Tools for Stream Restoration: Morphology & Structures

Greg Jennings, PhD, PE, Jennings Environmental LLC

Fluvial Geomorphology:

study of landforms and the fluvial processes that shape them

Fluvial Processes:

associated with flowing water, including sediment erosion, transport, and deposition

Stream: A *system* of fluvial forms & habitats

- Channel (bed & banks)
- Floodplain
- Water
- Sediment
- Plants & animals

Fluvial Forms

- Bar
- Channel
- Confluence
- Cutoff channel
- Delta
- Floodplain
- Gorge
- Gully
- Meander
- Oxbow lake
- Pool
- Riffle
- Stream
- Valley
- Waterfall
- Watershed

Sediment Deposition:

bars, benches, fans, & floodplains

- Point bar
- Lateral bar
- Mid-channel bar
- Transverse bar
- Delta
- Alluvial fan
- Inner berm

Point Bar

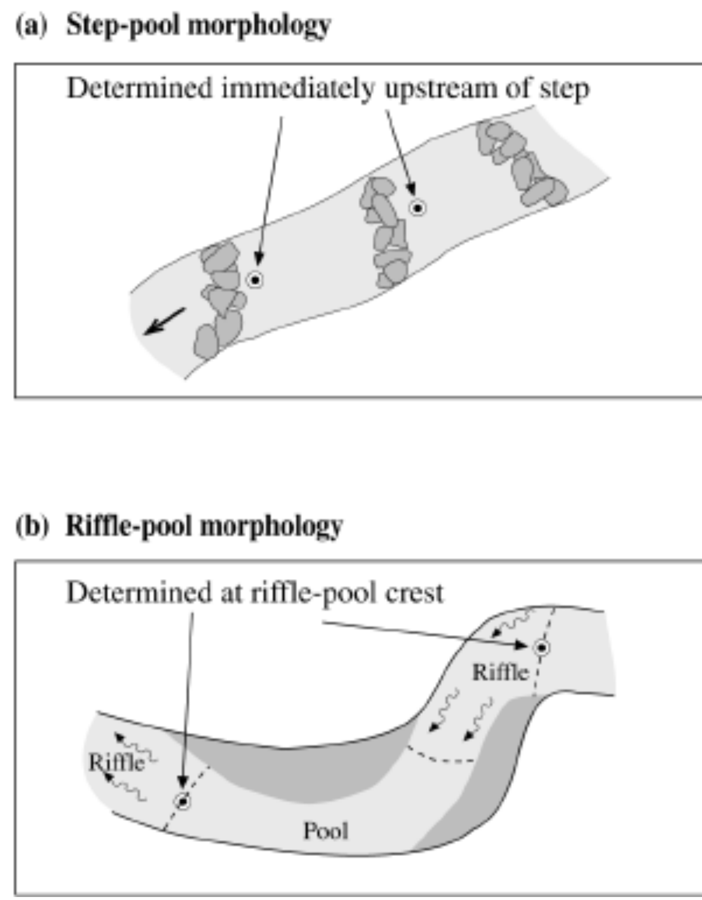
Lateral Bar

Mid-channel Bar

Transverse Bar

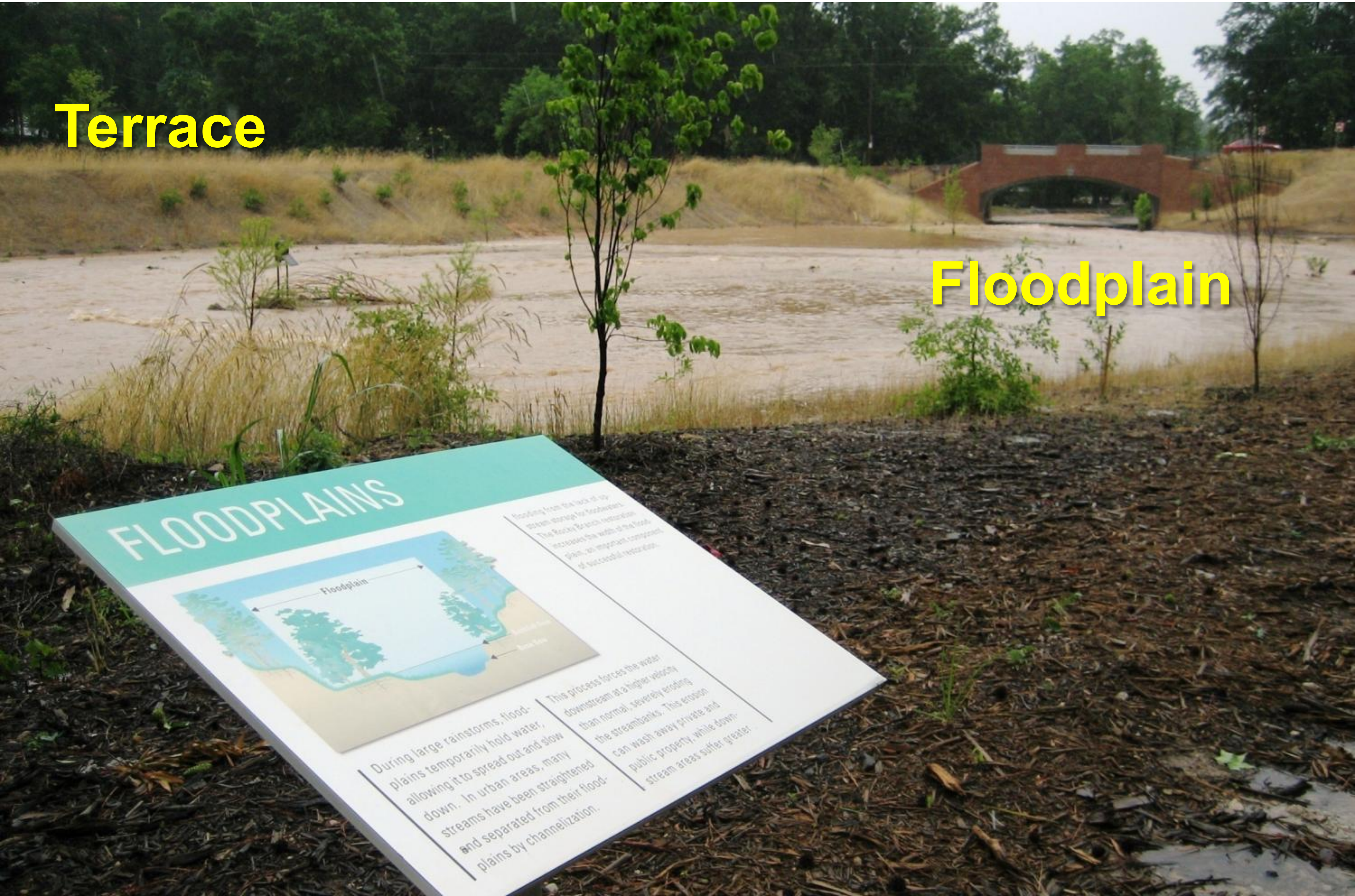
Stream Morphology:

size and shape of channel & floodplain (dimension, pattern, profile)




Terrace
Floodplain
Left Bank
Right Bank
Thalweg
Streambed
Downstream

Incised Stream System: Floodplain Creation



Valley type affects stream morphology

Colluvium: loose sediment transported by gravity and deposited down slope

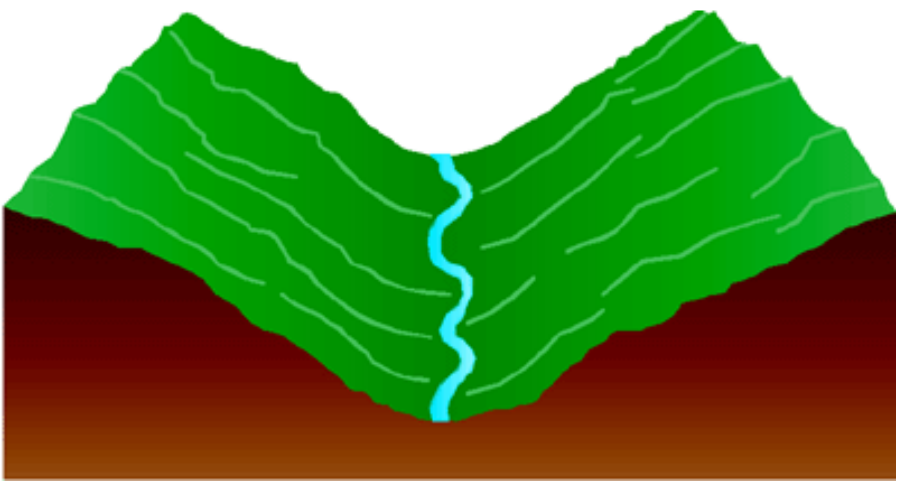
Alluvium: sediment deposited by flowing water in a channel or floodplain

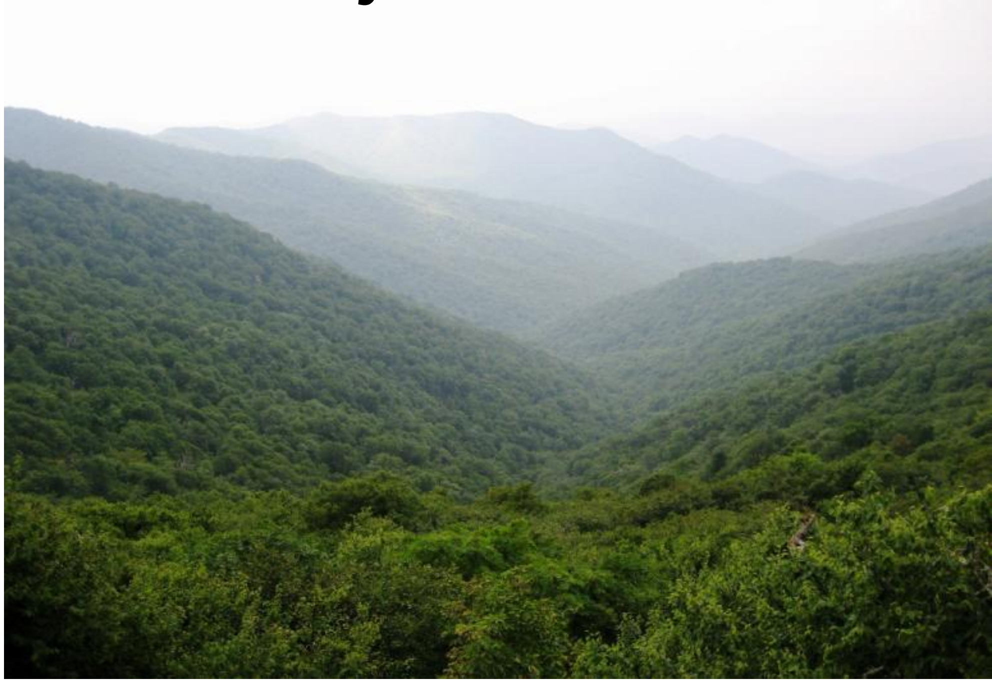
Alluvial valleys occur where sediment particles are dropped by slow-moving water

Valley Types:

www.epa.gov/watertrain/stream_class

Valley Type II
Moderately steep, gentle sloping side slopes often in colluvial valleys





From EPA Watershed Academy: Fundamentals of the Rosgen Stream Classification System

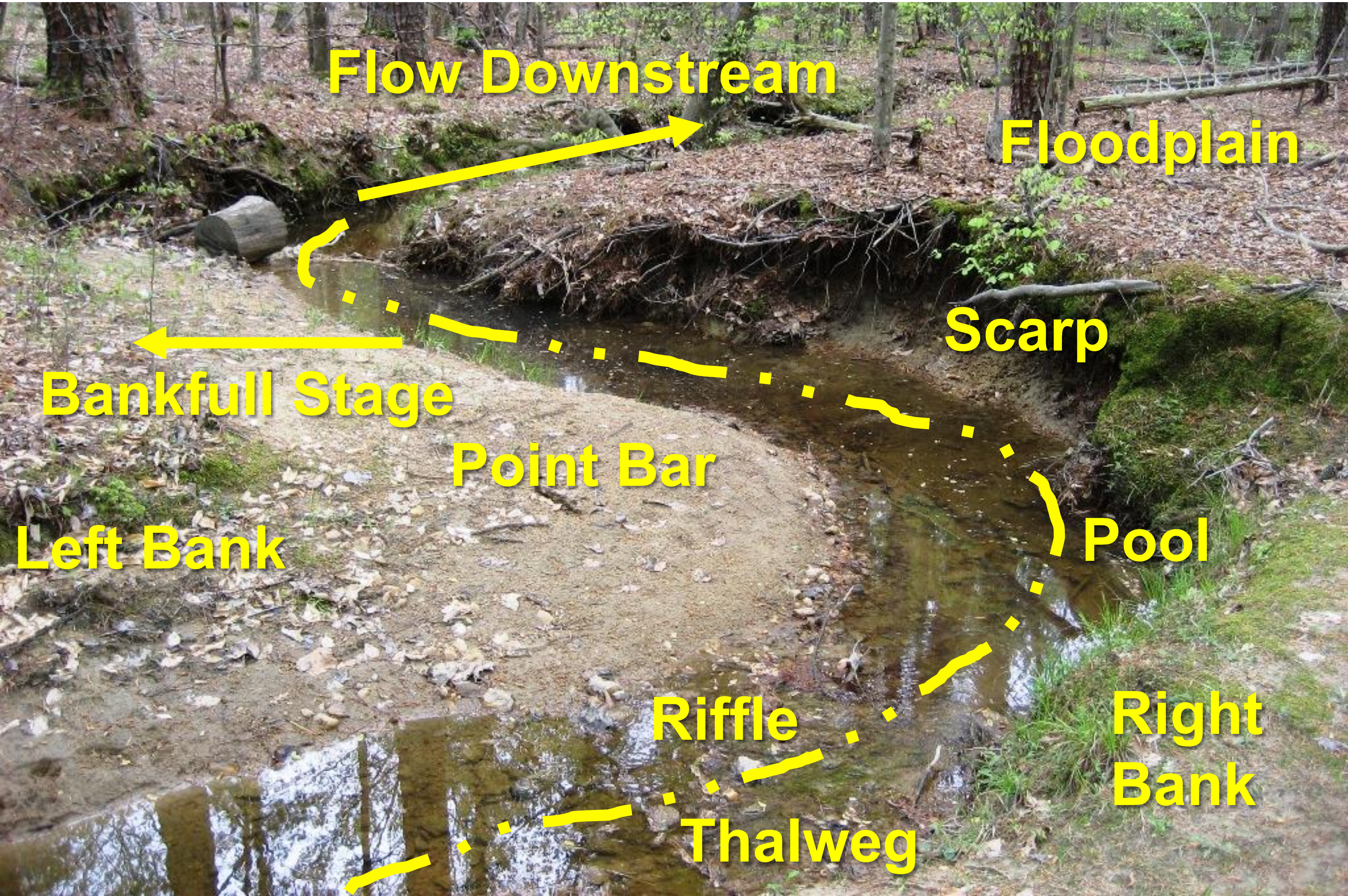
Valley Types:

www.epa.gov/watertrain/stream_class

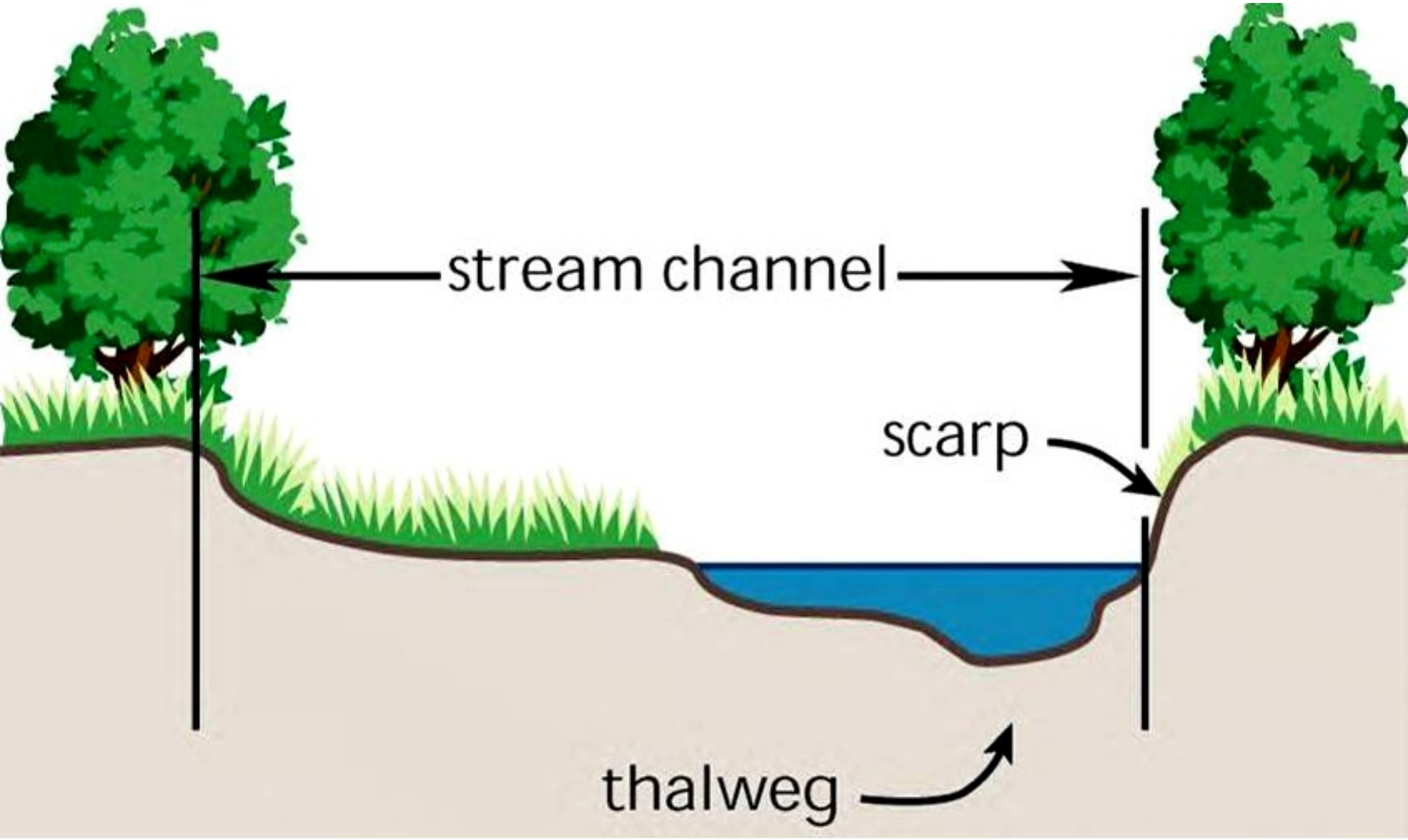
Valley Type VIII
Wide, gentle valley slope with well-developed floodplain adjacent to river terraces

From EPA Watershed Academy: Fundamentals of the Rosgen Stream Classification System

Meandering Stream: Alluvial Forms



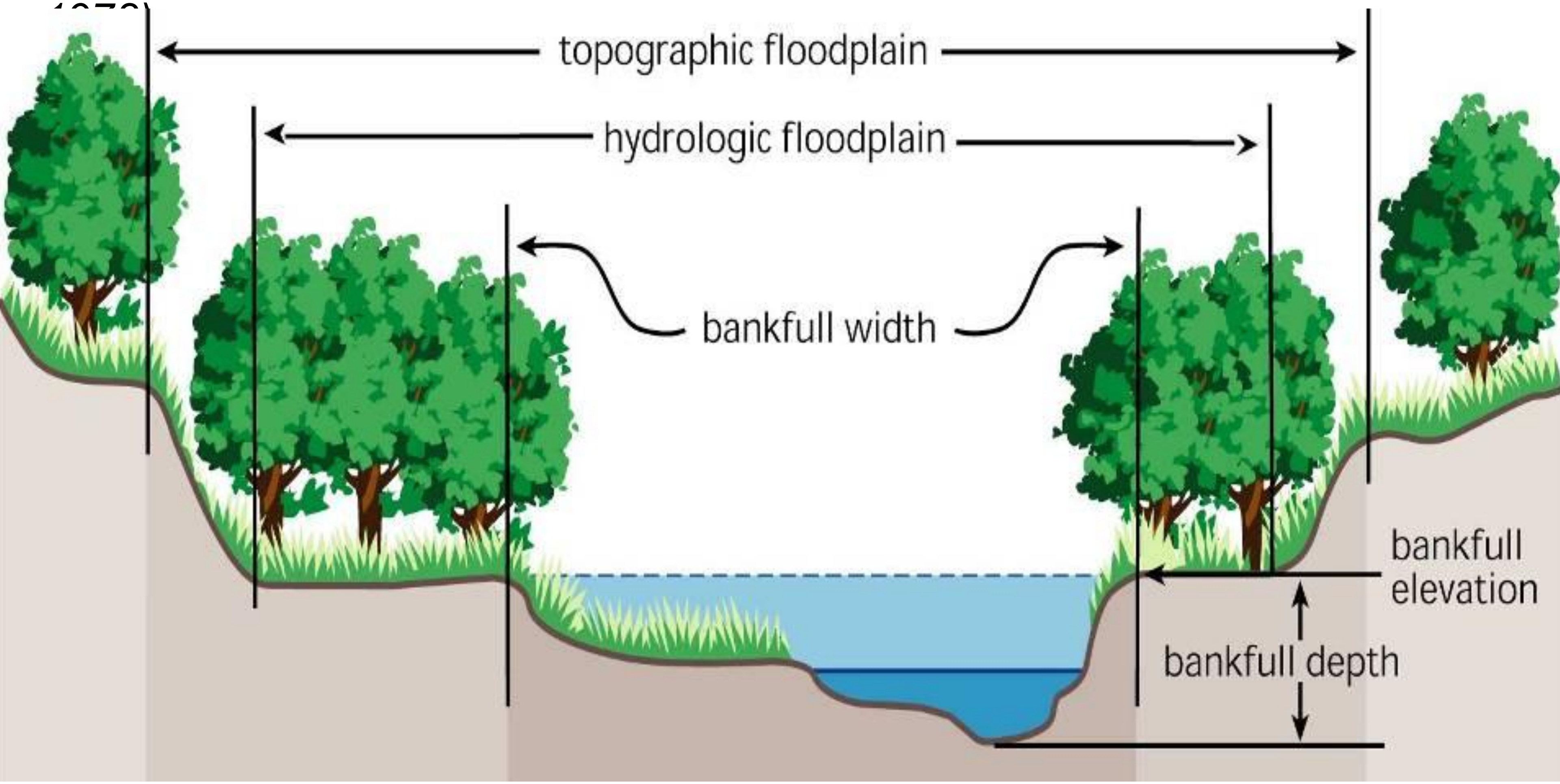
Pool Cross-Section *(Meandering Stream)*



Stream Corridor Restoration: Principles, Processes, and Practices. 1998. Federal Interagency Stream Restoration Working Group.

Bankfull Stage: "incipient flooding"

"corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work results in the average morphologic characteristics" *(Dunne & Leopold, 1978)*



Stream Corridor Restoration: Principles, Processes, and Practices. 1998. Federal Interagency Stream Restoration Working Group.

Bankfull Discharge

- Flow fills active channel and spreads onto floodplain
- Represents break between channel & floodplain processes
- For channel in equilibrium, assumed to equal effective discharge
- Typical Return Period 1 to 2 yrs

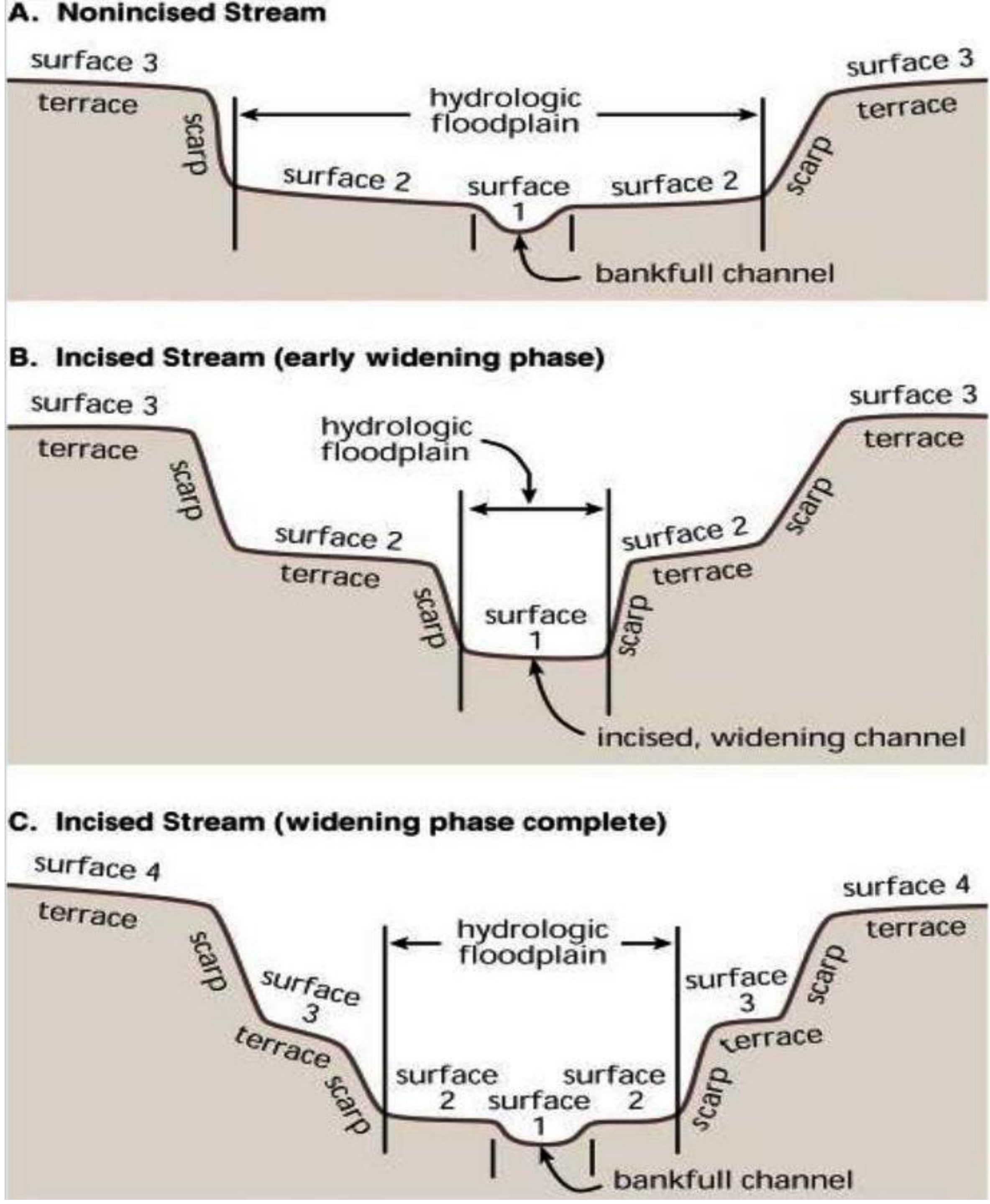

Bankfull


Bankfull


Bankfull

Channel Evolution (Succession)

Response to incising forces



Stream Corridor Restoration: Principles, Processes, and Practices. 1998. Federal Interagency Stream Restoration Working Group.


Terrace
Bankfull

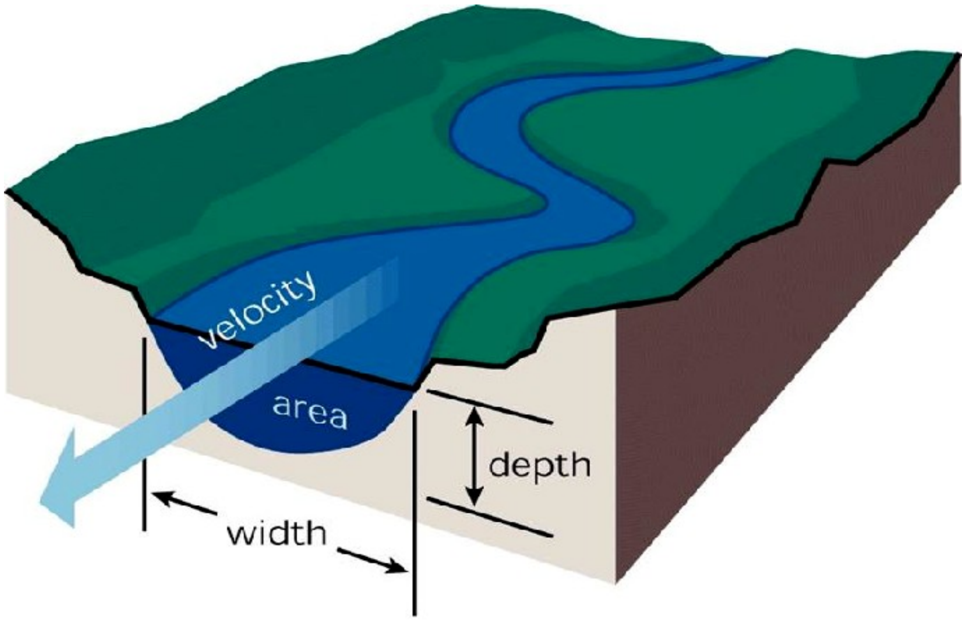
Equilibrium Controlling Variables

- Width
- Depth
- Slope
- Velocity
- Discharge
- Flow resistance
- Sediment size
- Sediment load

Leopold et al (1964)

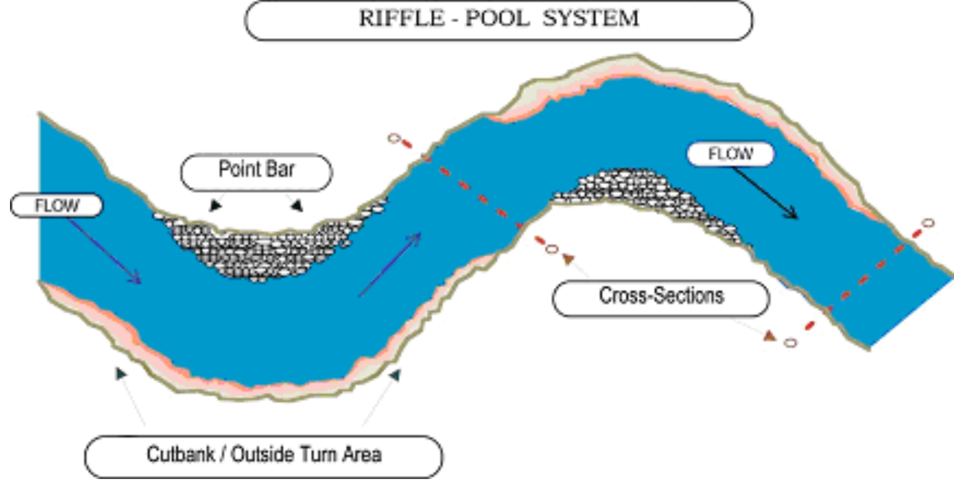
Dimension
(cross-section)

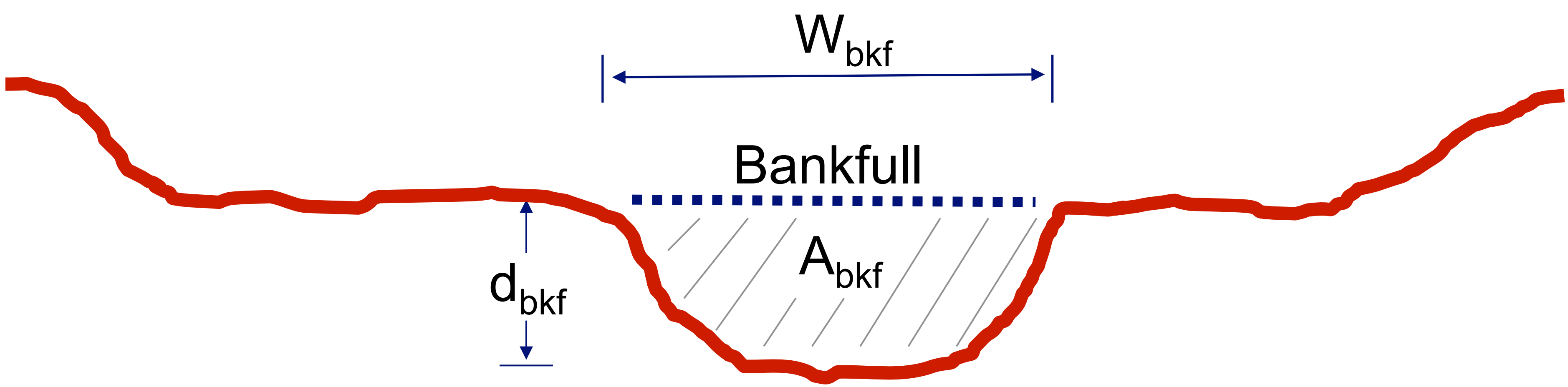
- Area
- Width
- Depth
- Width/Depth Ratio
- Entrenchment Ratio
- Bank Height Ratio



Dimension: Cross-Section

Riffle Dimensions





Measure Bankfull Width (W_{bkf}) and Bankfull Area (A_{bkf})

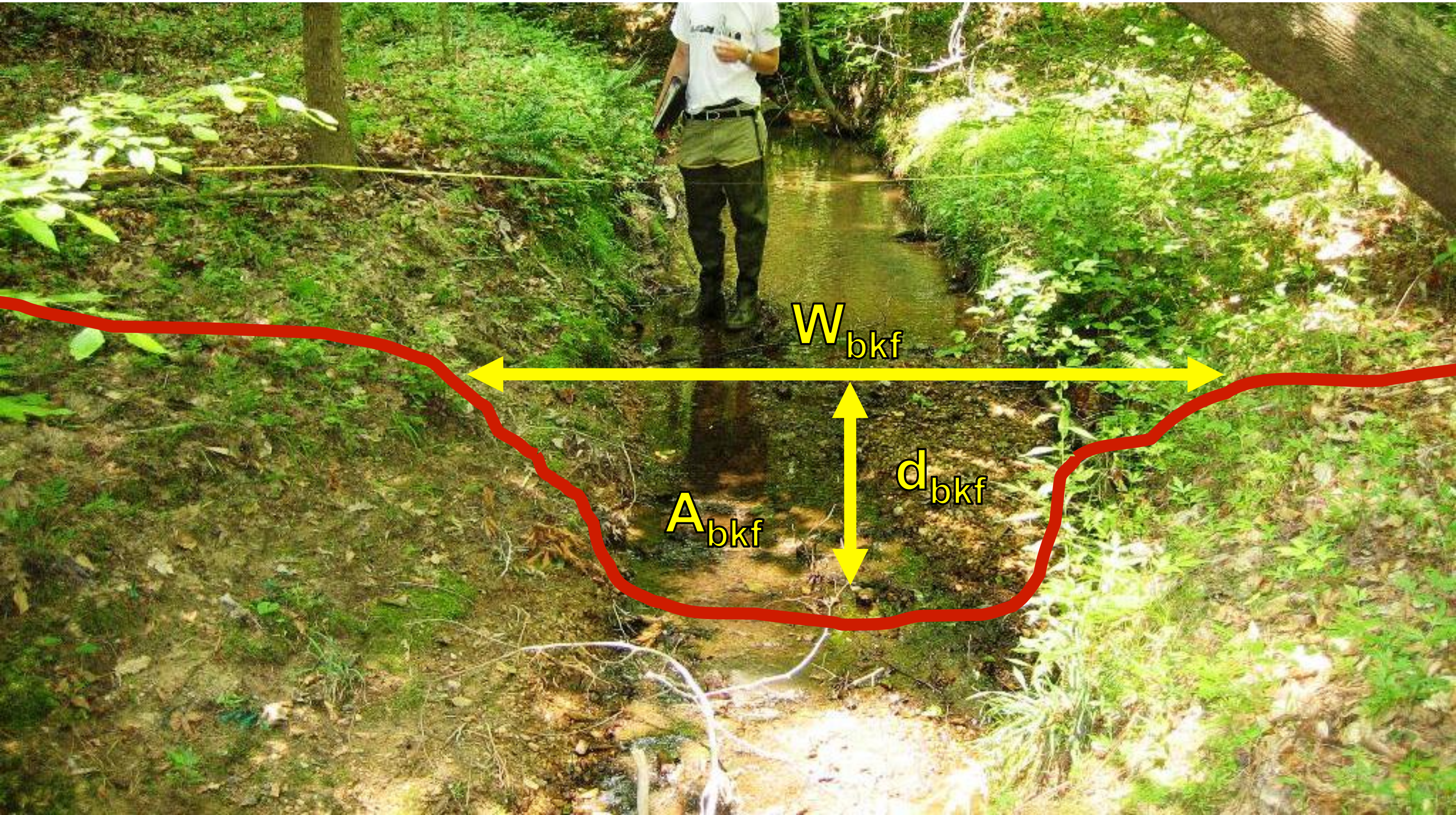
Mean Depth, $d_{bkf} = A_{bkf} / W_{bkf}$

Width to Depth Ratio, $W/d = W_{bkf} / d_{bkf}$

Bankfull Width, W_{bkf} = 9.3 ft;   Bankfull Area, A_{bkf} = 13.9 ft^2

Mean Depth, $d_{bkf} = A_{bkf} / W_{bkf}$ = 13.9 / 9.3 = 1.5 ft

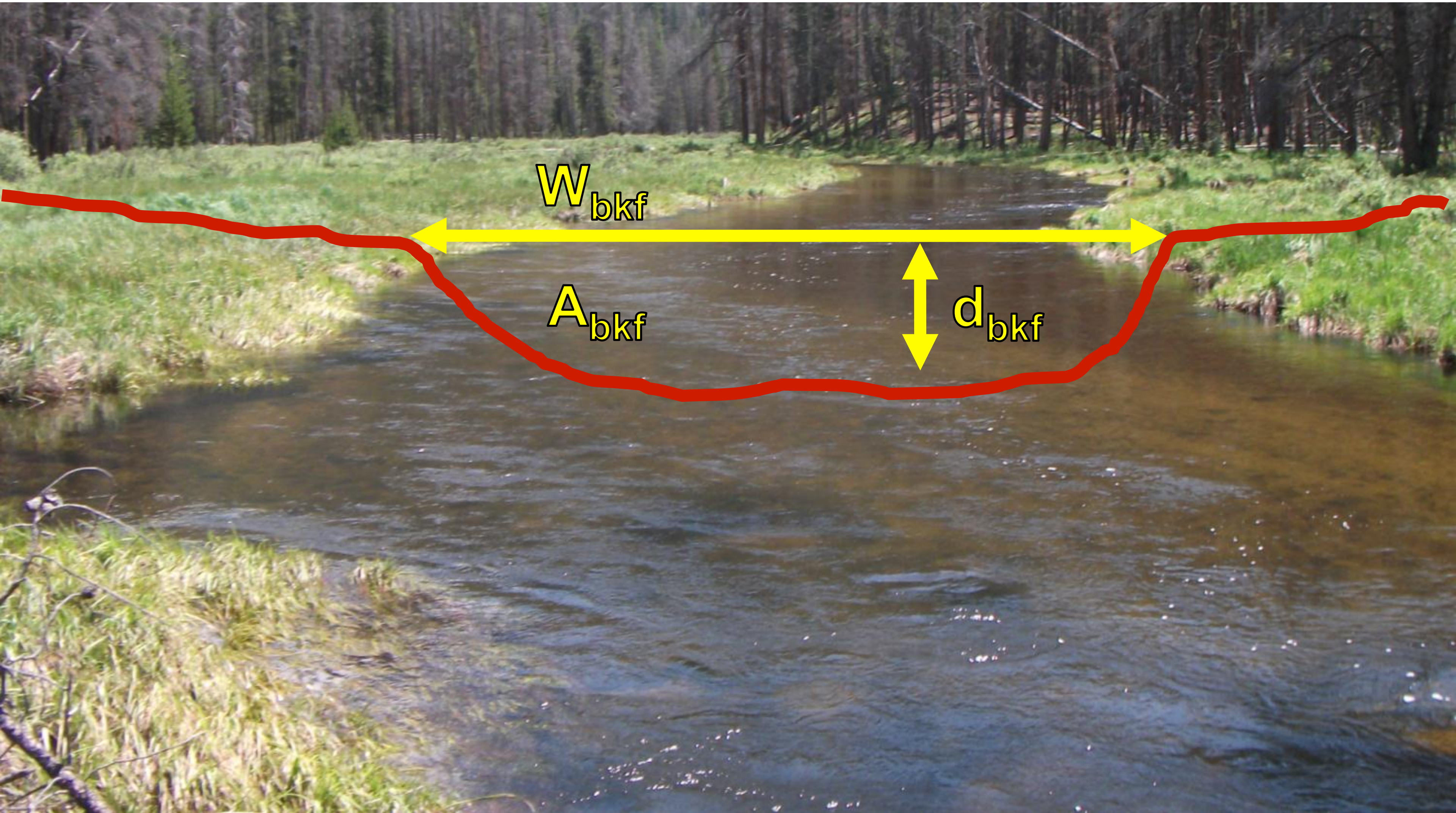
Width to Depth Ratio, $W/d = W_{bkf} / d_{bkf}$ = 9.3 / 1.5 = 6.2



Bankfull Width, W_{bkf} = 36 ft; Bankfull Area, $A_{bkf} = 112\ ft^2$

Mean Depth, $d_{bkf} = A_{bkf} / W_{bkf} = 112 / 36 = 3.1$ ft

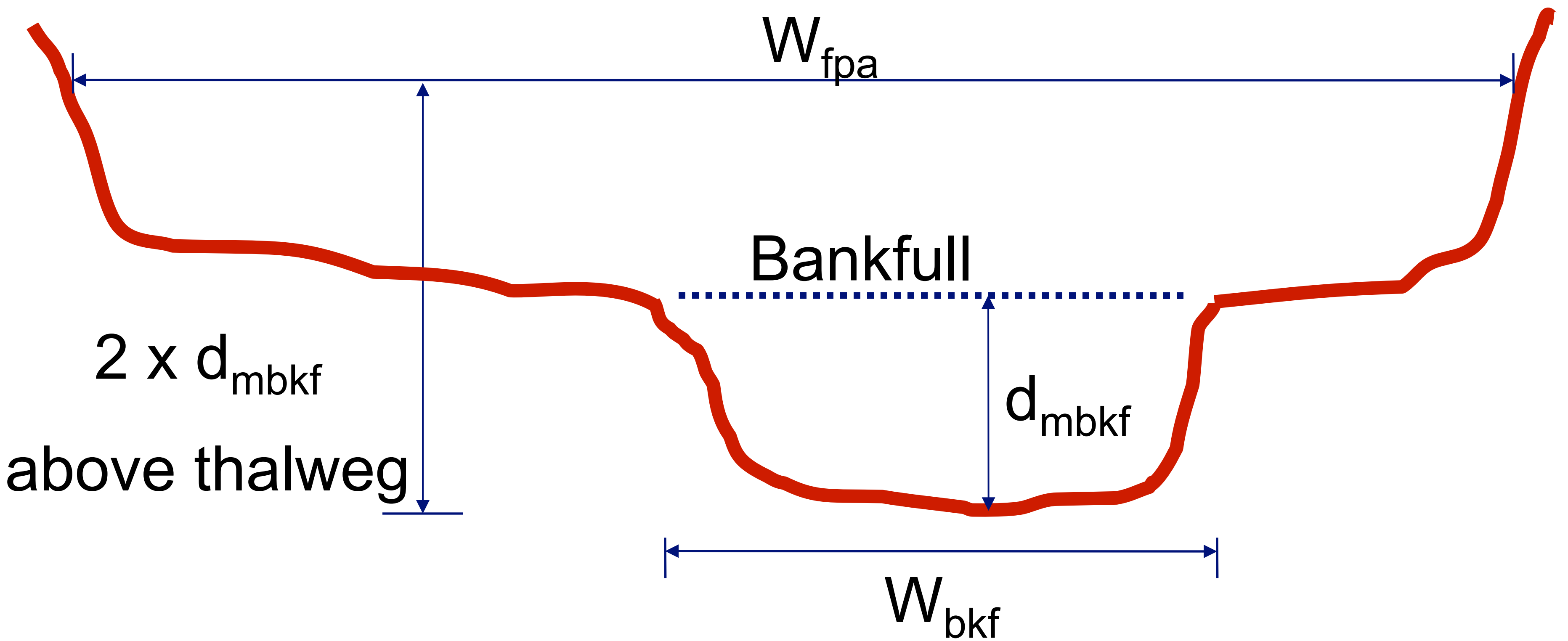
Width to Depth Ratio, $W/d = W_{bkf} / d_{bkf} = 36 / 3.1 = 11.5$



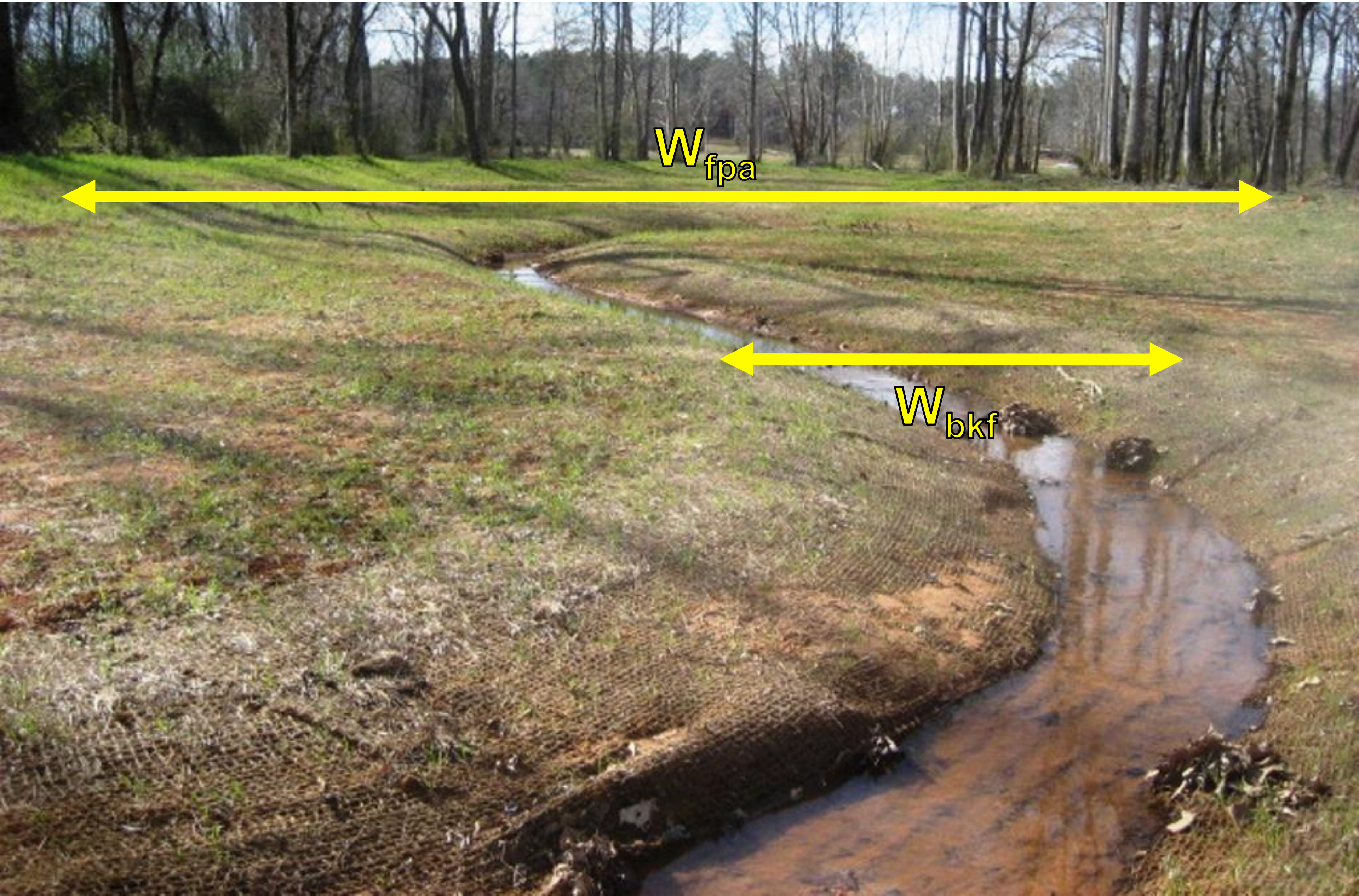
Entrenchment Ratio, $ER = W_{fpa} / W_{bkf}$

W_{fpa} = Width of Flood Prone Area measured at the elevation twice bankfull max depth above thalweg

W_{bkf} = Width of Bankfull Channel

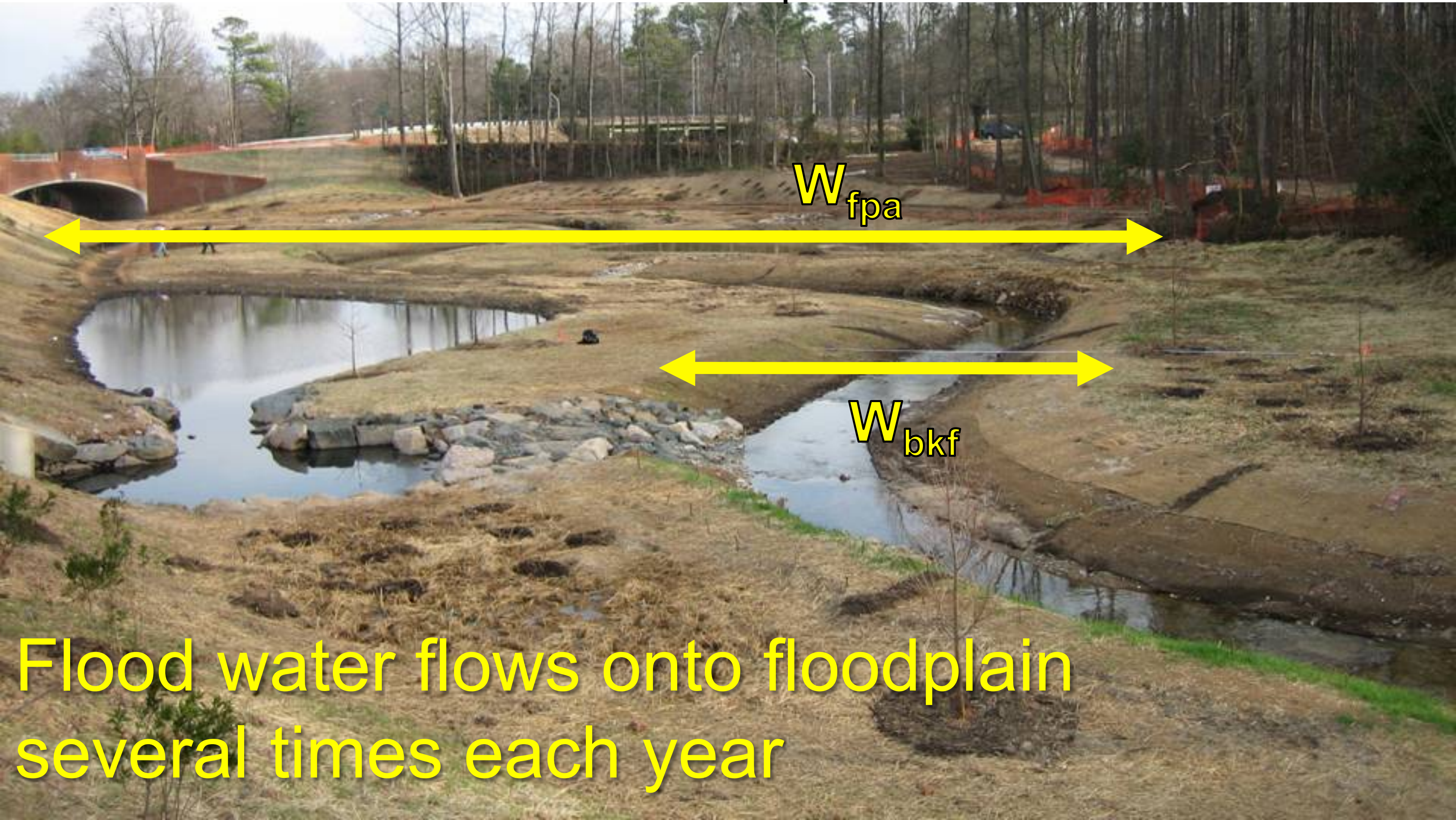


$ER = W_{fpa} / W_{bkf} = 75 / 15 = 5.0$



Rocky Branch Phase II Reach 2: Priority 2 (floodplain excavation, C channel)

Entrenchment Ratio = $W_{fpa} / W_{bkf} = 90/20 = 4.5$

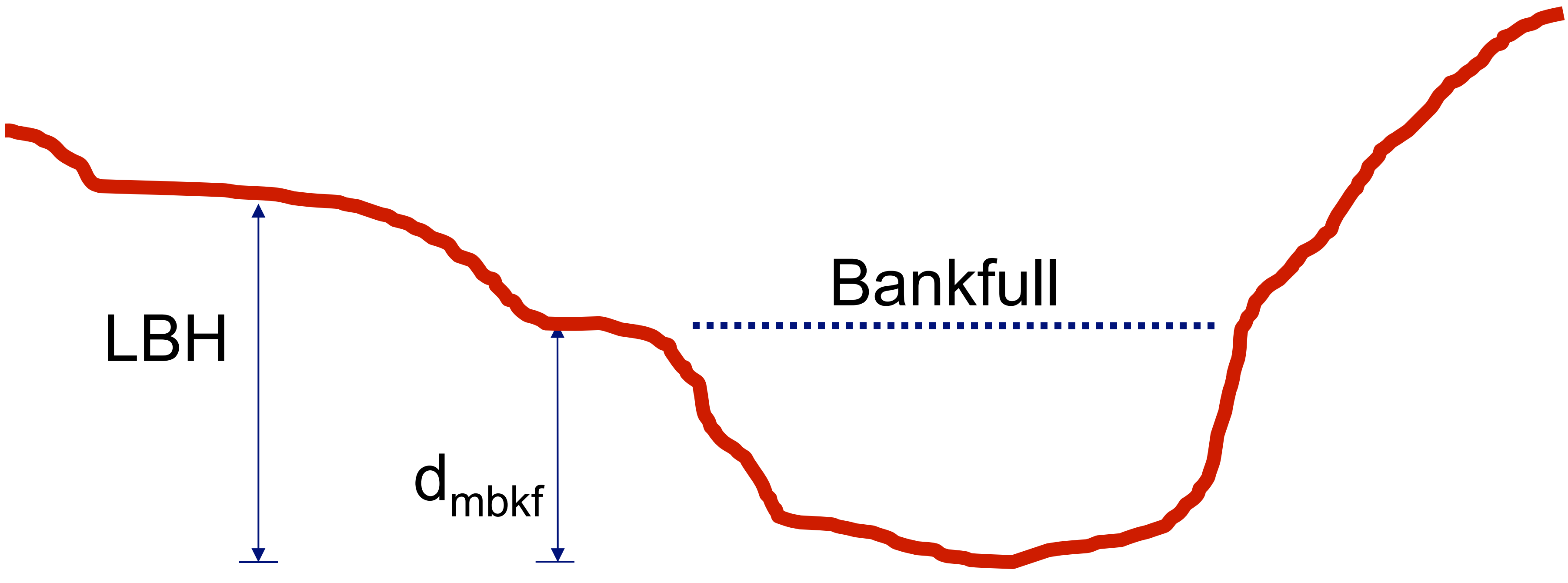


Rocky Branch Phase II Reach 1:
Priority 3 (floodplain excavation, Bc channel)
Entrenchment Ratio = W_{fpa} / W_{bkf} = 40/20 = 2

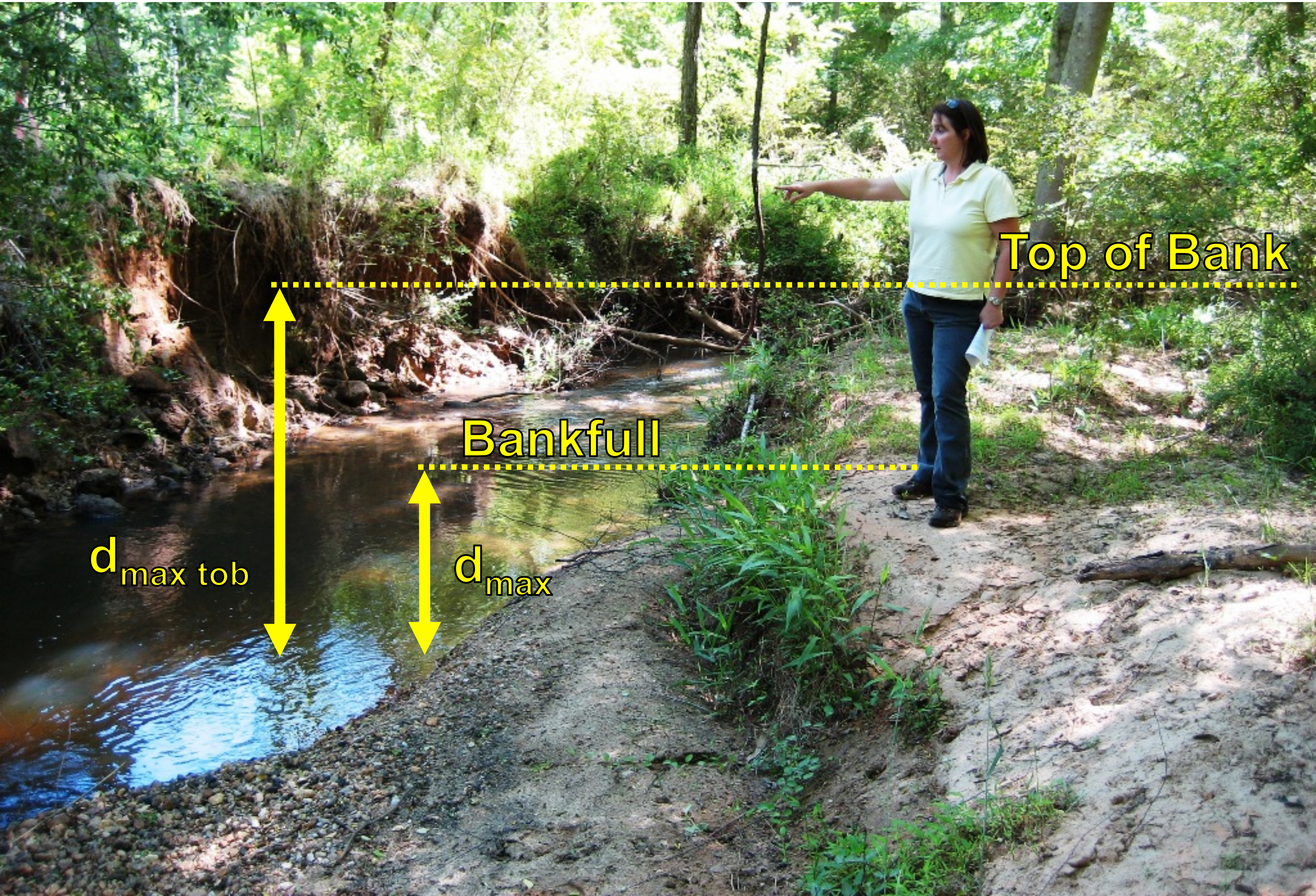
Bank Height Ratio, BHR = LBH / d_{mbkf}

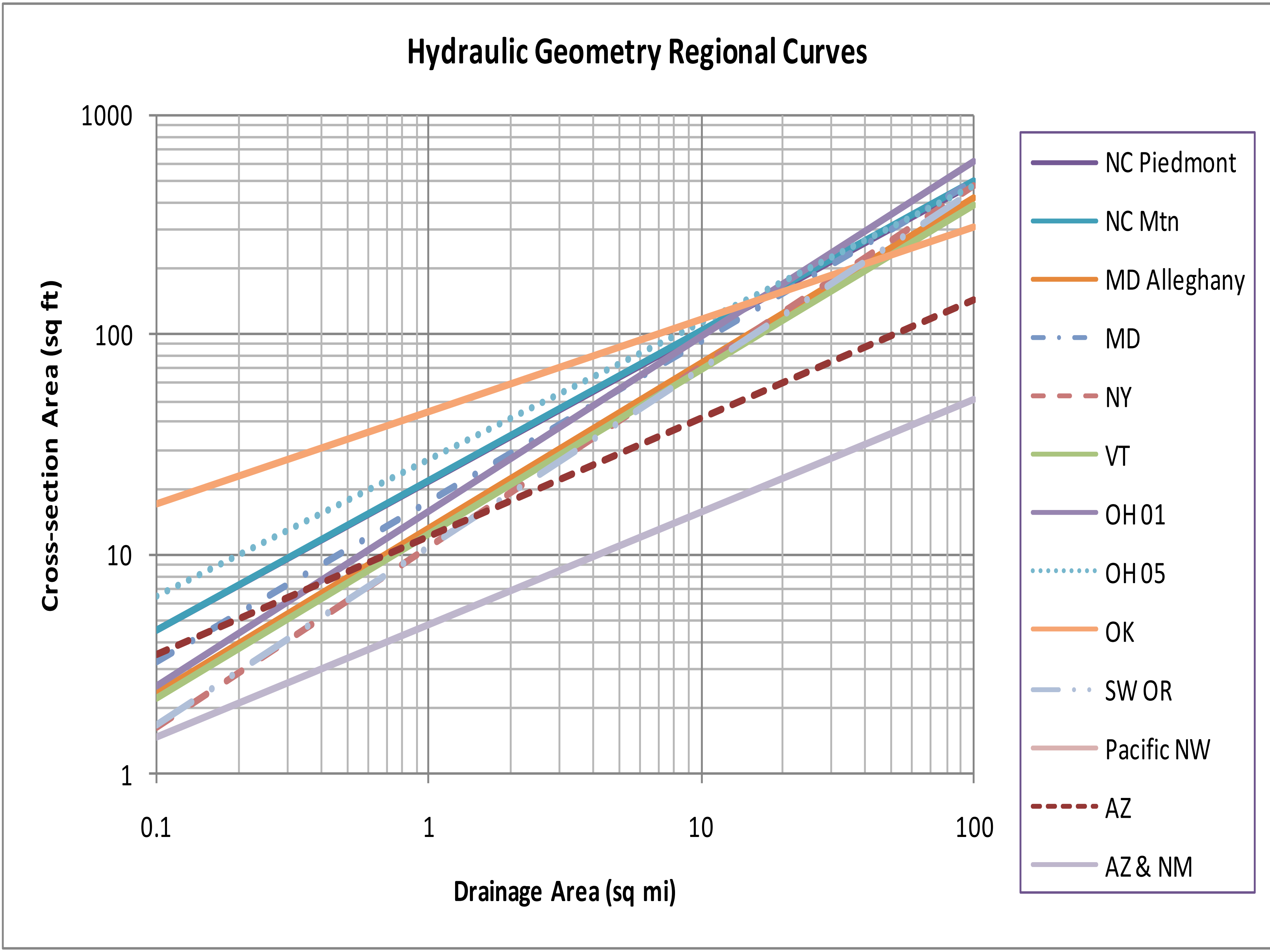
LBH = Low Bank Height (Max Depth to thalweg)

d_{mbkf} = Max Depth from bankfull stage to thalweg

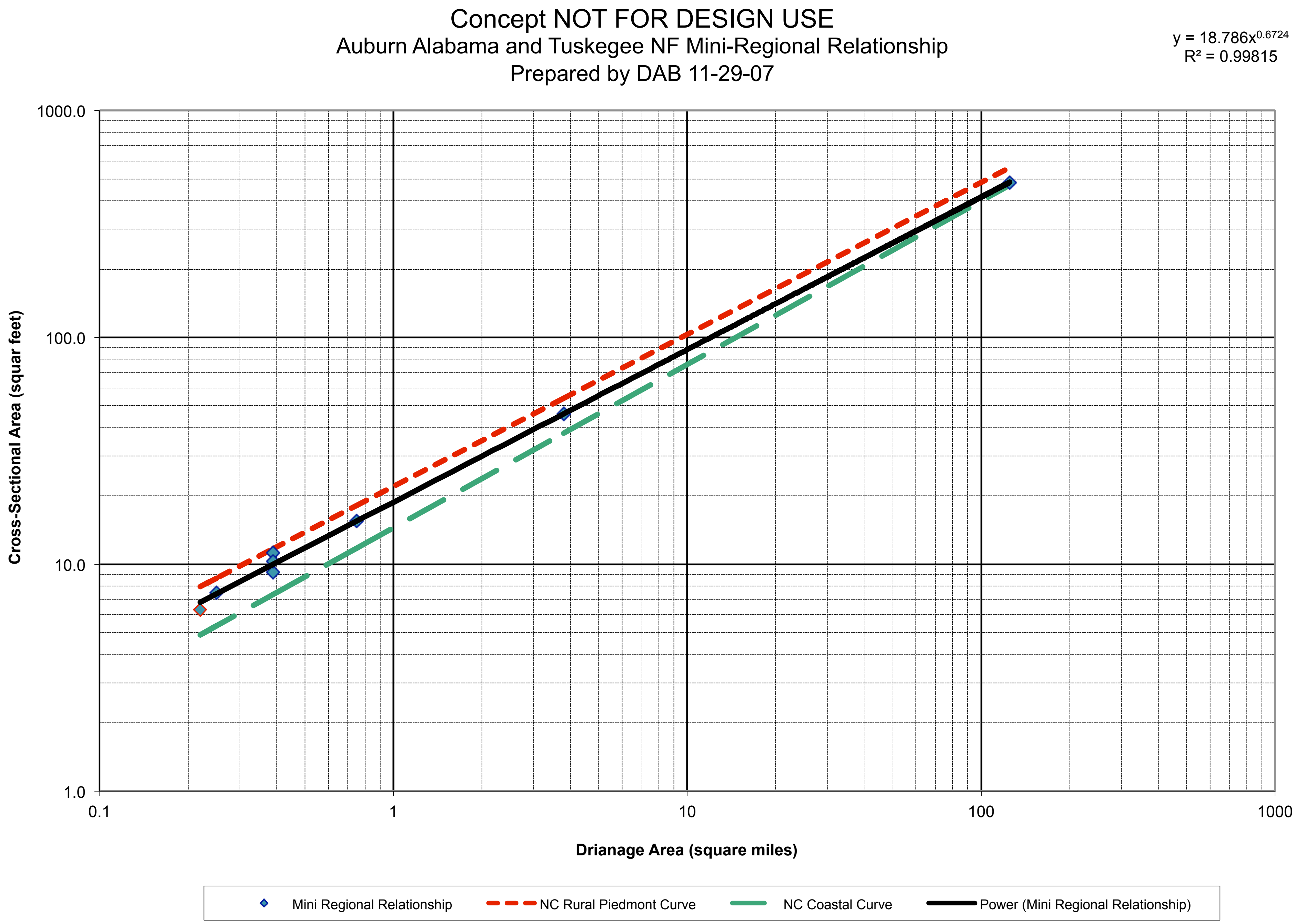


BHR = 5.3 / 2.5 = 2.1





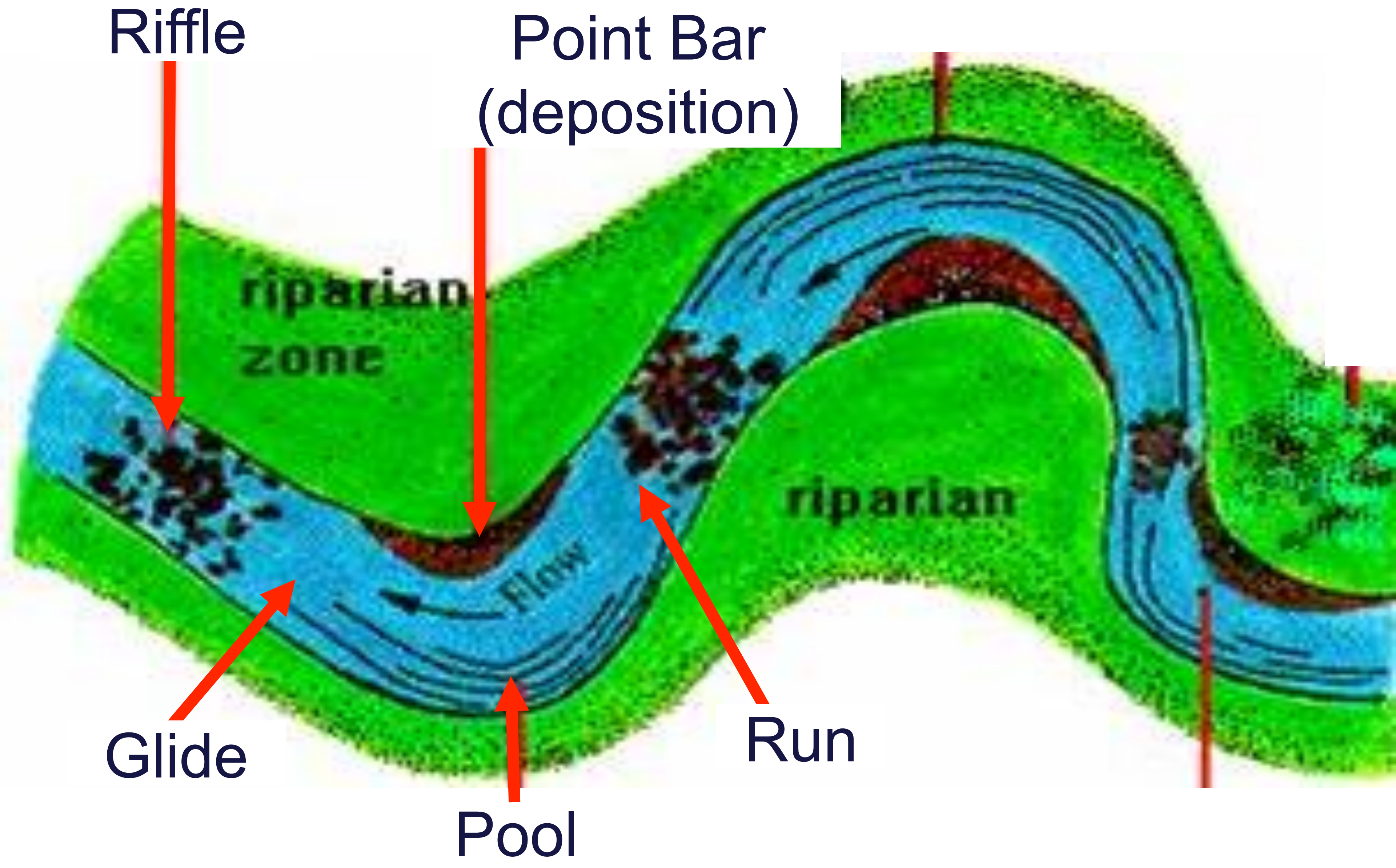
Hydraulic Geometry Regional Curves
1000
100
10
1
0.1
1
10
100
Cross-section Area (sq ft)
Drainage Area (sq mi)
NC Piedmont
NC Mtn
MD Alleghany
MD
NY
VT
OH 01
OH 05
OK
SW OR
Pacific NW
AZ
AZ & NM


Concept NOT FOR DESIGN USE
Auburn Alabama and Tuskegee NF Mini-Regional Relationship
Prepared by DAB 11-29-07
y = 18.786x^0.6724
R² = 0.99815
1000.0
100.0
10.0
1.0
0.1
1
10
100
1000
Cross-Sectional Area (squar feet)
Drianage Area (square miles)
Mini Regional Relationship
NC Rural Piedmont Curve
NC Coastal Curve
Power (Mini Regional Relationship)

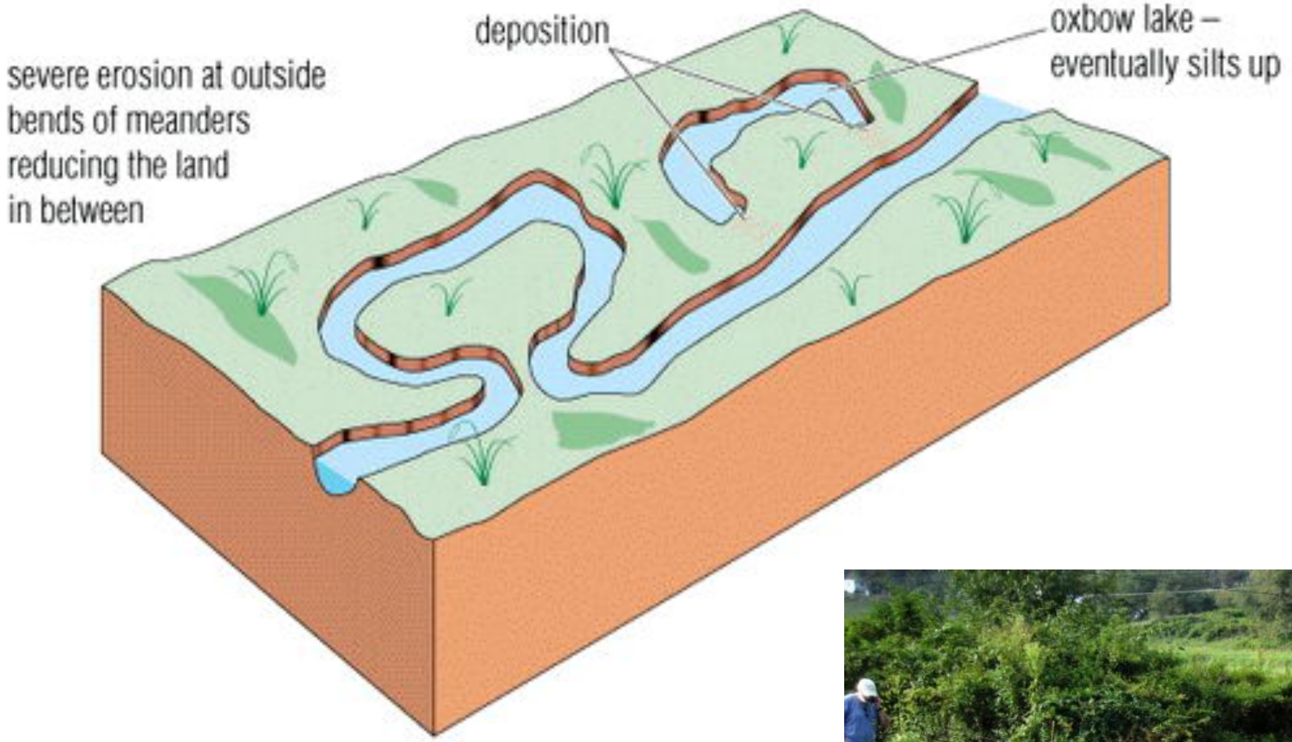
Pattern (plan form)

Alluvial (low-gradient) streams naturally meander across a valley with a somewhat predictable pattern

Meandering Stream: Alluvial Forms



Oxbow Formation in Meandering Streams



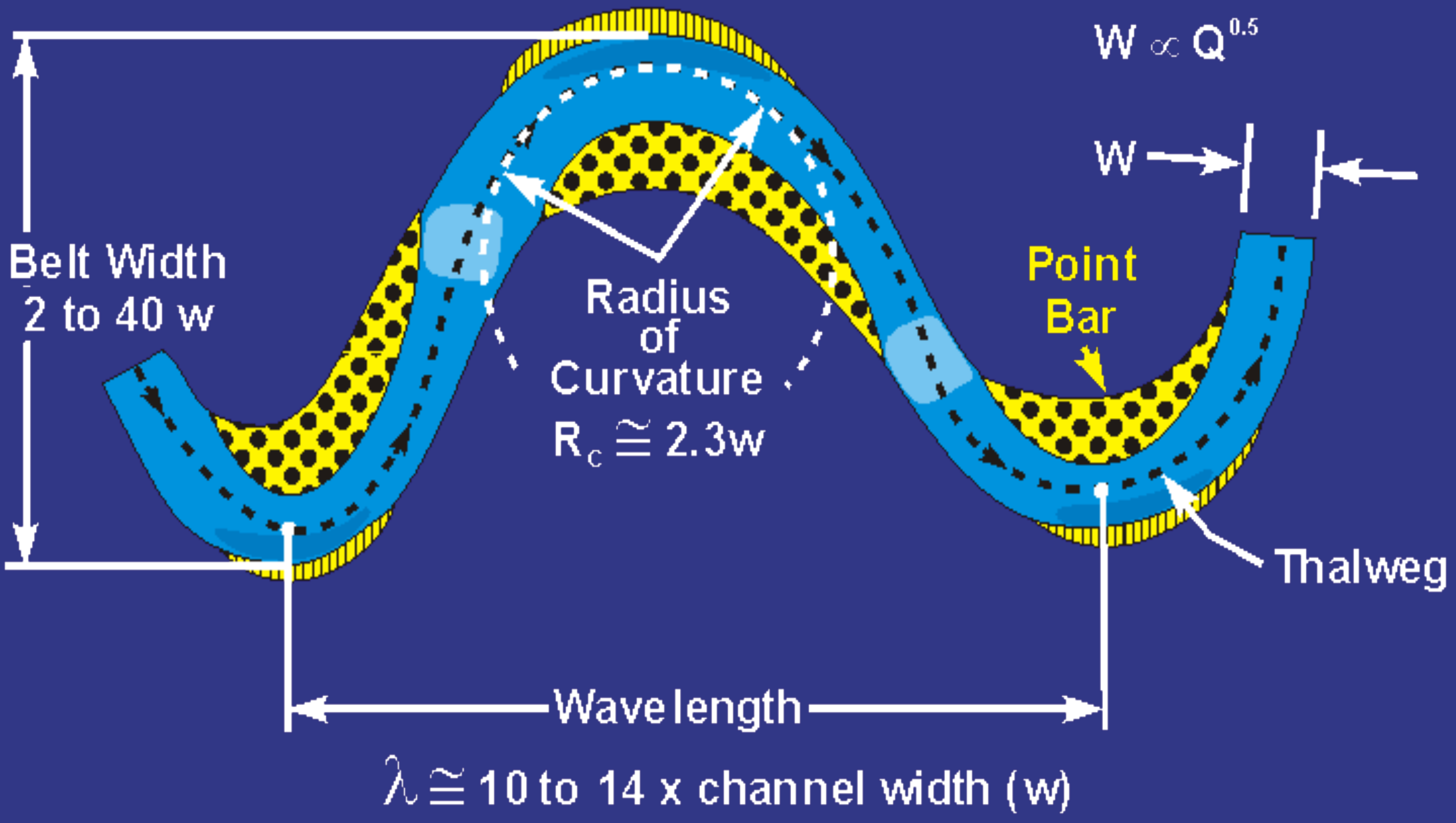
Stream Corridor Restoration: Principles, Processes, and Practices. 1998. Federal Interagency Stream Restoration Working Group.

Chute cutoff across tight meander bend

Sinuosity = stream length / valley length

$K = 1850 / 980 = 1.9$

Plan Form Relationships



Modified from Simons and Senturk, 1973; and Leopold, et. al., 1964

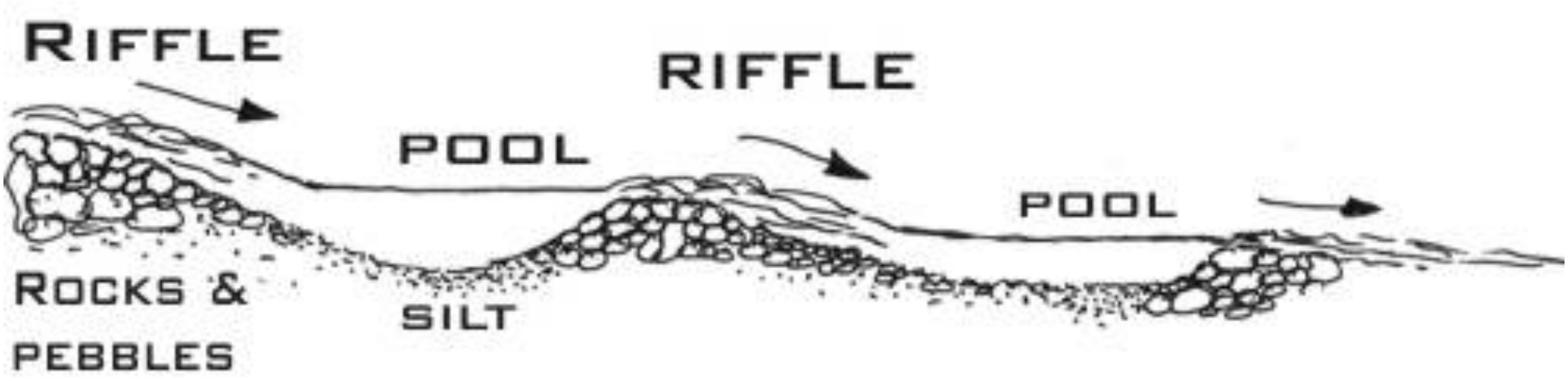
Meander Length Ratio = meander length / width = 78/15 = 5.2

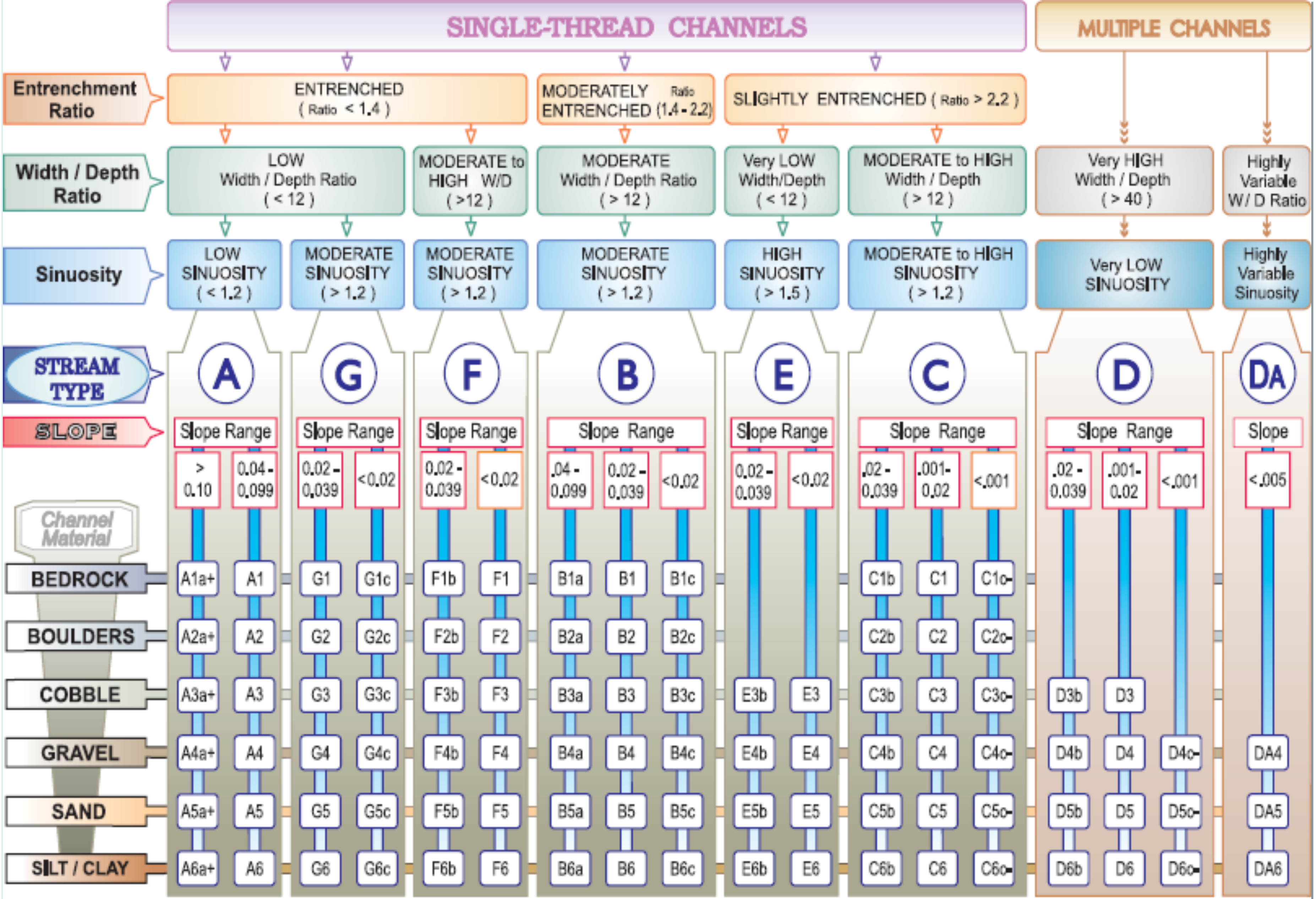
Meander Width Ratio = belt width / width = 57/15 = 3.8

Radius of Curvature Ratio = radius / width = 23/15 = 1.5

Stream Bedform Variability:

- Slope
- Velocity
- Shear stress
- Substrate size
- Oxygenation
- Habitats





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.

www.wildlandhydrology.com

Ecosystem Restoration:

“activities that initiate or accelerate the recovery of ecosystem health, integrity, and sustainability” (*SER, 2004*)

Planning a Stream Project:

- Goals? Stability, Habitat, Recreation?
- Constraints? Access, Land Availability, Utilities?
- Feasibility? Will it Work?
- Constructability? Equipment, Materials, Time/$?

Restoration Components

1. Channel & Floodplain Morph
2. In-stream Structures
3. Habitats & Vegetation
4. Site & Watershed Conditions
5. Hydrologic & Hydraulic Analysis
6. Implementation
7. Monitoring, Maintenance, & Education

1. Channel & Floodplain Morphology

Dimension, Pattern, Profile, Floodplain Connection

2005 NCSU Rocky Branch 2009

High-quality "reference" streams serve as design templates

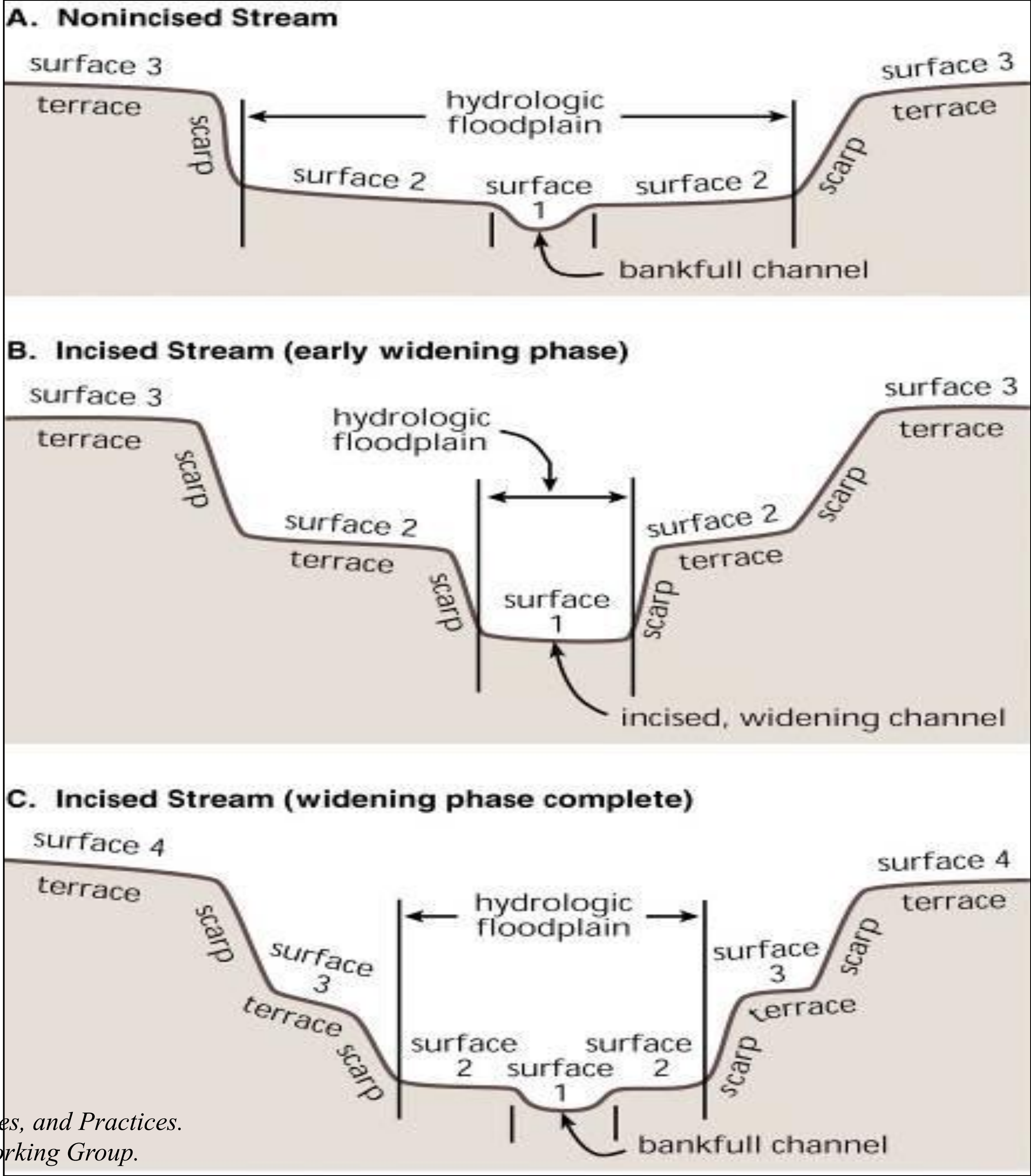
Floodplain Structure

- Regular (every year) flooding to relieve stress
- Floodwater retention & riparian wetlands
- Stormwater discharge retention & treatment

Priority 1:
lift channel

Incised Stream

Priority 2 & 3:
lower floodplain



Stream Corridor Restoration: Principles, Processes, and Practices. 1998. Federal Interagency Stream Restoration Working Group.

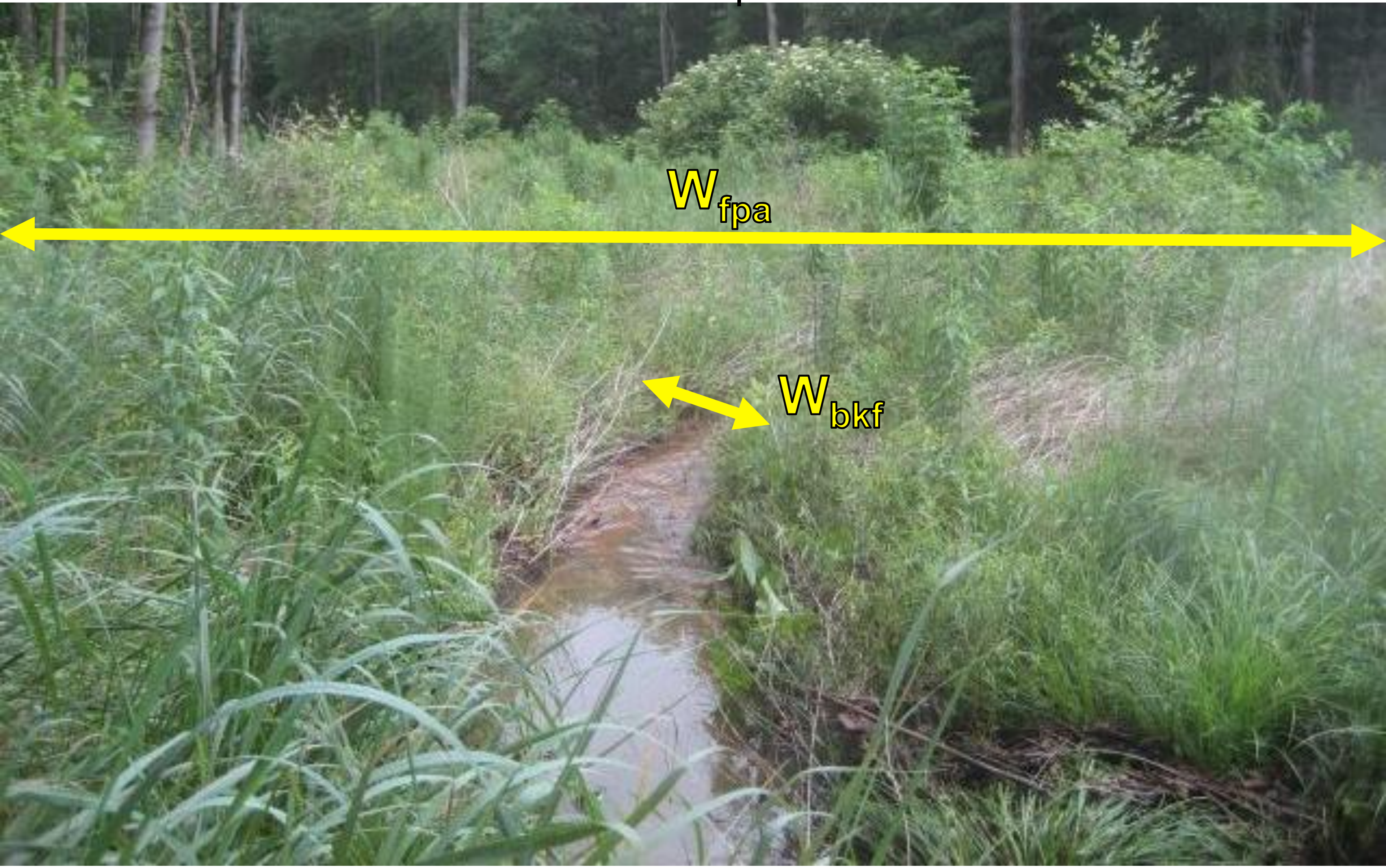
Priority 1: Raise channel to existing valley and construct new meandering channel

ER = 15; W/d = 12

Rain will come during and immediately following construction!

2006 Town Creek Tributary 2007

Entrenchment Ratio = W_{fpa} / W_{bkf} = 150/10 = 15



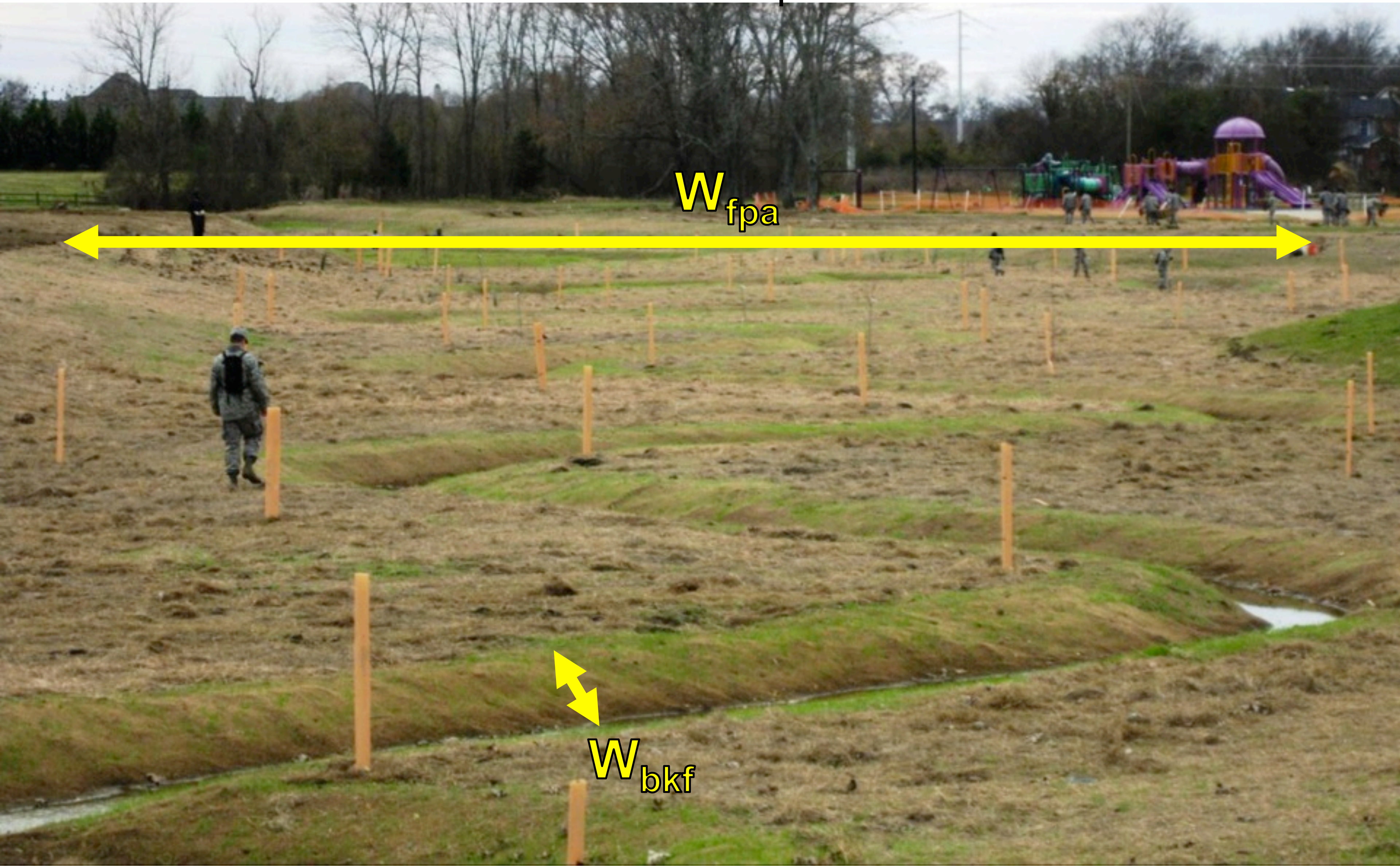
2008 Town Creek Tributary

Priority 2: Excavate lower floodplain and construct new meandering channel

ER = 6; W/d = 11

2008 White Slough 2010

Entrenchment Ratio = W_{fpa} / W_{bkf} = 90/15 = 6

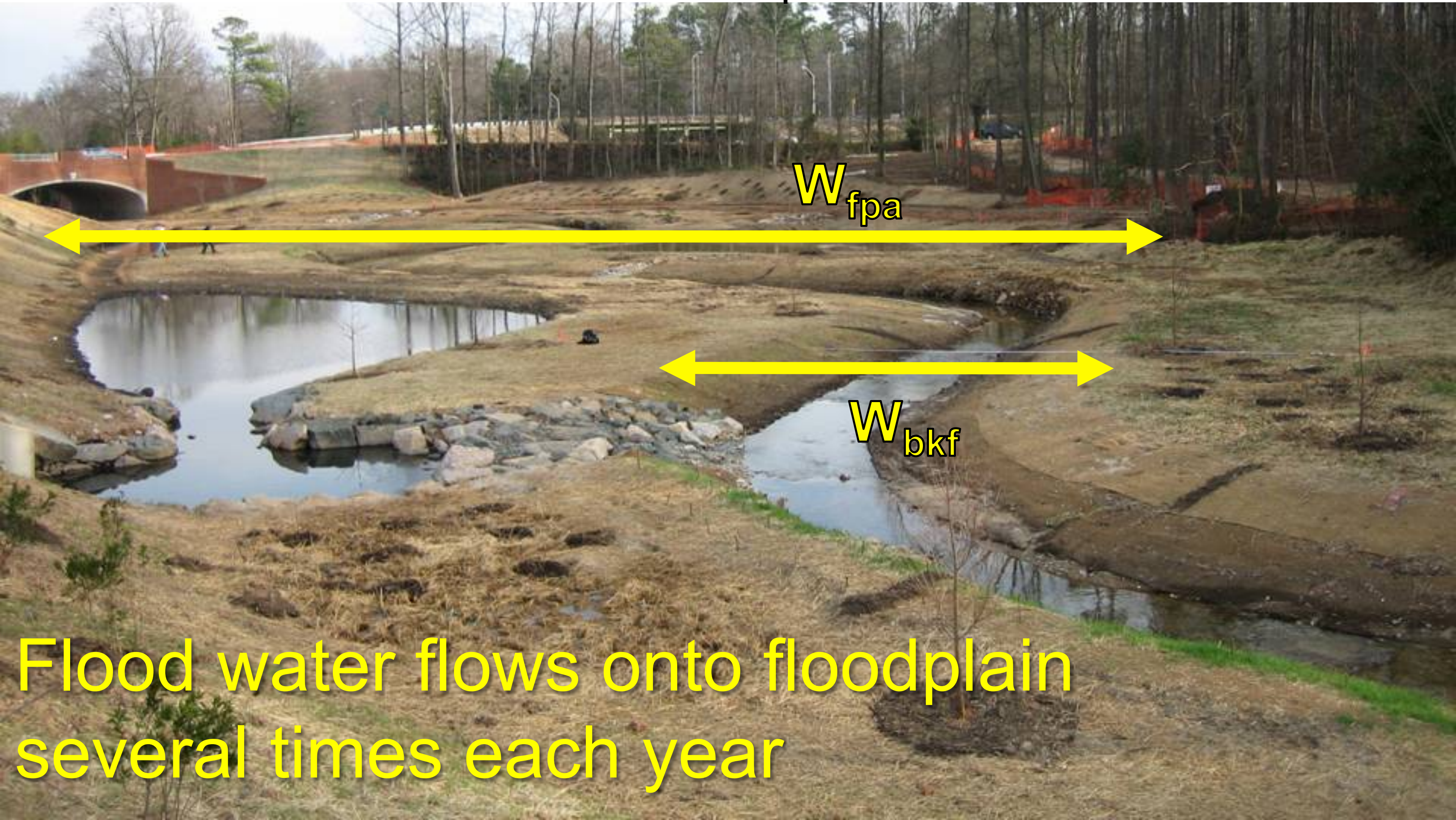


White Slough 2010

Priority 2: Excavate lower floodplain and construct new meandering channel

2004 NCSU Rocky Branch 2005

Rocky Branch Phase II Reach 2:
Priority 2 (floodplain excavation, C channel)
Entrenchment Ratio = W_{fpa} / W_{bkf} = 90/20 = 4.5




2000


2001


2003


2003

Priority 3: Excavate narrow floodplain benches in confined systems

ER = 2.2; W/d = 12

2005 NCSU Rocky Branch 2006

Rocky Branch Phase II Reach 1:
Priority 3 (floodplain excavation, Bc channel)
Entrenchment Ratio = W_{fpa} / W_{bkf} = 40/20 = 2

2008 NCSU Rocky Branch

Priority 3: Excavate narrow floodplain benches in confined systems

ER = 1.6; W/d = 15

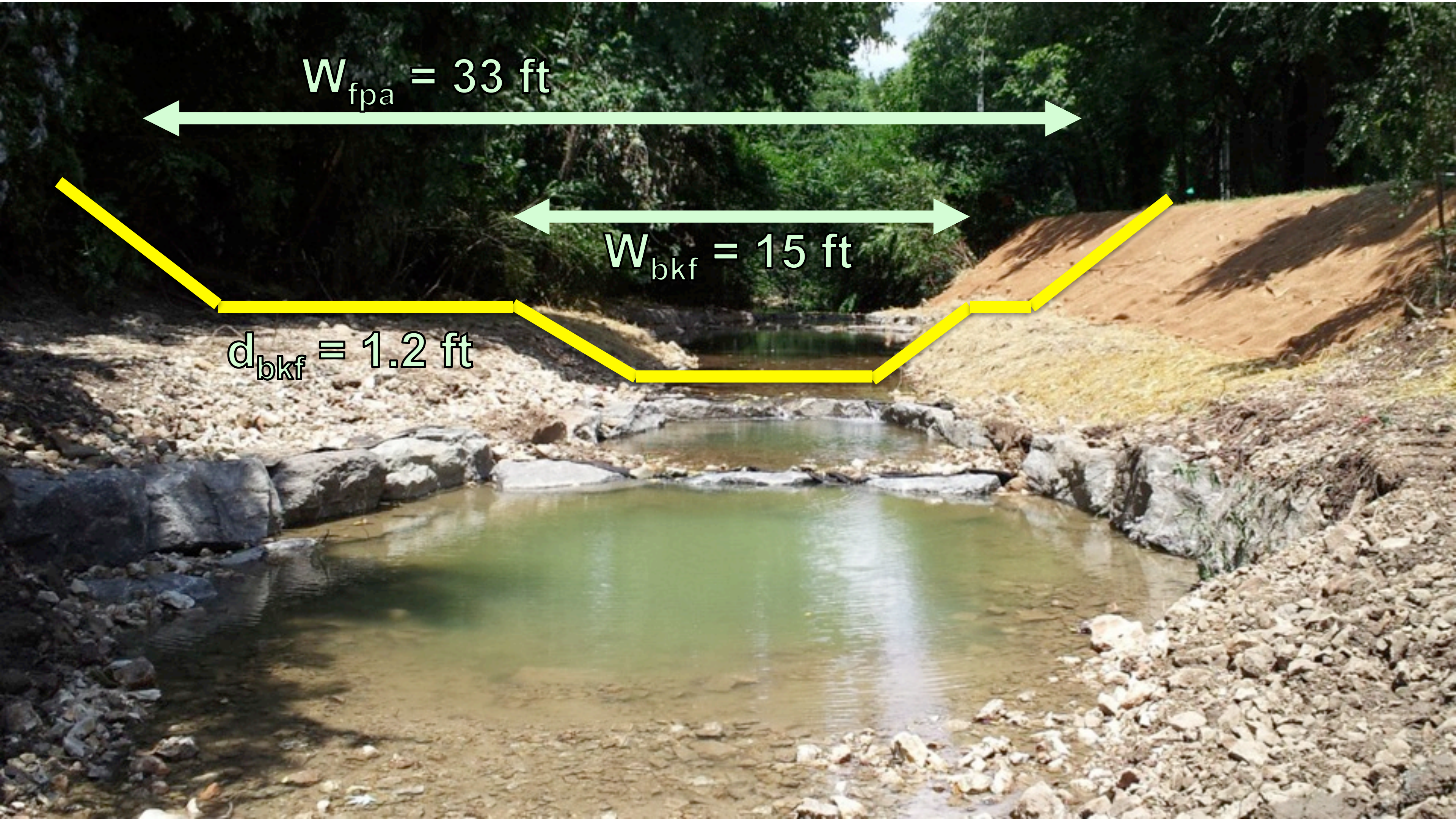
2009 Little Shades Creek 2010

Entrenchment Ratio = W_{fpa} / W_{bkf} = 60/38 = 1.6

Riffle Morphology: Bankfull Width = 15 ft; Depth = 1.2 ft

Floodprone Width = 33 ft

Entrenchment Ratio, ER = 33/15 = 2.2



2. In-Stream Structures (Logs & Rocks)

- Streambank protection
- Habitat enhancement (pools, aeration, cover)
- Grade control
- Sediment transport

Structure Criteria:

- Natural materials
- Habitats & passage for aquatic organisms
- Natural sediment transport (alluvial systems)

Do you like these?

Boulder J-Hook Vane

Runaway Truck Ramp

Roaring River, Stone Mt State Park (2000-10)

- Trout Stream: Channel Realignment, Structures, Planting

10 years later

Boulder J-Hook Vane

- 3-5 % arm slopes
- 20-25 degree arm angles
- Boulder footers & non-woven geotextile
- 0.5 ft drops over j-hook inverts

Boulder Vane

20-25 degree angles

3-5 % arm slopes

20-25 degrees

3-5 % arm slopes

Chinking Boulders to Prevent Piping

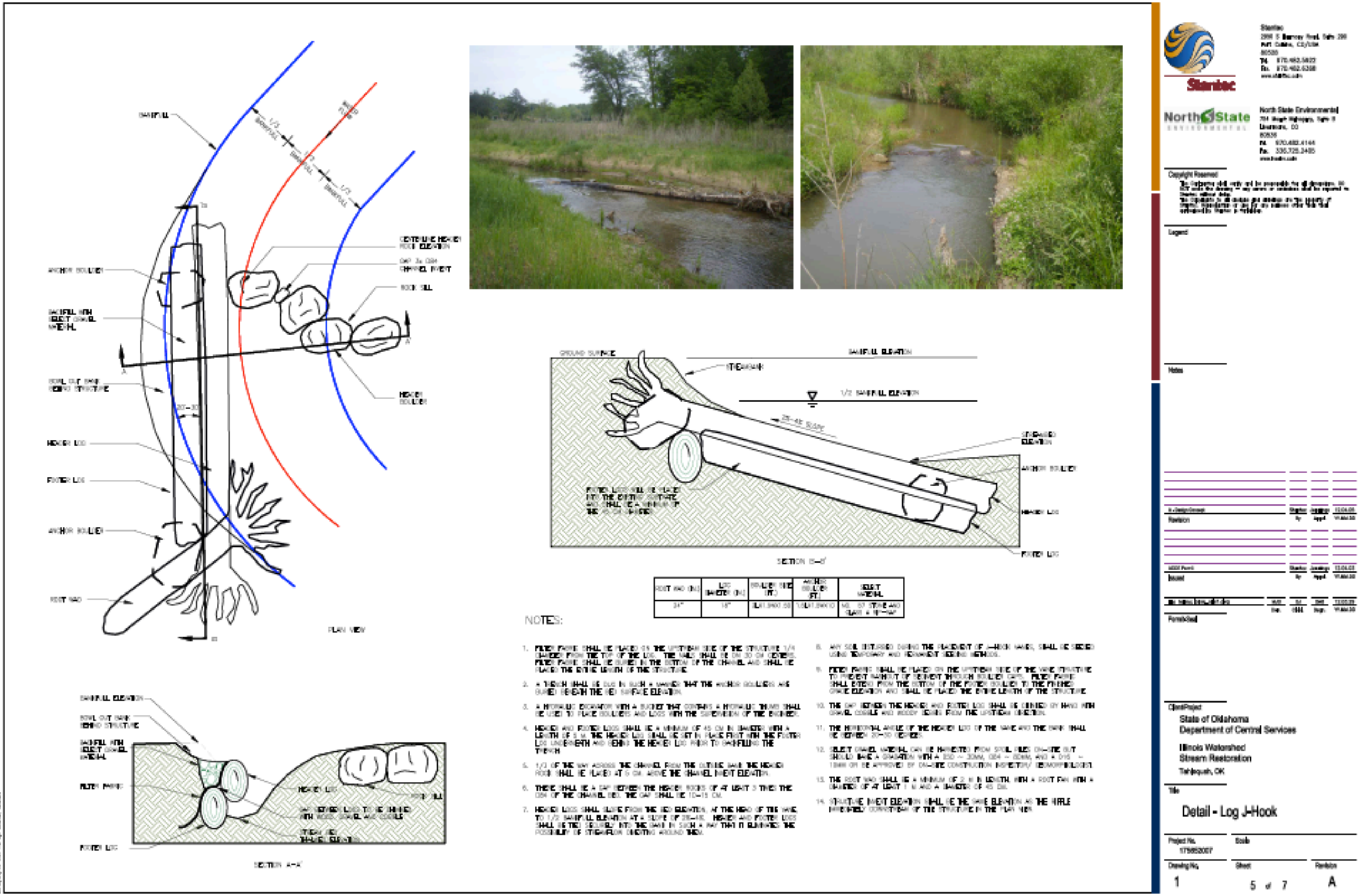
Geotextile Curtain to Prevent Piping

Boulder

J-Hook Vane

Log J-Hook Vane

Log J-hook Vanes for flow direction & habitat



Log Vane

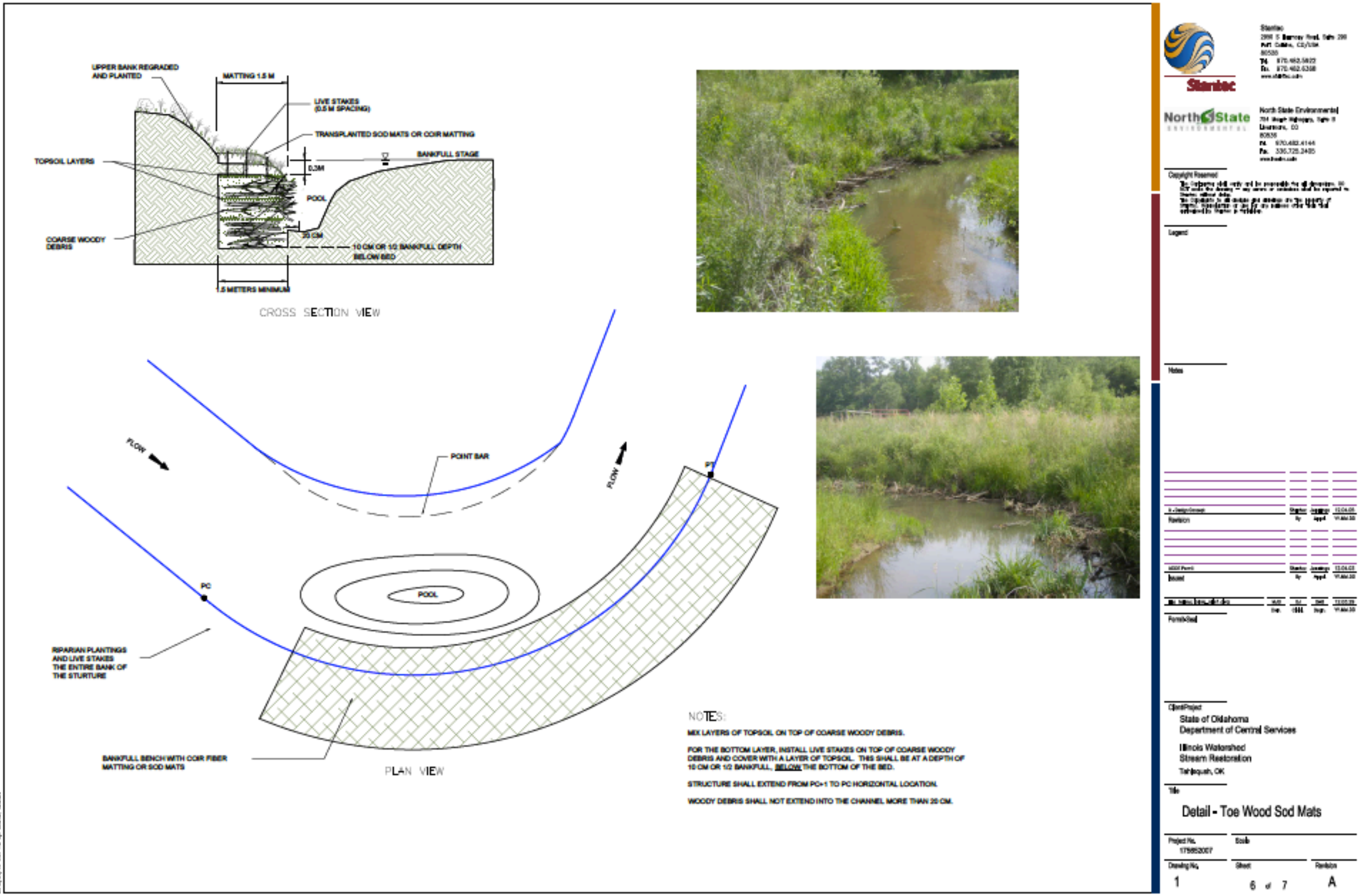
- 2-4 % arm slopes
- 20-25 degree arm angles
- Sealed with woven geotextile & backer logs

Log J-Hook Vane: Flow direction, bank protection, habitat

Arm slope = 1.2 / 30 = 4%; Arm angle = 25 degrees

Storm Flow: Flow direction + Bank protection

Toe Wood for bank protection, roughness, habitat



Toe Wood for bank protection, roughness, habitat

Log J-hook: Habitat enhancement

Log J-hook Installation

1. Root wad
2. Header log
3. Backer log
4. Chinking
5. Geotextile

Log J-hook Installation

6. Backfill gravel
7. Wash in
8. Boulder hook
9. Chinking
10. Geotextile

Log J-hook with Toe Wood

Multiple Log Vanes

Saugahatchee Creek

2007

2008

Multiple Log Vanes

Saugahatchee Creek

2009 January

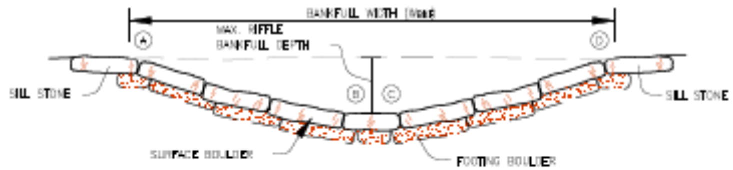
2009 July

Photo Credit: Dan Ballard, Town of Auburn

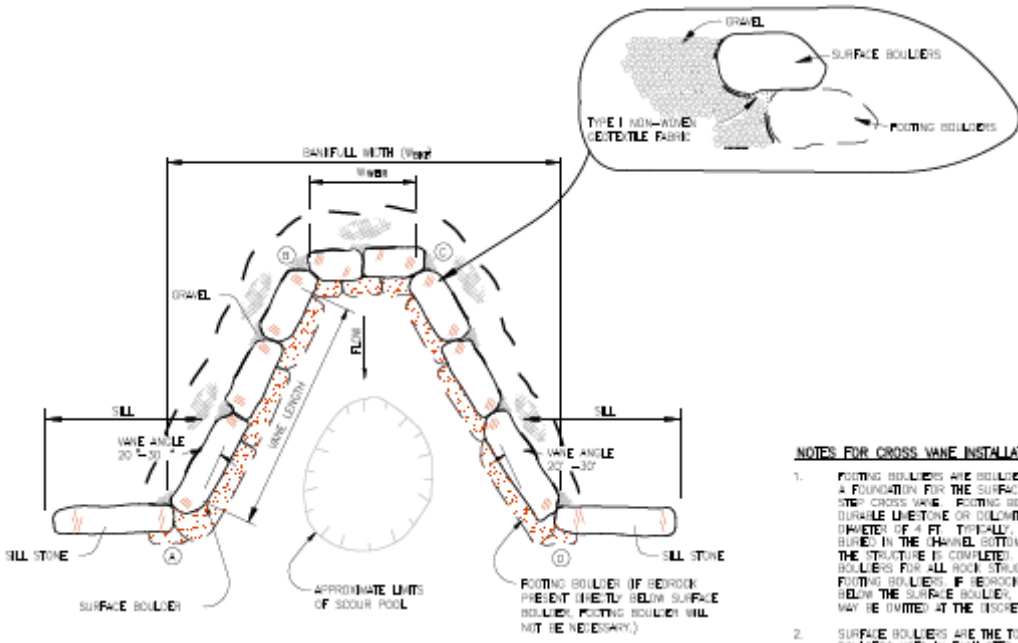
Multiple Log Vanes: Saugahatchee Creek

Boulder Cross Vane: Flow Concentration

Cross Vanes for flow direction & grade control



CROSS VANE TYPICAL CROSS-SECTION



CROSS-VANE PLAN VIEW

CROSS VANE LONGITUDINAL PROFILE

NOTES FOR CROSS VANE INSTALLATION:

1. FOOTING BOULDERS ARE BOULDERS PLACED TO PROVIDE A FOUNDATION FOR THE SURFACE BOULDERS IN EACH STEP CROSS VANE. FOOTING BOULDERS SHALL BE DURABLE LIMESTONE OR DOLOMITE WITH A MINIMUM DIAMETER OF 4 FT. TYPICALLY, FOOTING BOULDERS ARE BURIED IN THE CHANNEL BOTTOM AND NOT SEEN WHEN THE STRUCTURE IS COMPLETED. ALL SURFACE BOULDERS FOR ALL ROCK STRUCTURES REQUIRE FOOTING BOULDERS. IF BEDROCK IS PRESENT DIRECTLY BELOW THE SURFACE BOULDER, THE FOOTING BOULDER MAY BE OMITTED AT THE DISCRETION OF FVSM.

2. SURFACE BOULDERS ARE THE TOP MOST COURSE OF BOULDERS USED IN EACH STEP CROSS VANE. ALL SURFACE BOULDERS CAN BE SEEN PROTRUDING FROM THE WATER SURFACE DURING EXTREMELY LOW FLOWS. SURFACE BOULDERS SHALL BE DURABLE LIMESTONE OR DOLOMITE WITH A MINIMUM DIAMETER OF 4 FT.

3. THE VANE LENGTH IS THE STRAIGHT LINE PORTION OF CROSS VANE STRUCTURES MEASURED FROM THE STREAM BANK AT BANKFULL ELEVATION TO THE CHANNEL BED.

4. THE VANE ANGLE IS THE SMALLEST ANGLE MEASURED BETWEEN A VANE AND A LINE TANGENT TO BANKFULL ELEVATION AT THE POINT WHERE THE VANE INTERSECTS THE BANK.

5. CONSTRUCT STEP CROSS VANE STRUCTURES BY FIRST SHAPING THE BANK TO THE GRADES SPECIFIED. NEXT EXCAVATE ENOUGH BED MATERIAL TO PLACE THE BOULDERS, GEOTEXTILE FABRIC AND GRAVEL OVERLAY. ONCE THE INVERTS HAVE BEEN ESTABLISHED THE REMAINDER OF THE FOOTING AND SURFACE BOULDERS SHALL BE PLACED, MINIMIZING VOIDS. PLACE GEOTEXTILE FILTER FABRIC AT THE UPSTREAM FACE OF THE STRUCTURE AS SHOWN AND BACKFILL (OVERLAY) WITH GRAVEL. FILL THE VOIDS ON THE UPSTREAM SIDE OF SURFACE BOULDERS WITH GRAVEL. DO NOT LEAVE EXPOSED GEOTEXTILE FABRIC AND TRIM EXPOSED GEOTEXTILE FABRIC. ONCE STRUCTURE IS INSTALLED, EXCAVATE SCOUR POOL AND PLACE GRAVEL SUBSTRATE AS REQUIRED. RE-DRESSING OF CHANNEL AND BANKFULL BENCH/FLOODPLAIN WILL LIKELY BE REQUIRED FOLLOWING INSTALLATION OF IN-STREAM STRUCTURES AND SHALL BE CONSIDERED INCIDENTAL TO CONSTRUCTION.

6. THE SURFACE OF CROSS, J-HOOK AND LOG VANES SHALL BE FINISHED TO A SMOOTH AND COMPACT SURFACE IN ACCORDANCE WITH THE LINES, GRADES AND CROSS-SECTIONS OR ELEVATIONS SHOWN ON THE DRAWINGS. THE DEGREE OF FINISH FOR INVERT ELEVATIONS SHALL BE WITHIN .1 FT OF THE GRADES AND ELEVATIONS INDICATED PROVIDED ANY HEIGHT DOES NOT EXCEED 2 INCHES. ALL GAPS OR VOIDS SHALL BE PLUGGED WITH ROCK TO FORM A TIGHT-FITTING SEAL.

7. CONTRACTOR SHALL USE AN EXCAVATOR WITH A HYDRAULIC THUMB TO CONSTRUCT HYDRAULIC STRUCTURES.

Stantec

North State Environmental

Legend

Notes

Revision

Issued

Permit-Seal

Client/Project
State of Oklahoma
Department of Central Services

Illinois Watershed
Stream Restoration
Tahlequah, OK

Title
Detail - Toe Wood Sod Mats

Project No. 175652007

Scale

Drawing No. 1

Sheet 7 of 7

Revision A

Cross Vane

- Direct flow in new channel alignment
- Grade control and scour pool
- Footer boulders & geotextile

<u>Cross-Vane (Double-Drop):</u> Flow direction straight & center

Arm Angles: 25 degrees from parallel to bank

<u>Cross-Vane (Double-Drop):</u> *Limit drop over each step to 0.5 ft*

Cross-Vane (Double-Drop): Grade control, flow direction, scour

Arm slope = 1.8 / 36 = 5%

Max drop over each step = 0.5 ft

Cross-Vane (Double-Drop): Grade control, flow direction, scour

Arm slope = 2.5 / 50 = 5%; Arm angles = 25 degrees

Max drop over each step = 0.5 ft

Cross Vane (logs embedded)

Multiple Cross Vanes in Straight Urban Stream

Double-Drop Boulder Cross Vane

Photo Credit: Darrell Westmoreland, North State Environmental, Inc.

Double-Drop Boulder Cross Vane

Offset Boulder Cross Vane at a Bridge

Boulder W-Vane: Bridge Pier Protection

Boulder Double Wing Deflector

Constructed Riffle

Stream Competence *(www.epa.gov/WARSSS)*

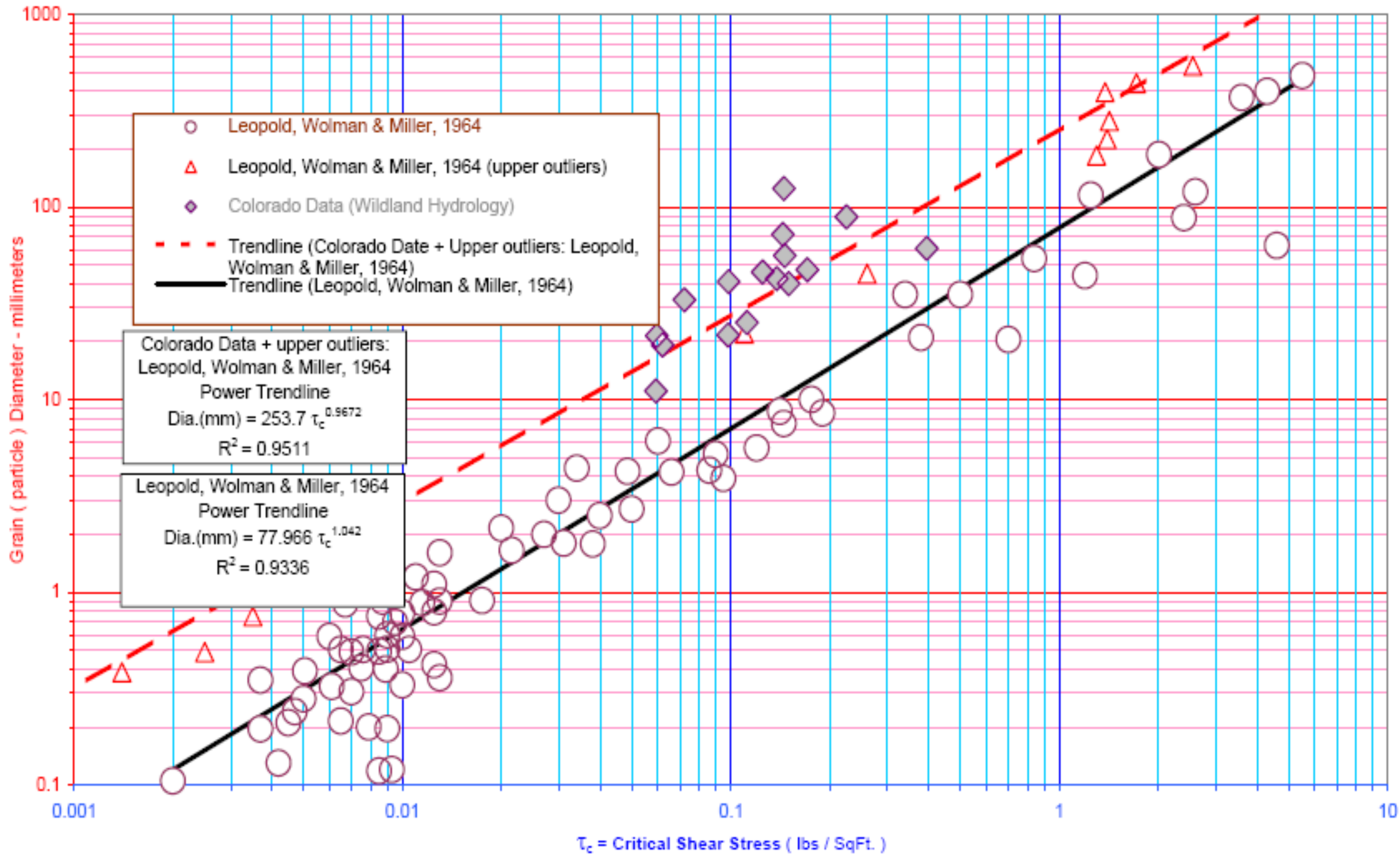


Figure 126. Critical Shear Stress (tc: Range .001 to 10) Required to Initiate Movement of Grains (particles), revised for Colorado Rivers.

1st Order Streambed Transplant

- Substrate transfer from old channel to new channel

Constructed Riffle

- Undercut bed 2 ft and backfill with gravel, cobble, boulders, wood
- Cut thalweg 0.5 ft deep

Constructed Riffle with Embedded Wood

Vanes, Toe Wood, Transplants

Riffles with Bouder/ Log Steps

Step-Pool: Boulder Cascade

March, 2011

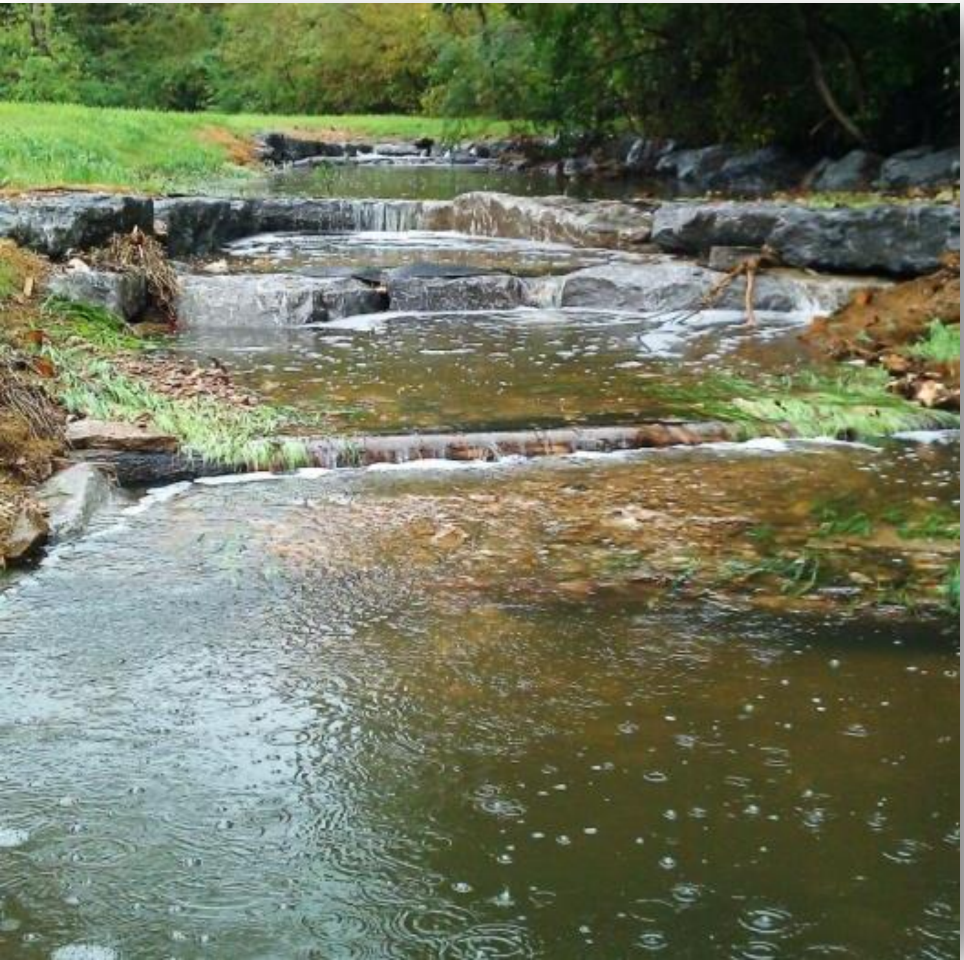
April, 2011

March, 2011
Native Riparian
Plants

August, 2011
Early Succession
Forest

Illinois River Site 5: Tahlequah – Kaufmann

Boulders & logs in new channel



Step-Pool:
Stormwater Conveyance

Chapel Hill, NC
Bolin Creek Watershed

Step-Pool: Stormwater Conveyance, Maryland