Cross Overs

Shear Stress

$$\tau_{avg} = \gamma * R_h * S$$

$$\tau_{max} = \gamma * y_{max} * S$$

where

τ = shear stress along perimeter (#/sf)

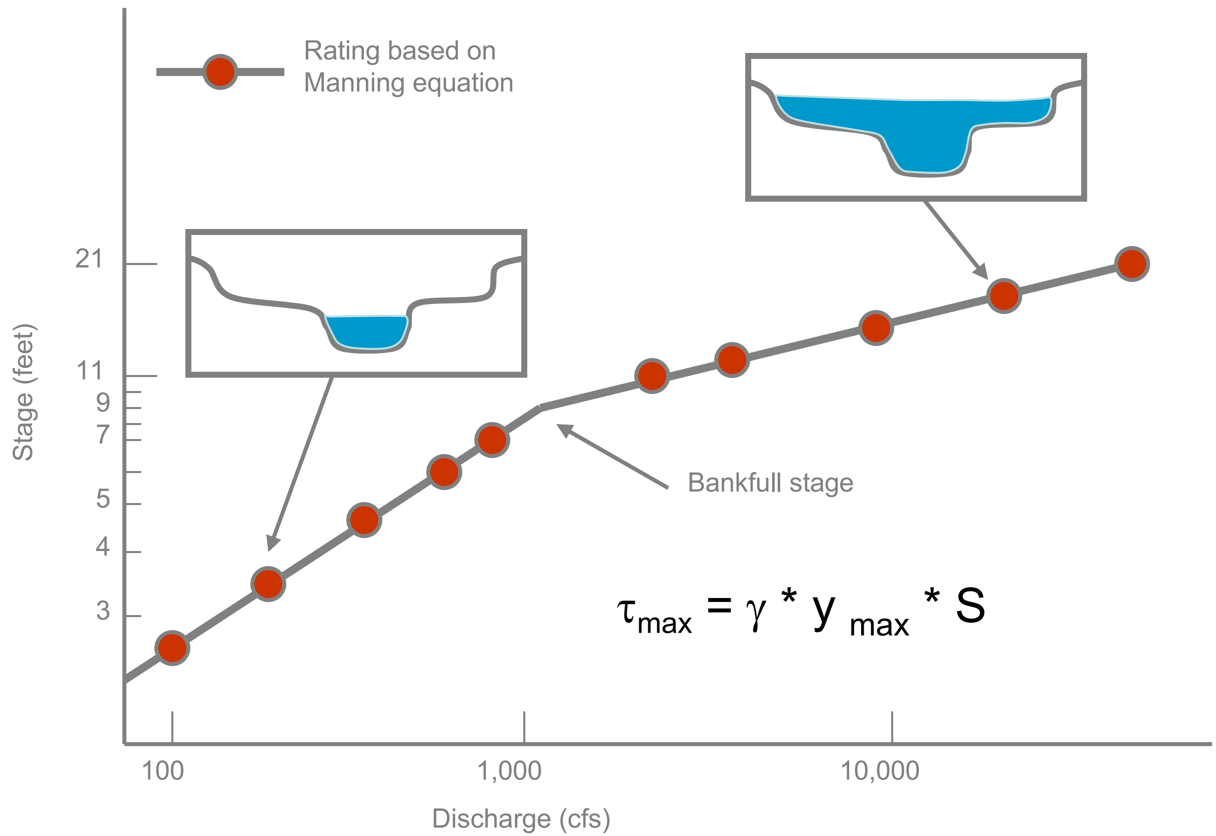
γ = unit weight of water = 62.4 #/cu ft

R_h = hydraulic radius = A/Pw (ft)

S = energy slope (ft/ft)

y = depth

Flow and Shear Changes at Bankfull

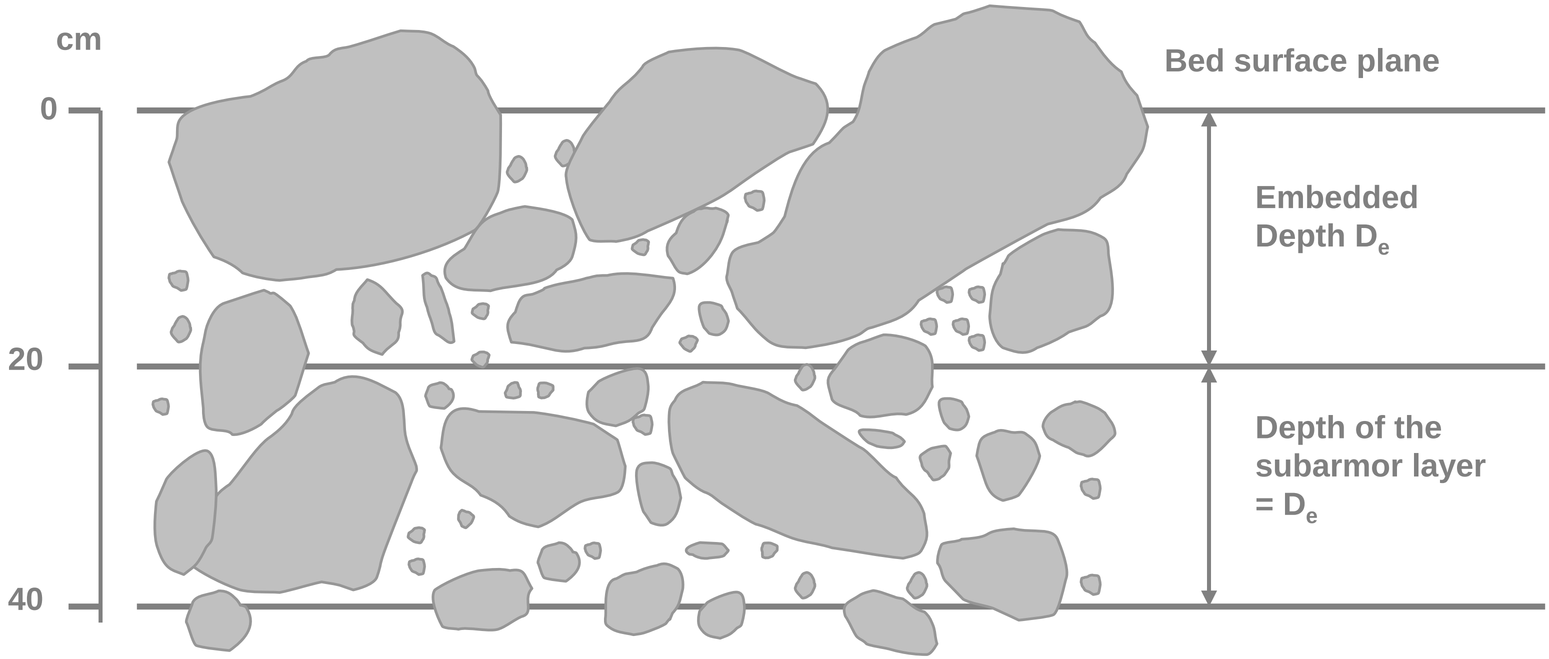


$$\tau_{max} = \gamma * y_{max} * S$$

Geology and Soils

- Form of stream dependent upon geology
  - Bedrock controlled
  - Sand bed streams
- Gravel and Cobble streams
- Bed and banks distinct
- Non-cohesive soils – shear resistance by size
- Cohesive Soils – act as clumps, cohesive strength, saturation, chemical properties, weather, etc.

Pavement or Armor layer



Armor layer and subarmor layer adjusted to the depth of a large particle (D_{max} or D_{dom}). (Figure courtesy of Winema National Forest, Klamath Falls, OR; slightly altered).

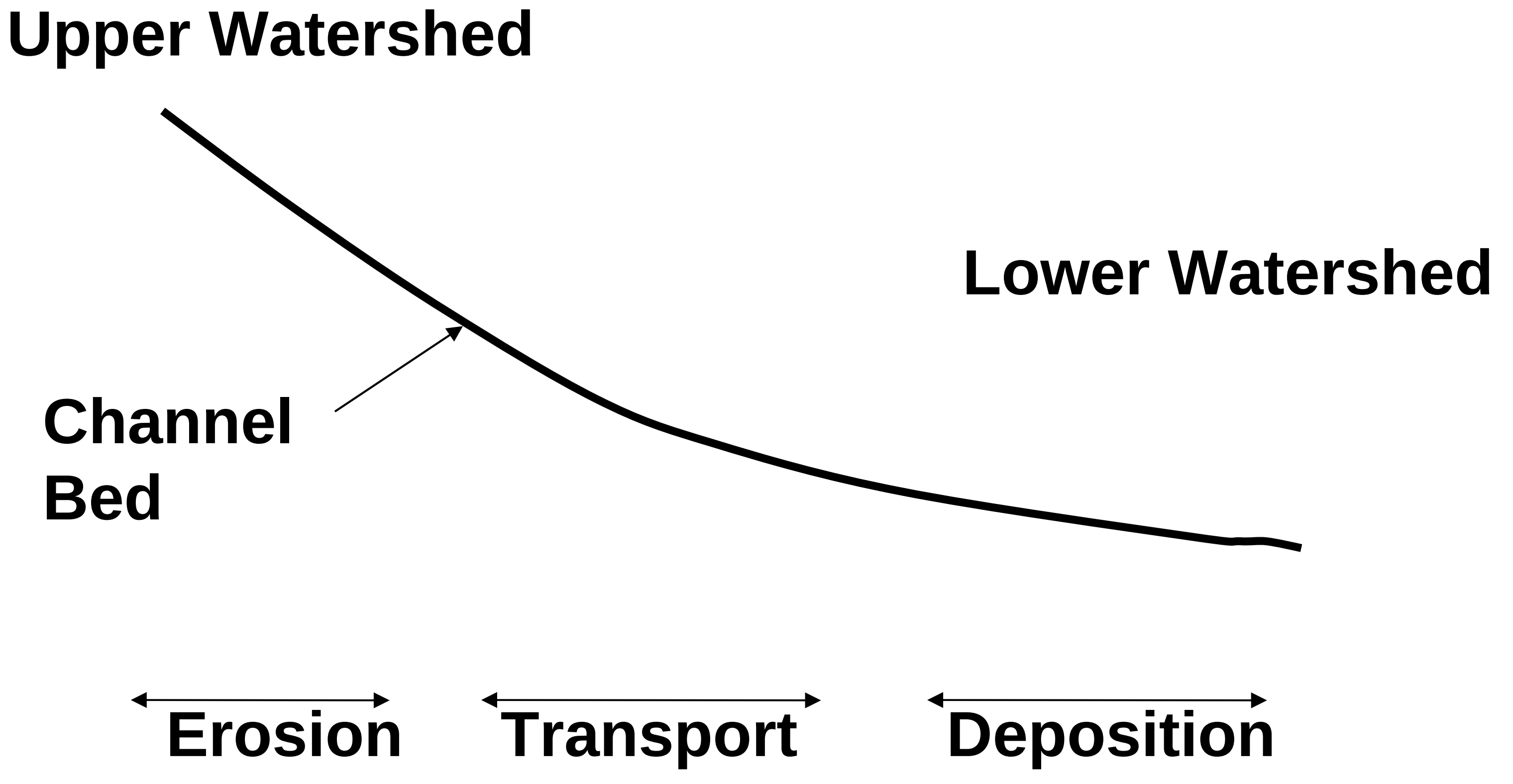
Vegetation

- Native Grasses or Trees
- Root mass acts as reinforcement (rebar), can double strength of soils
- Roots dewater the soil, reducing saturation, increasing strength (highly variable)
- Roughness reduced over all velocity/shear, and moves areas of highest shear away from banks

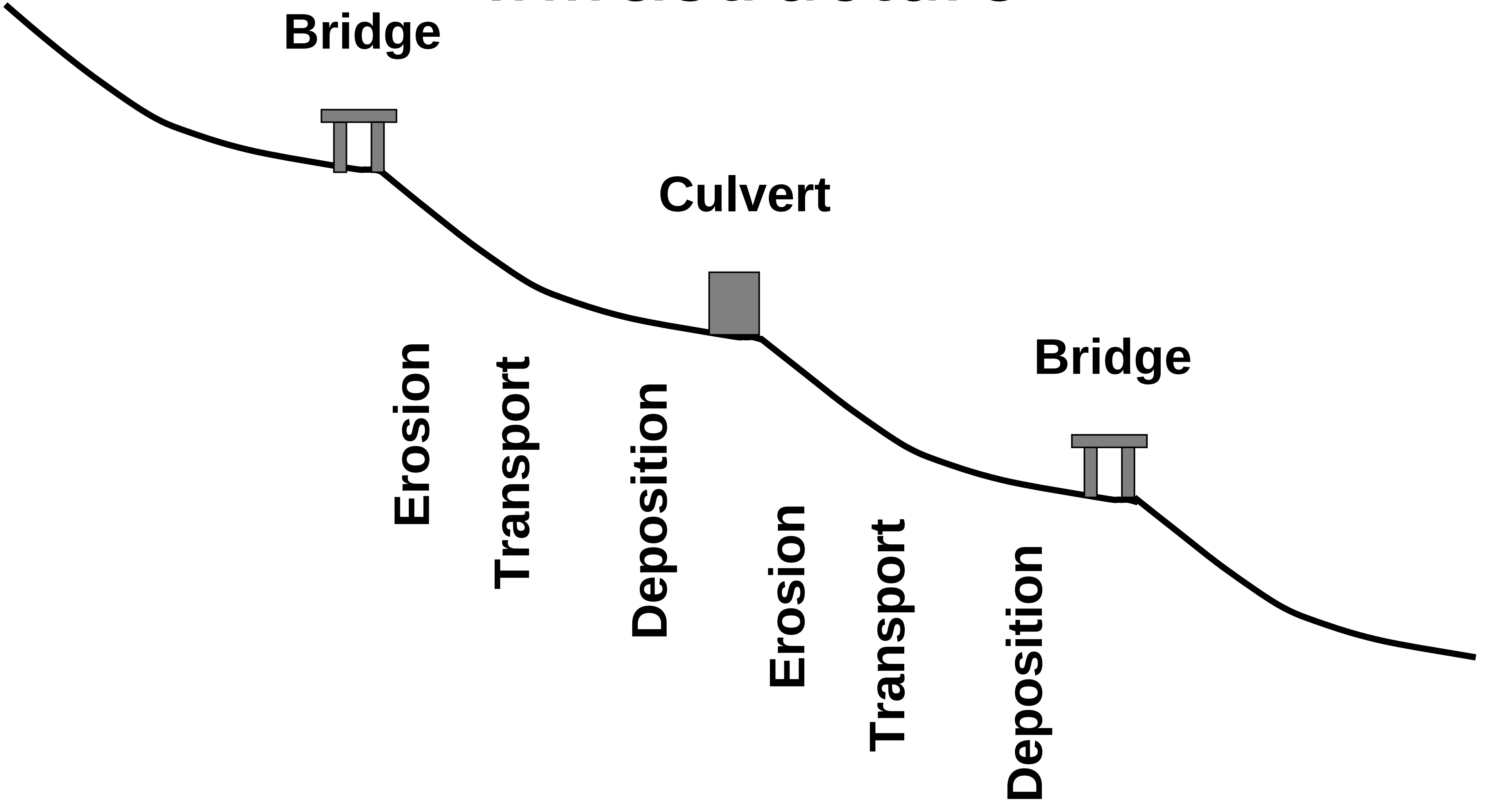
Sediment Transport

- The missing link of stormwater management
- Analysis is dependent upon
  - Sampling and data
  - Predictive equations: empirical, complicated, and not that good
- Sediment competency
  - Maintain Energy Grade Line
  - Maintain Shear

Sediment Transport Zones



Geomorphic Isolation by Infrastructure



Urbanization - 7 Deadly Sins

- Channelization
- Removing Wooded/Vegetated Corridor
- Excessive Armor
- Inducing Channel Braiding by widening
- Re-setting Meander Patterns
- Complaint Driven Repairs
- High-efficiency Conveyance

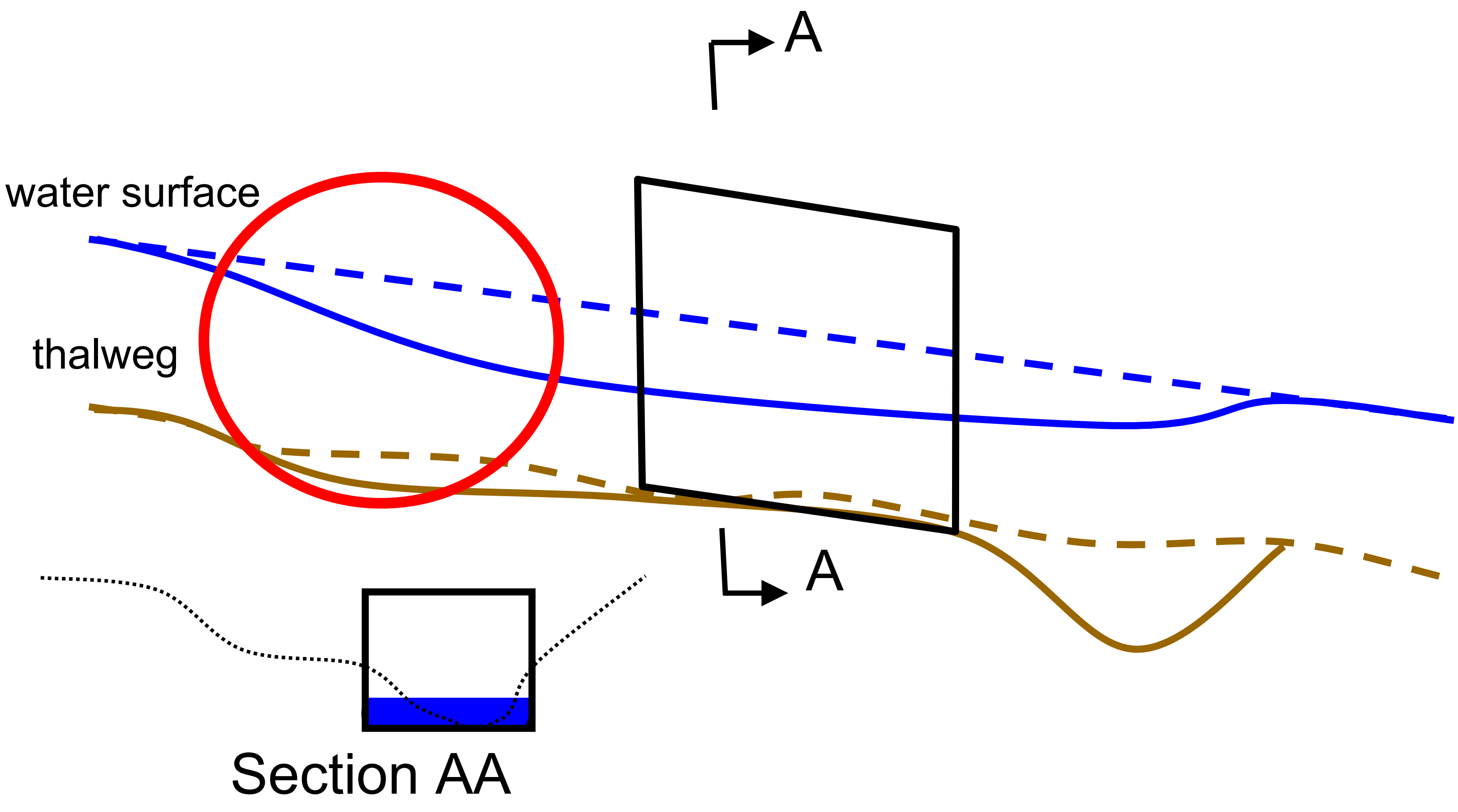
Reasonable Do's for Urban Streams

- Preserve streams instead of conduits.
- Place streams inside protected buffers. Preserve native grasses and trees.
- Expect the stream to move, stay out of its way, plan for "urban stable" condition.
- Good erosion control on uplands, avoid shocks to the sediment balance.

Reasonable Do's for Urban Streams

- Disturbances/crossings at or between riffles, using grade control to isolate.
- Consider grade control (with prudence).
- Avoid or mitigate for steepened water surface profiles/drawdowns.

Steepened Water Surface Profile



Reasonable Do's for Urban Streams

- Avoid bank armoring except when critical.
- When armoring, need good keys and transitions, keep rough, isolate with grade control, think about toe protection, and be stout.
- In-channel methods of flow and stress control.
  - Use upstream pointing chevrons to direct flow.

Reasonable Do’s for Urban Streams

- For flood control, try to leave main channel alone, get extra conveyance in graded (then restored) overbanks.
- 2-stage culverts, or plan for deposition
- Energy dissipaters.
- Consider geomorphically wise flow control, emphasis on volume of frequent storms.

Buffer Zones

- Flood Protection
- Stable Banks
- Room for Meander and Erosion
- Aesthetics
- Ecology and Habitat
- Pollutant Reduction
- Infiltration/Evapotranspiration

Summary

- Streams are self-forming and complex, yet understandable.
- Streams are essential to ecology.
- Urbanization disrupts dynamic equilibrium.
- Mitigation is possible, but takes new approaches.