Streambank Protection Design

Hard & Soft Applications & Techniques (Part II)

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DTW and Associates, LLC

Agenda

Part One

- Streambank Zones
- Total Scour at Streambank Toes
- Causes of Local Streambank Instability
- Basics of Toe and Bank Protection
- Design Considerations for Toe Protection

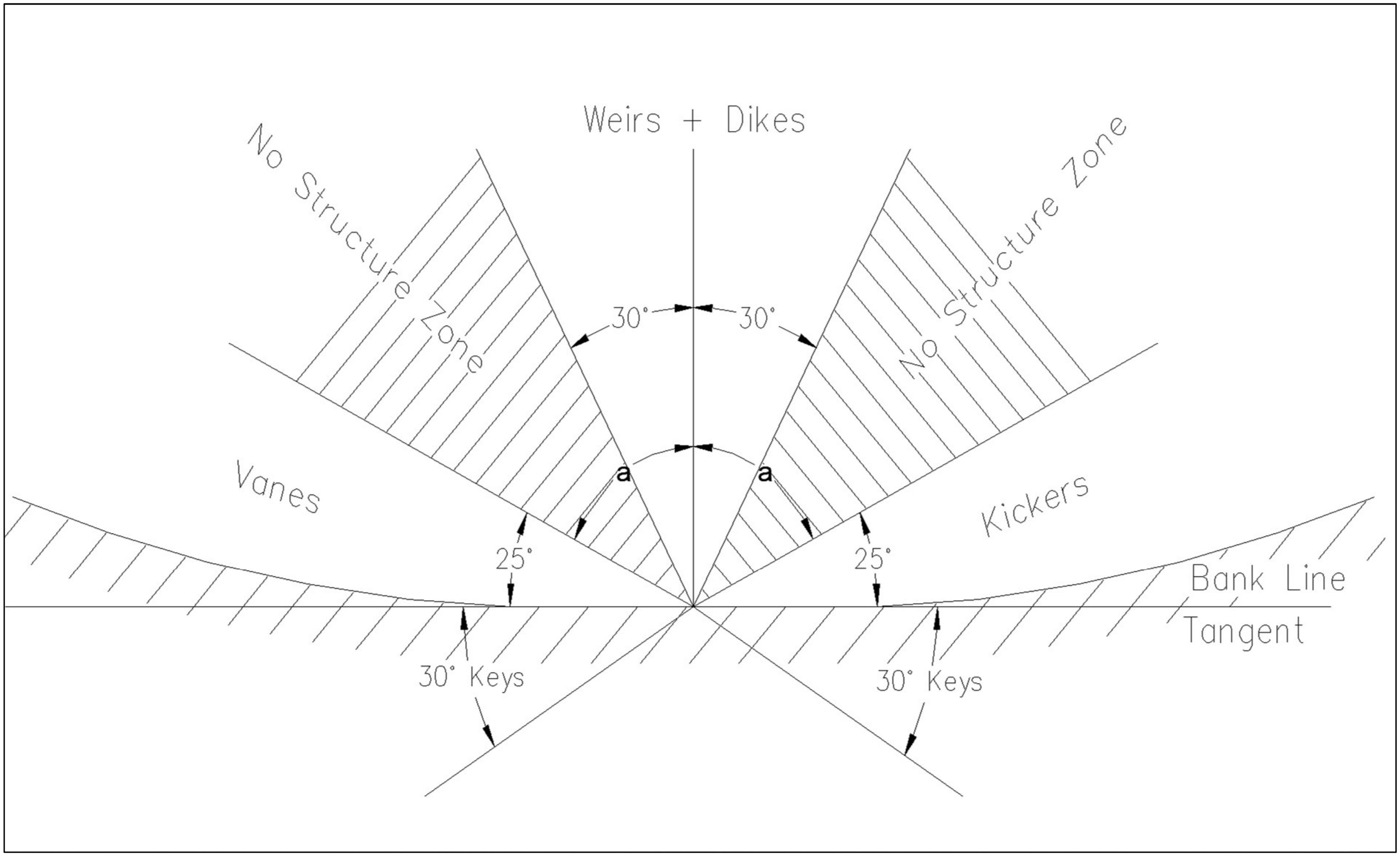
Part Two

- Redirective Methods
- Resistive Methods
- Bioengineering / Vegetative Methods
- Criteria for Use of Various Bioengineering/ Vegetative Methods

Redirective Bank Protection Techniques

- **Dikes**
  - Palisades
  - Retards
  - Jacks (Large Type)
- **Vanes**
- **Bendway Weirs**
- **For All Techniques:**
  - Avoid angles between ±30^{o} and ±65^{o} from perpendicular to bank tangent
  - Structures with these angles serve as dividers and cause large amounts of erosion!

Redirective Angles



Design of Dikes

- **Dikes**

A series of structures that protrude into the channel generally transverse to flow (approx 90° or in a range of 60° – 120° from bank)

- **Also Called:**
  - Groins
  - Jetties
  - Spurs
  - Wing dams
  - Hard points (short)
  - Palisades

Dike Overview

- **Pervious or impervious structures projecting from streambanks**
- **Used to deflect flowing water away from or reduce the velocities in critical zones near streambanks**
- **Increased bank protection can be achieved as deposition occurs due to reduced velocities**
    - Permeable retarding dikes are often constructed at 90^{o} from bank
- **Permeability**
    - Impermeable Spurs:
      used on sharp bends to divert flow away from outer banks
    - Permeable Spurs:
      highly permeable retarding dikes/retards are used at mild bends

Permeable Dike Field (Palisades)

Spur Dikes: Design Guidelines

- Impermeable spurs create erosion of the streambank at the spur root (occurs when spur crest is lower than the bank height)
- 70% permeability causes very little bank erosion
- 35% or less permeability causes bank erosion similar to the effect of impermeable spurs
- Impermeable spurs height is limited by bank height
- Permeable spur heights are set to allow heavy debris to pass over top
- Spacing is a function of spur length, spur angle, permeability, and bend radius of curvature

Design of Dikes

- **Dike length related to permeability**
  - Less permeable = shorter
  - More permeable = longer

- **To Stabilize Bank**

Permeability	% Channel Width
<35%	<15%
35%	15%
36% - 79%	(linear interpolation)
80%	25% maximum

Dike Tie Backs (Dike Heads & Key-Ins)

- Excavate trench into bank and fill with rock.
- Tie back should be sufficient so dike is not flanked.
- A typical rule of thumb for the depth to key into the bank is the bank height plus the anticipated scour depth.
- It is suggested that key-ins <u>not</u> be positioned at 90 degrees to the flow, but rather at an angle (30 to 45 degrees to the direction of flow) into the bank.

Structural Protection

- **Apron Under and Adjacent to Dike**
- **Additional Material on Dike**
- **Goal**
  - Be sure dike doesn't disappear into river
  - Same thing as toe protection at tips
    - How big is the scour hole?
    - How much material will I need to fill it?
    - Add that much material to dike

Rock Sizing for Dikes

- **Size Rock to withstand velocities present in stream** (use formulas/etc.)

- **Use safety factor according to sharpness of bend** (up to 2.5)

    - Size rocks to be stable at that velocity

        - Assumes subcritical flow

        - If supercritical, probably want concrete

- **See what others are using in similar sized streams**

    - Corps, NRCS, Local or State Agencies

Palisades

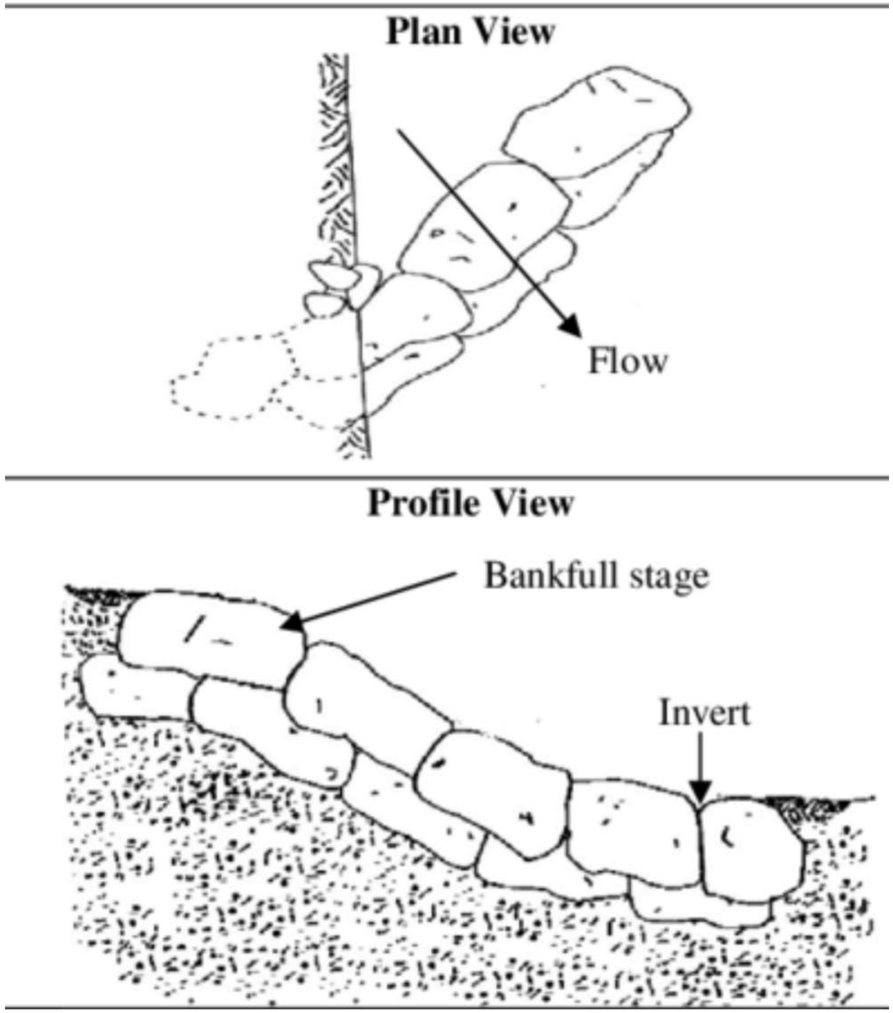
Don’t Let Water Behind You

- Tie into bank at least 10’.
- If using adjustable dikes (palisades, etc.) be sure not to leave gap on bank side of structure!!!!
- Structures not attached to bank are called obstructions and worsen bank erosion!

What Are Vanes?

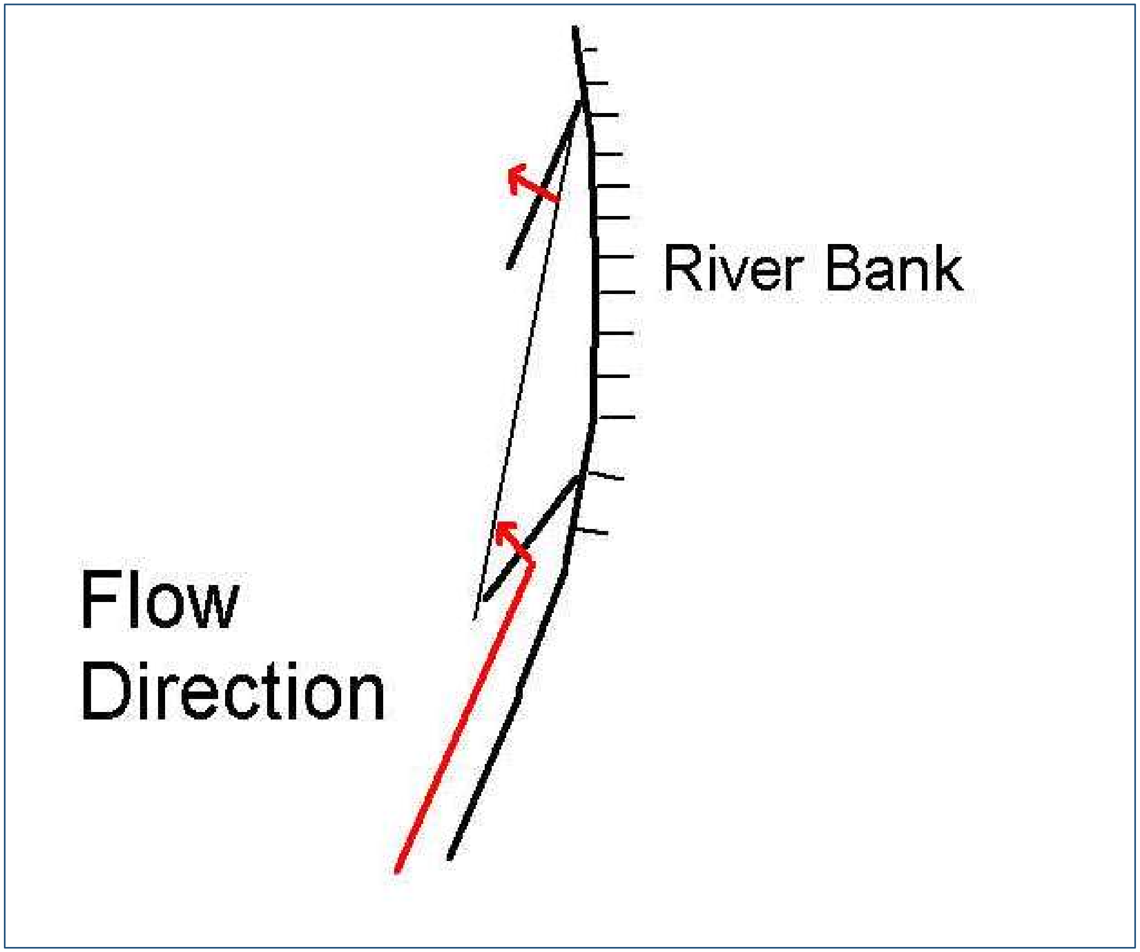
- Vanes are upstream angled structures that have an angle from bank perpendicular > 60^{o}
- The end of the vane is low and the elevation rises as you approach the bank.
- Vanes squeeze out flow as it moves downstream and force it over the vane and away from the bank.

Stream Vane Layout



Vane Spacing & Layout

Vanes should be spaced such that the flow missing the upstream vane does not impact the bank prior to arriving at point where next downstream vane attaches to bank.

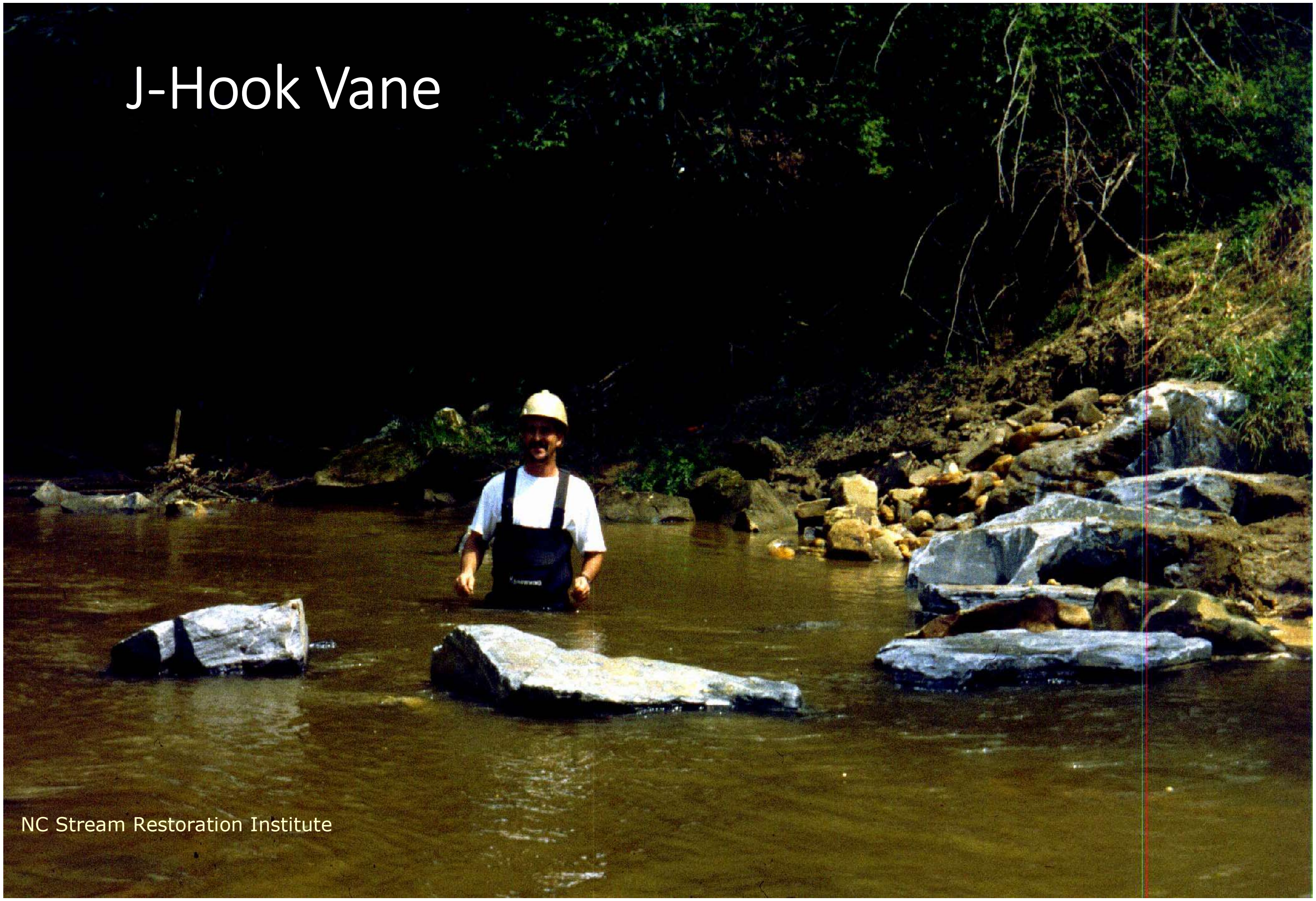


Vane Variations

- **J-Hook Vane**

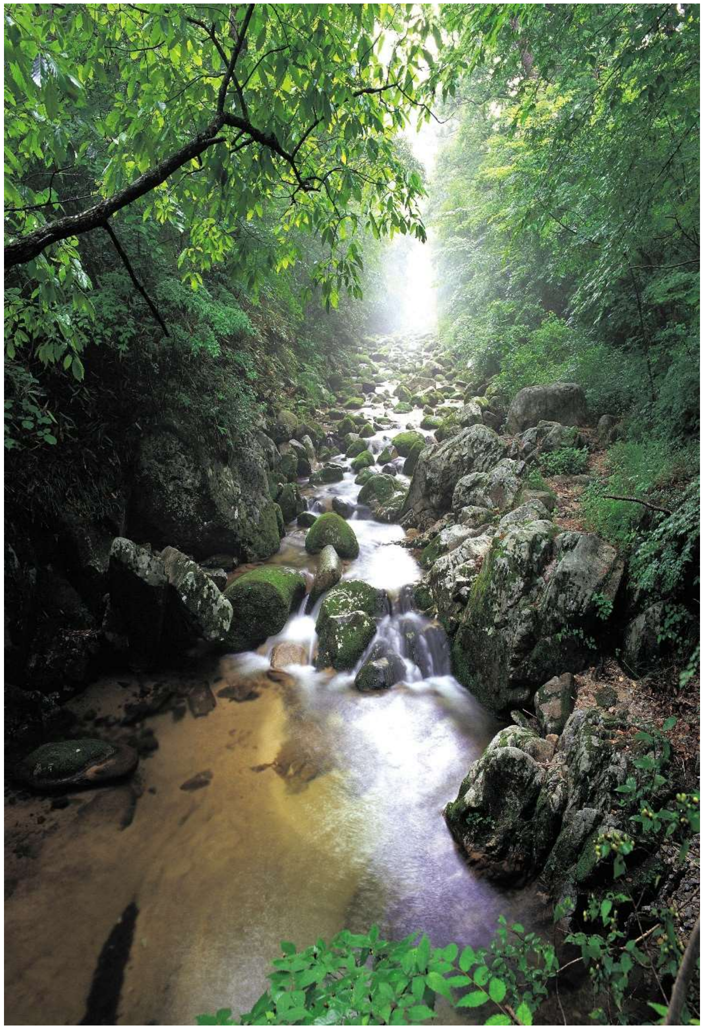
Vane with end that forms a J when viewed in planform

- Creates scour hole just behind (downstream) the vane and inside the hook of the J.
- End of hook points downstream.
- The top of the J attaches to the bank.

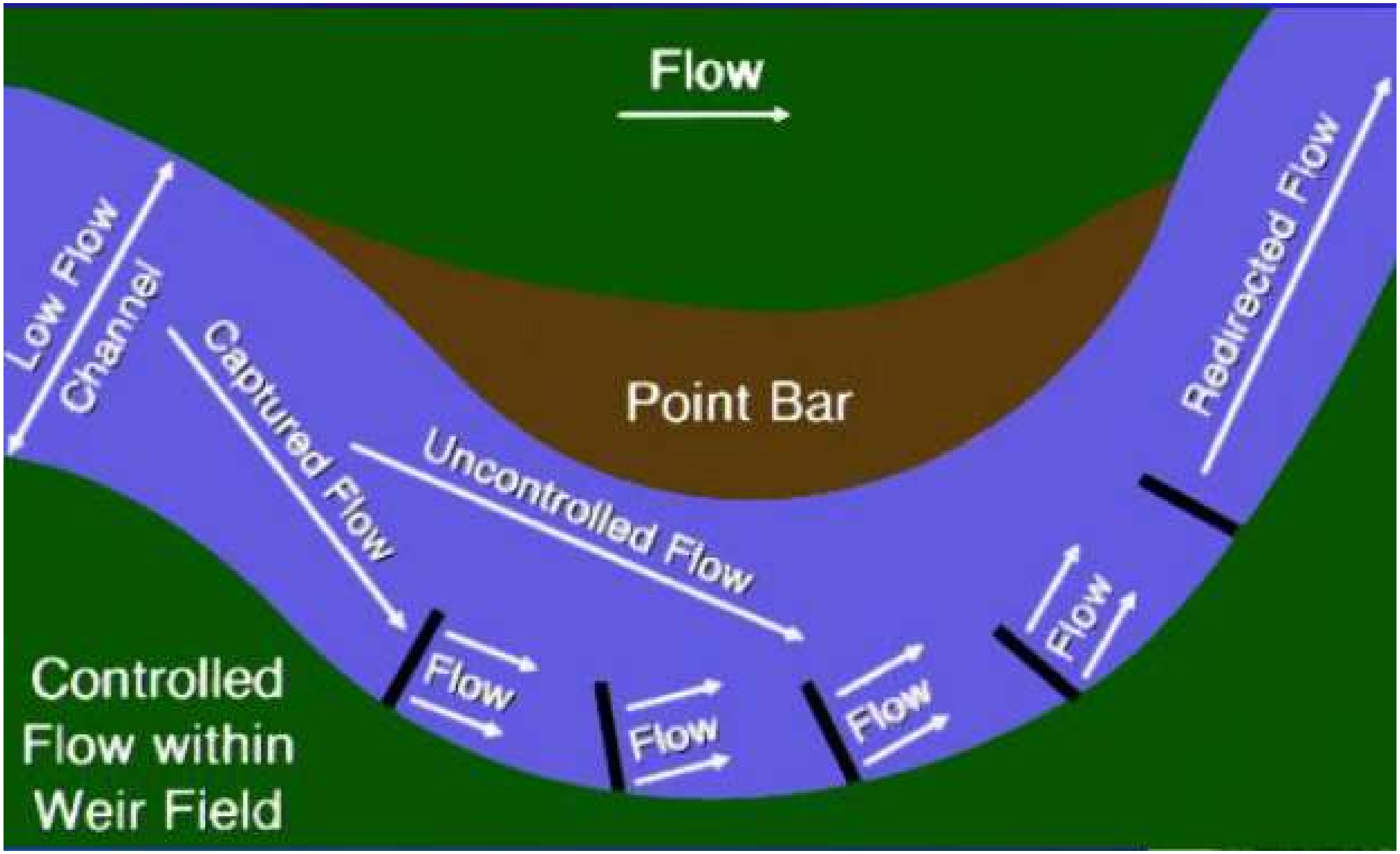

J-Hook Vane
NC Stream Restoration Institute

Bendway Weirs

- **Low Underwater Dikes**
- **Angled Between:**
  - 25^{o} upstream
  - Few degrees downstream
- **Act as Weir**
  - Redirect flow perpendicular to weir axis



Bendway Weir Layout



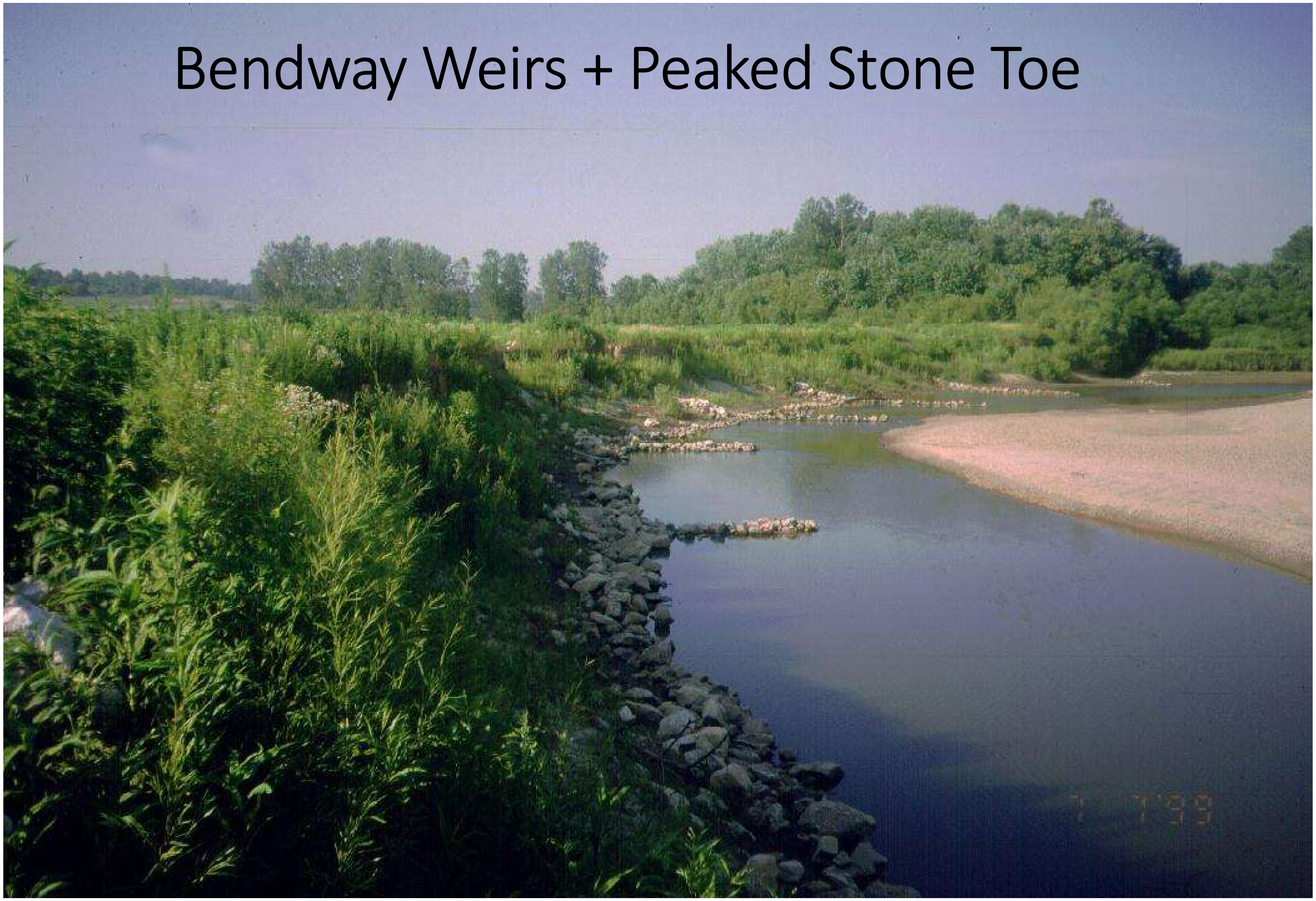
Bendway Weirs

- Improves lateral stream stability
- Improves flow alignment problems at river bends
- Improves inadequate navigation channel width at bends on large rivers
- Often used for bankline protection
- Used on Missouri and Mississippi rivers by the USACE

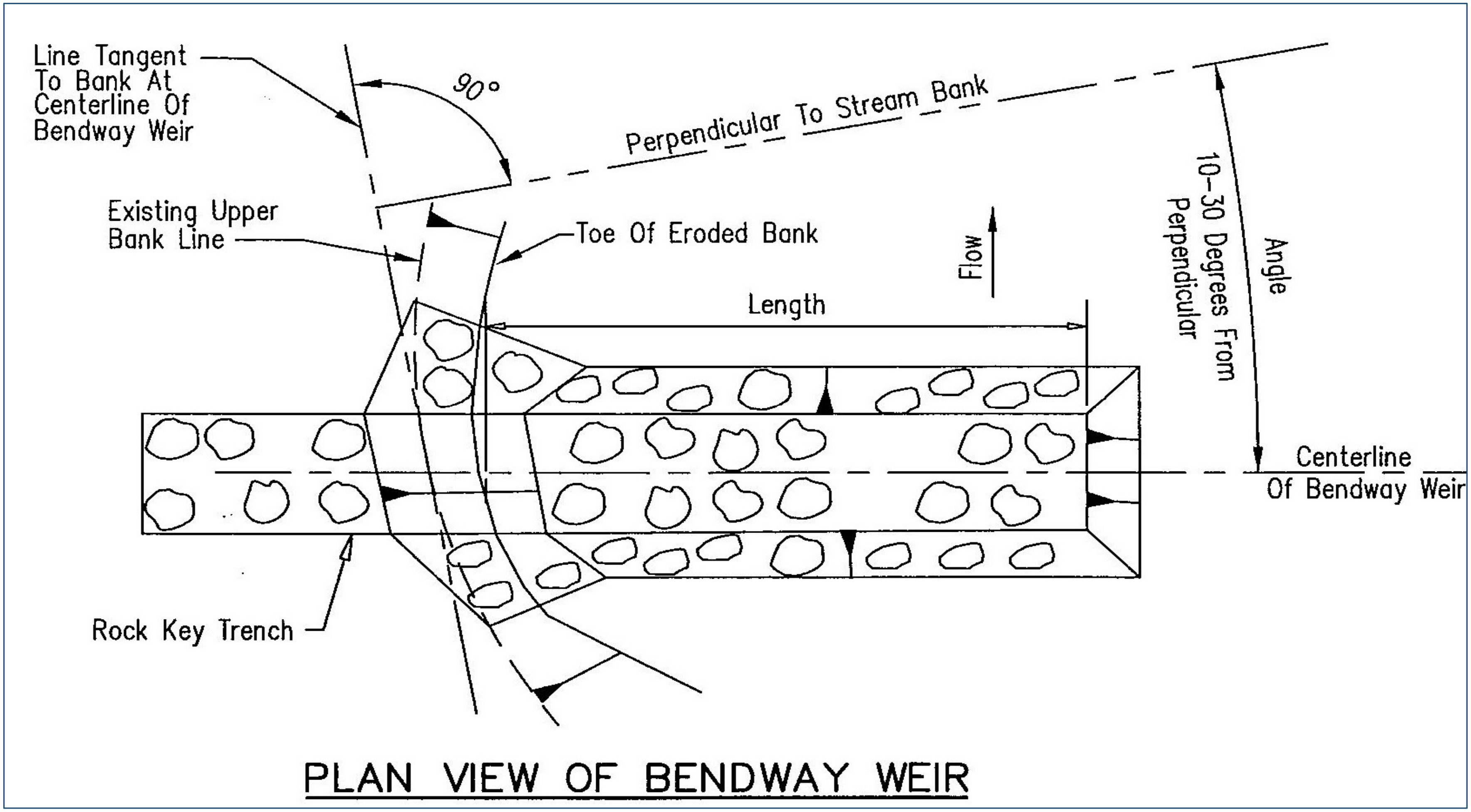

Bendway Weirs


Bendway Weirs

Bendway Weirs + Peaked Stone Toe



Bendway Weir



Bendway Weirs: Design Guidelines

Height

- Determined by analyzing various depths of flow
- Should be between 30-50% of the depth at mean annual high water
- Below normal mean water level
- Equal to or above the mean low water level

Angle of Projection

- Determined by location of weir and flow line angle of attack normal of the weir centerline
- High flow streamline angle of attack should not be greater than 30^{o}

Bendway Weirs: Design Guidelines

Length, L

- Should not exceed 1/4 the mean channel width (W)
- Typically: W/10 < L < W/4
- Length depends on whether point bar is erodible or not (erodible = longer)

Spacing, Sp

- Influenced by site conditions
- Guideline formula based on tests done at WES and MRD:

$$Sp = 1.5L(R_c/W)^{0.8}(L/W)^{0.3}$$

$$Sp = (4 \text{ to } 5)L$$

$$Sp_{max} = R_c(1-(1-(L/R_c))^2)^{0.5}$$

R_c= bend radius of curvature

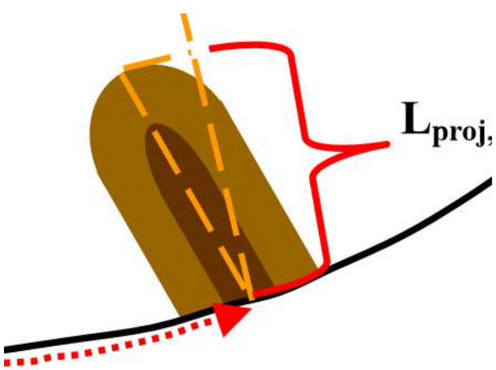
Bendway Weirs: Design Guidelines: Spacing Ratio

Spacing ratio is:

Sp/Lproj, Where:

Sp = distance between weirs

Lproj = length of weir projecting into the flow

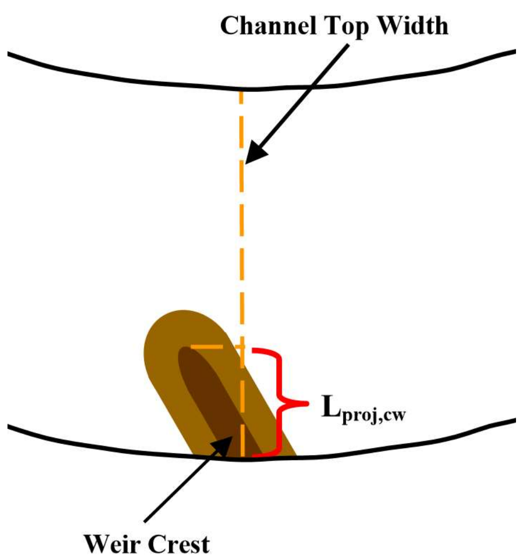


Author	Recommended Spacing Ratio	Type of Bank	Remarks
United Nations (1953)	1	Concave	General Practice
	2-2.5	Convex	General Practice
Ahmad (1951)	4.29	Straight	
	~5	Curves	
Joglekar (1971)	2-2.5		Upstream Groynes
US Army (1984a)	2		Mississippi River
Mathes (1956)	1.5		
Strom (1962)	3-5		
Acheson (1968)	3-4		Varies depending on curvature and stream slope
Richardson et al. (1975)	2-6		For bank protection
	3-4		T-head groynes for navigation channels
Mamak (1956)	1.5-2		Deep channel for navigation
Blench et al. (1976)	3.5		
Copeland (1983)	>3	Concave	
Kovacs el al. (1983)	1-2		Danube River
Mohan and Agraval (1979)	5		Submerged groynes of height one-third the depth
Maza Alvarez (1989)	5.1-6.3	Straight	Sloping crested weirs for bank protection
	2.5-4	Curves	

Bendway Weirs: Design Guidelines: Length

Length is measured as shown below:

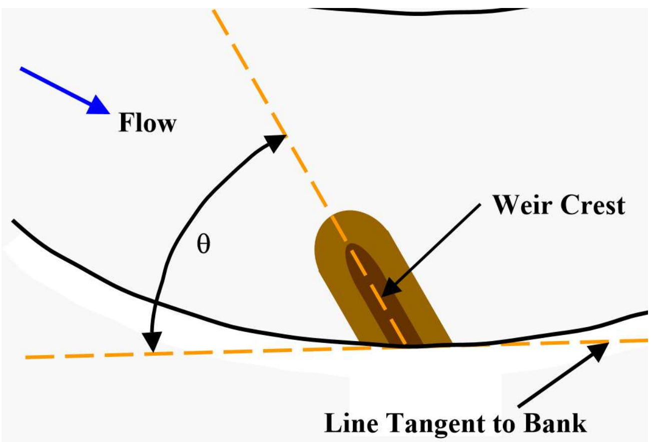
Note the top of the weir is used for measurement



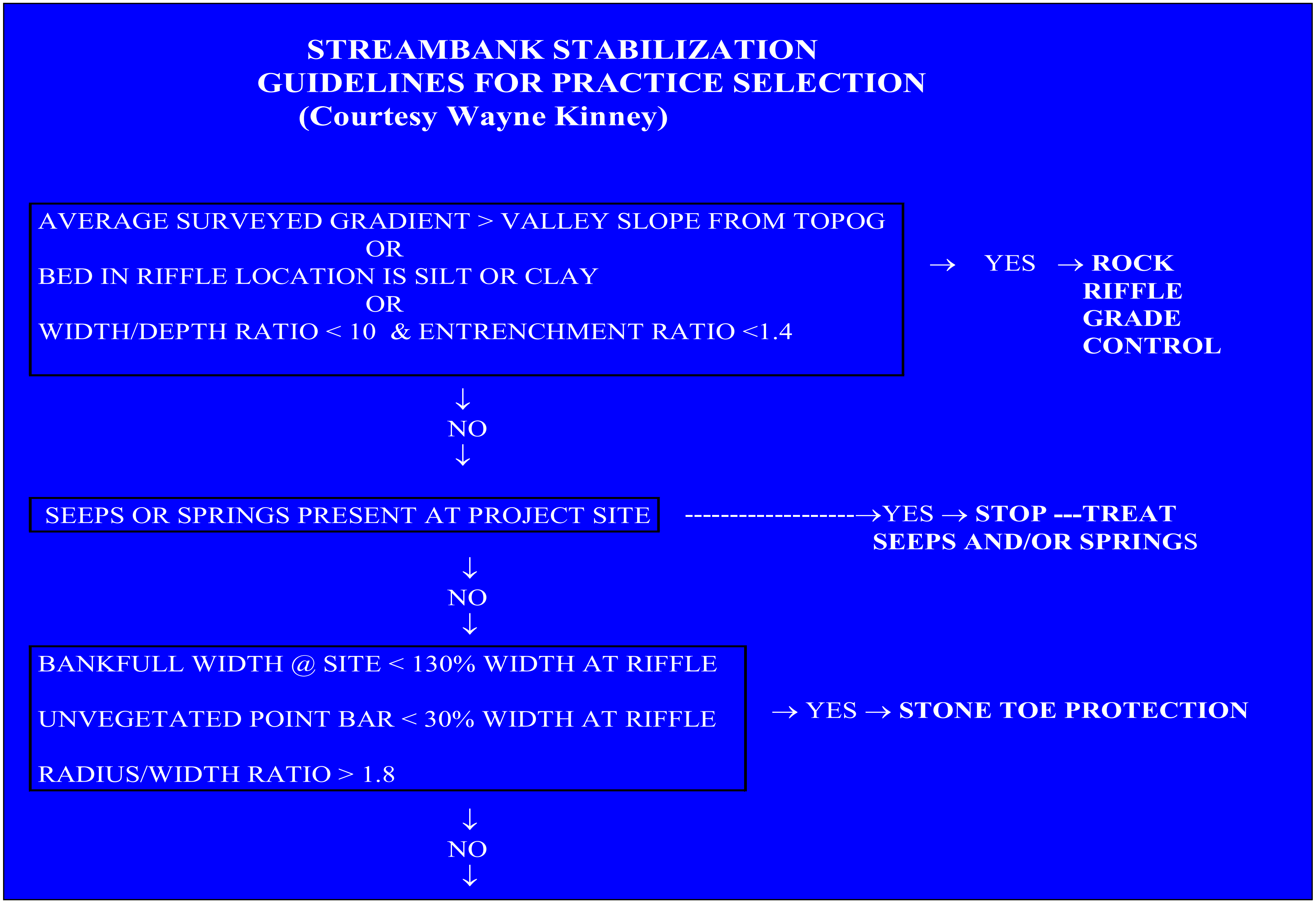
Author	Suggested Length
United Nations (1953)	"Start with a shorter length and extend the groynes after space between them has been silted up"
ICBIP (1971):	No rules apply, build models to determine appropriated length
Richardson (1975)	50 feet or less
USACE (1980)	Should be set at the desired constriction width of channel for navigation purposes
Brown (1985)	Less Than 15% of bankfull channel width for impermeable structures
Maza Alvarez (1989)	Less than 25% of bankfull channel width
Lagasse (1997)	Less than 33% of bankfull channel width
Derrick (1998)	Site-Specific Basis, engineering judgment
LaGrone (1998)	16.67%, not a design guideline but a site specific design

Bendway Weirs: Design Guidelines: Orientation Angle

Orientation angle is measured as shown below on left.



Author	Range of Angles	Suggested Angle
Brown (1985)	30-150	150 decreasing to 90
Copeland (1983)	60-120	90
Derrick (1994)	45-80	60
Indian Central Board of Irrigation and Power (1965):		60-80
Lagasse (1997)	50-85	60
Mamak (1964): (Copeland Literature Review)		70-80
Maza Alvarez (1989)		110
Richardson (1975)	60-150	70-80
Smith (1998)		60-75
United Nations (1953)		60-80
USACE (1980)		100-105


STREAMBANK STABILIZATION
GUIDELINES FOR PRACTICE SELECTION
(Courtesy Wayne Kinney)
AVERAGE SURVEYED GRADIENT > VALLEY SLOPE FROM TOPOG
OR
BED IN RIFFLE LOCATION IS SILT OR CLAY
OR
WIDTH/DEPTH RATIO < 10 & ENTRENCHMENT RATIO <1.4
→ YES → ROCK RIFFLE GRADE CONTROL
↓ NO ↓
SEEPS OR SPRINGS PRESENT AT PROJECT SITE
------------------→YES → STOP ---TREAT SEEPS AND/OR SPRINGS
↓ NO ↓
BANKFULL WIDTH @ SITE < 130% WIDTH AT RIFFLE
UNVEGETATED POINT BAR < 30% WIDTH AT RIFFLE
RADIUS/WIDTH RATIO > 1.8
→ YES → STONE TOE PROTECTION
↓ NO ↓

↓
NO
↓

RADIUS/WIDTH RATIO > 4.0

UNVEGETATED POINT BAR < 50% BANKFUL DEPTH

UNVEGETATED POINT BAR MATERIAL < 1 INCH DIA.

→ YES → **BENDWAY WEIRS**
OR
STREAM BARBS

↓
NO

↓

RADIUS/WIDTH RATIO < 4

UNVEGETATED POINT BAR < 50% BANKFULL DEPTH

UNVEGETATED POINT BAR MATERIAL < 1 INCH DIA.

→ YES → **BENDWAY WEIRS &**
STONE TOE PROTECTION
OR
STREAM BARBS

↓
NO

↓

STREAM BARBS
OR
TRADITIONAL BANK TREATMENT

--- **CALL FOR ASSISTANCE**

Courtesy Wayne Kinney

Resistive Methods: Examples

- Bank Paving (e.g., riprap)
- Concrete Channels
- Geowebs
- Articulated Concrete Blocks
- Jacks (Small Type)
- Many others

Riprap

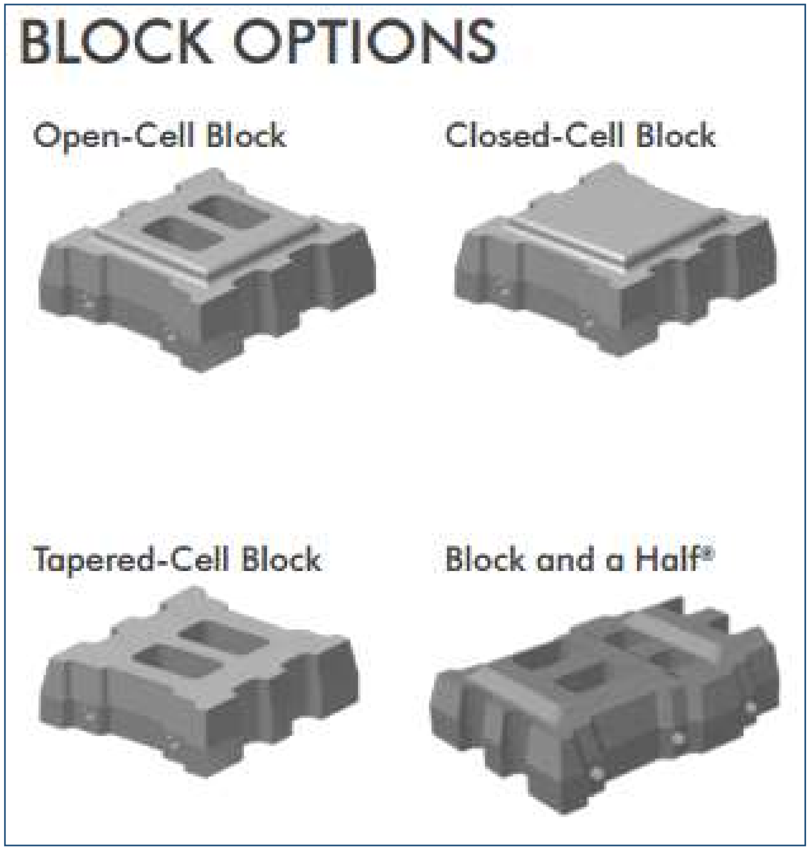
Geowebs (Gravel or Concrete Filled)

Courtesy of Presto Geosystems

Good for steep slopes

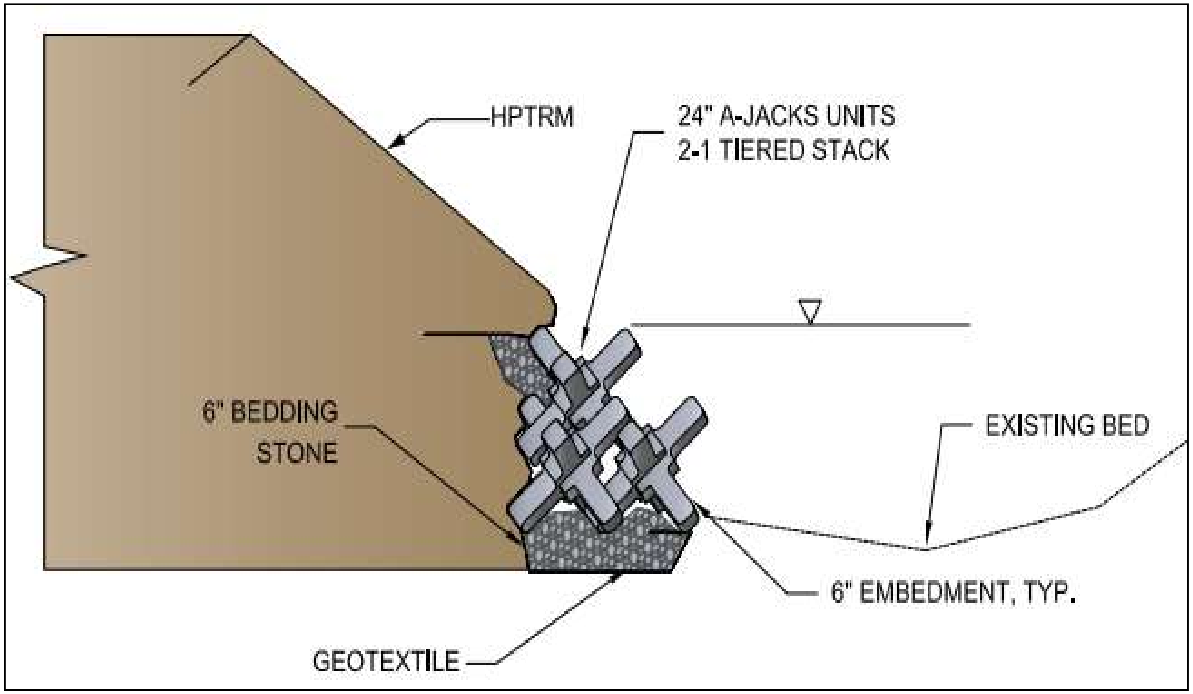
Articulated Concrete Blocks

(Armorflex)



A-Jacks

(from ArmorTec)



Shear Stress – Basis of Resistive Designs

- τ_o = Forces on bed or bank due to moving water
- τ_c = Critical Shear Stress - Stress at which sediment particle is just barely stable
- **If $\tau_o > \tau_c$**
  - Erosion or movement occurs
- **If $\tau_o < \tau_c$**
  - Bed or bank is stable

Shear Stress Calculation

Channel Tractive Force

$$\tau_o = \gamma_w R S_f$$

- γ_w = unit weight of water;
- **R** = the hydraulic radius;
- S_f = energy slope (often water surface slope is used)

Critical Shear Stress = τ_c

Depends on the material on the bed and banks

See manufacturer's manuals for particular material

Example Testing Results
Used for Design Manuals

Colorado State University

Engineering Research Center
1320 Campus Delivery
Fort Collins, CO 80523

Geoweb® Cellular Confinement System
Presto Products Geosystems®
Performance Testing

Maximum Hydraulic Conditions Tested

Geoweb® Type	Rock Size in	Hydraulic Data					
		Maximum Velocity (ft/s)	Maximum Shear Stress (lb/ft²)	Maximum Flow Depth (ft)	Maximum Rock Loss (in.)	Minimum Manning n	Maximum Manning n
GW20V	1.14	16.12	9.28	0.91	3.24	0.02	0.04
	3.50	11.50	15.10	1.04	1.61	0.03	0.08
GW30V	1.14	12.01	13.17	0.96	4.09	0.03	0.06
	3.50	11.69	17.98	1.05	1.86	0.03	0.07
GW40V	1.14	16.31	14.85	1.42	5.98	0.04	0.05
	3.50	17.50	15.38	1.79	2.85	0.04	0.05

(courtesy of Presto Products)

Resistive Methods – General

- Be sure to toe down sufficiently
- Slope the bank such that material is stable > 1.0V to 1.75H
  - Can be steeper if structurally supported
  - 2.0H or flatter better for Riprap
- Size material such that it is stable for design flows
- Add safety factor for sizes and toe down
- Use Design Software/Manuals from vendors

Design Manual Inputs

From Armorflex Design Manual

Table 2.3. Factor of Safety Equation Variables.					
Block Class	Submerged Weight (Lbs)	ℓ_1 (ft)	ℓ_2 & ℓ_4 (ft)	ℓ_3 (ft)	τ_c @ 0 degrees (psf)
30-S	19.80	0.198	0.726	0.317	14.40
50-S	28.60	0.250	0.726	0.400	19.00
45-S	24.50	0.198	0.726	0.317	17.90
55-S	33.30	0.250	0.726	0.400	22.10
40	37.30	0.198	0.971	0.317	22.40
50	47.80	0.250	0.971	0.400	26.60
60	60.60	0.313	0.971	0.500	31.00
70	75.30	0.375	0.971	0.600	35.50
45	45.50	0.198	0.971	0.317	27.30
55	58.30	0.250	0.971	0.400	32.80
75	74.60	0.313	0.971	0.500	38.20
85	91.00	0.375	0.971	0.600	43.00

Resistive Methods – General

- **Consider Filter Material Under Revetment**
  - Gravel usually better as can adjust to bank movement
  - Filter fabric (geotextile) often loses contact with bank and bank then erodes under fabric
  - Check to see if fines can get out of bank through protection material
  - If can – use filter material in combinations (gravel and geotextile)
  - Use Standard Equations – FHWA is most commonly used (HEC-11)

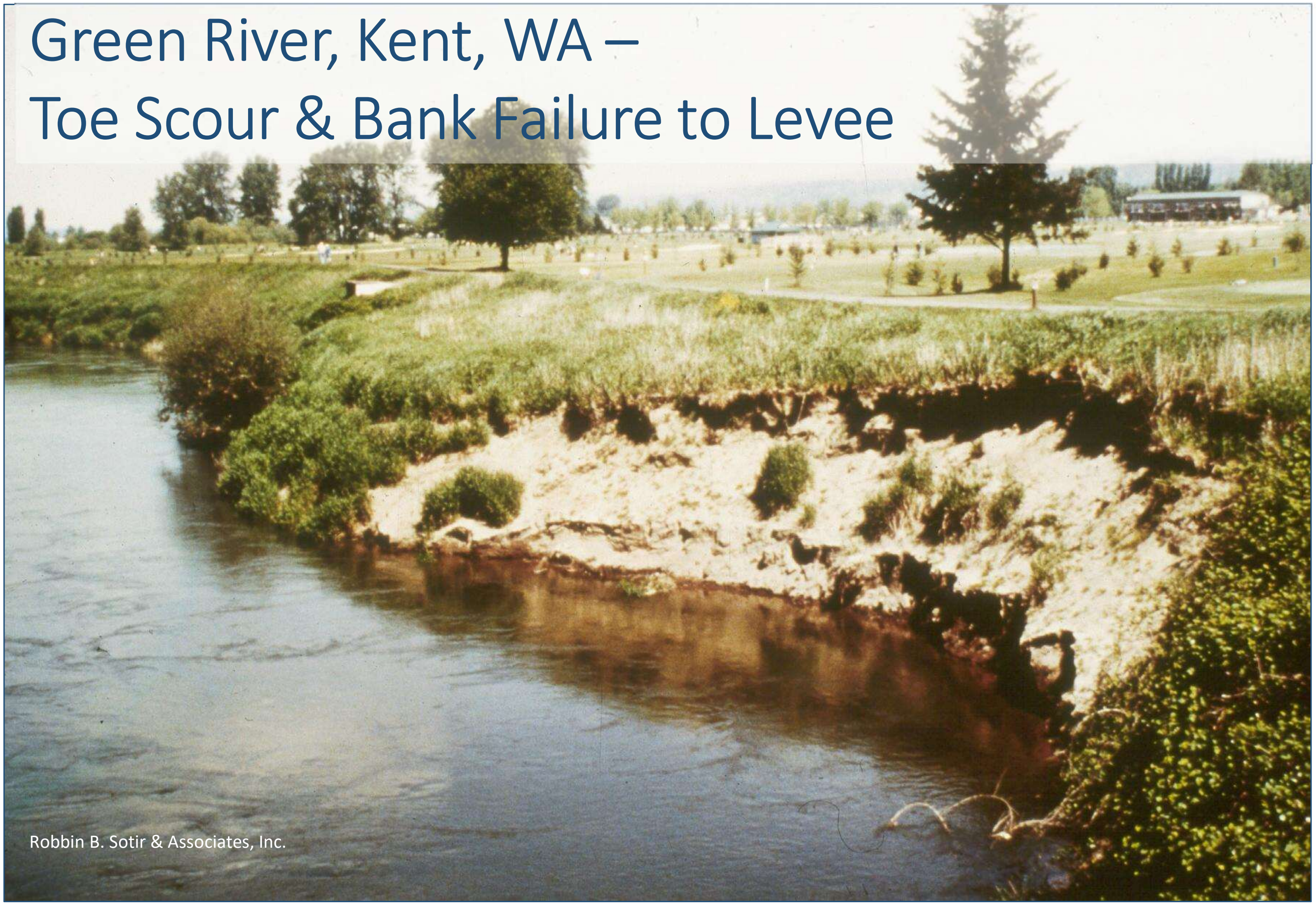
Sizing of Riprap

- **Numerous Methods**
  - Equations
    - USCOE / Maynord (EM 1110-2-1601)
    - California DOT
    - FHWA (HEC-11)
  - Software Programs
    - Chanlpro – USCOE / Maynord (free)
    - Riprap Design Package – WEST Consultants

Bioengineering / Vegetative Methods

- Vegetation functions as either armor or indirect protection, or both
- Grassy vegetation and roots of brushy and woody vegetation act as armor
- Brushy and woody vegetation function as indirect protection

Green River, Kent, WA –
Toe Scour & Bank Failure to Levee



Green River, Kent, WA –
Soil Bioengineering Construction Repair

Robbin B. Sotir & Associates, Inc.

Green River, Kent, WA – First Growing Season

Robbin B. Sotir & Associates, Inc.

Environmental Functions of Vegetative Bank Protection Structures

- Provide cover
- Stabilize or lower water and air temperatures
- Trap cool moist air moving (traveling) immediately above water
- Maintain dissolved oxygen levels
- Supply carbon material to the stream (leaf litter, debris, SWD & LWD)
- Provide habitat, food and shelter for insects and other critters, nesting areas, migration corridors, cover from predators, and other good riparian buffer zone features

Soil Bioengineering / Vegetative Methods

Advantages

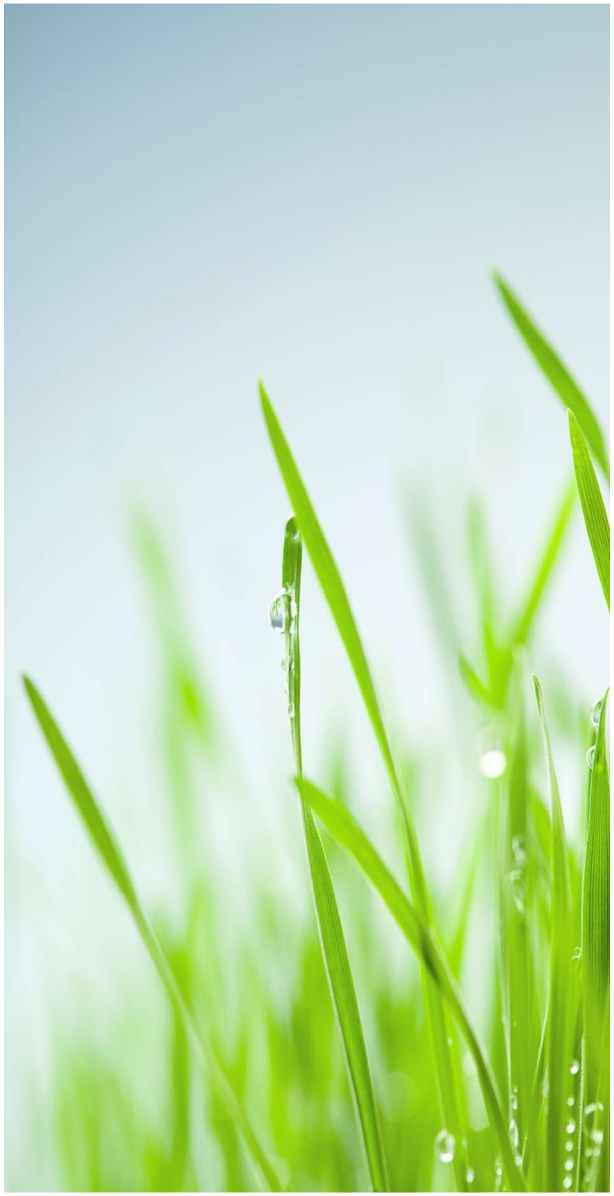
- Environmental Attractions
- Lower Cost (?)

Disadvantages

- Cannot be planned and installed with the same degree of confidence, or safety factor, as structural protection
- Vulnerable to extreme weather and inundation before well established

Bioengineering

- Requires Toe Protection Below/Near Water Table
  - Aquatic / Wetland Plants if VERY shallow
  - Hard / resistive toe if significant depth (> 6”)
  - Upper bank
    - Ground cover important - grasses
    - Slow velocities to safe range for soil
    - Hard to fail banks from above with plants



Bioengineering

- Consider maximum non-erosive velocity approach
  - Based on maximum velocities for different types of materials
  - Maximum 22.0 ft/sec in good rock
    - Igneous or metamorphic (plants not needed)
  - Maximum 2.0 ft /sec in sandy silt
  - Most Basic Method
  - Use conveyance methods to estimate velocity

Bioengineering

- **Be sure toe is stable!!!!!**
- **Most bioengineering projects fail from underneath – i.e., toe failure and plants just fall in stream!**
- **Not many erode from surface!**
    - **Exception – exposed soil banks**

Bioengineering Techniques

- Use biologists/plant scientists to recommend plants
- Plant according to recommendations
- Use estimated n value to determine expected velocities and depths
  - Newly Planted
  - Established
  - Consider plant flexibility / height
  - See "*Determination of Resistance due to Shrubs & Woody Vegetation*" by Freeman, Rahmeyer & Copeland ERDC/CHL TR-00-25

Samples of Bioengineering Methods

- Consider integrating when stone is placed or retrofitting existing projects: Soil "choked" & seeded riprap with rooted stock plants in interstices.
- Live Staking and Joint Planting
- Brush Layering, Brush Layering with Rock Toe
- Bent Willow Pole Method
- Live Wattles (branches every which way), Live Fascines (branches bundled in one direction only), and Reinforced Wattles and Fascines
- Turf Reinforcement Mats (TRMs) and Erosion Control Blankets (ECBs)

Bioengineering Methods

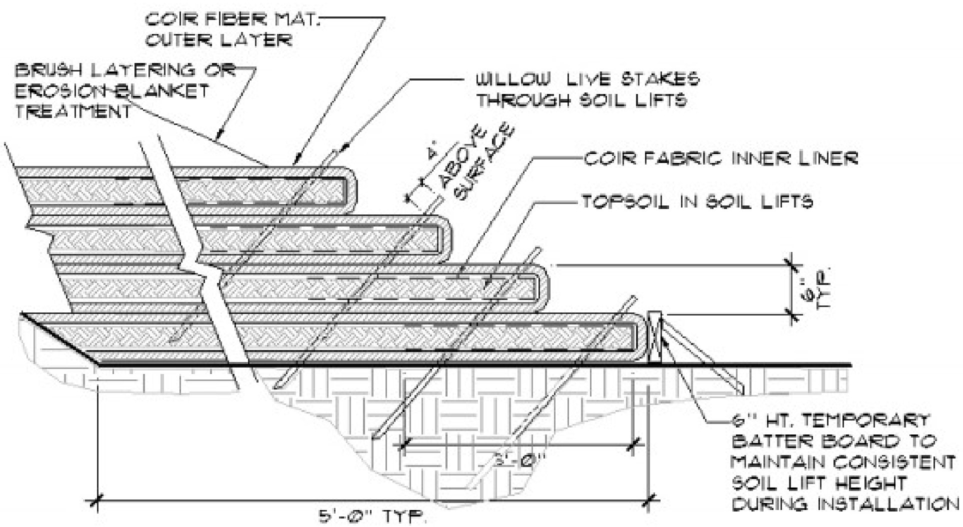
- **Coir Fiber Rolls and Mats** (including pre-seeded and pre-grown)
- **Brush Mattress**
- **Tree Revetments** (Cedar Tree Revetments)
- **Live Siltation combined with LPSTP**
- **Dormant Willow Post Method**
- **Willow Poles and Willow Curtains**
- **Debris Dikes and Living Dikes**
  (sediment catchers and velocity reducers)

Suggested guidelines for various bioengineering techniques. Santa Clara Valley Water District

Repair Method	Appropriate Slope	Appropriate Water Velocity	Environ Value	Cost
1. Modified floodplain	Varies	Varies	Positive	Low
2. Slope Grading with Vegetation	2:1 or flatter for vegetation section, 1.5:1 or flatter for boulder section.	Low – typically up to 6 ft/sec	Positive	Low
3. Erosion Mats	2:1 or flatter for erosion mat section, 1.5:1 or flatter if boulders used.	Generally 1-7 ft/sec but can go up to12ft/sec if vegetated.	Positive, if planted.	Low
4. Contour Wattling		Low	Positive	Low
5. Brush Mattresses	2:1 or flatter for erosion mat section, 1.5:1 or flatter if boulders used.	Low	Positive	Low
6. Brush Layering	2:01	Medium	Positive	Low
7. Vegetated Geogrids or Soil Lifts	Up to 1:1	Medium	Positive	Low
8. Root wads and boulders		Medium: (10 ft/sec or less)	Positive, if planted	High
9. Boulder/ Rock Revetment	Up to 1:1, preferably 2:1.	High: up to 15 ft/sec; less where voids in boulders are planted.	Negative. Negative to Neutral, if planted	Medium
10. Cellular Confinement System	Up to 0.5 to 1	Medium to High:5-21 ft/sec depending on vegetation)	Neutral	Medium
11. Live Log Crib Walls	Up to 0.25:1	Medium: up to 12 ft/sec or less	Neutral to High, if planted	High

Basic Concepts of Soil Lifts (MSE)

- Soil Stabilization on Steep Slopes
- Provides a Protected Toe
- Stabilized Bank
- Aesthetically Pleasing

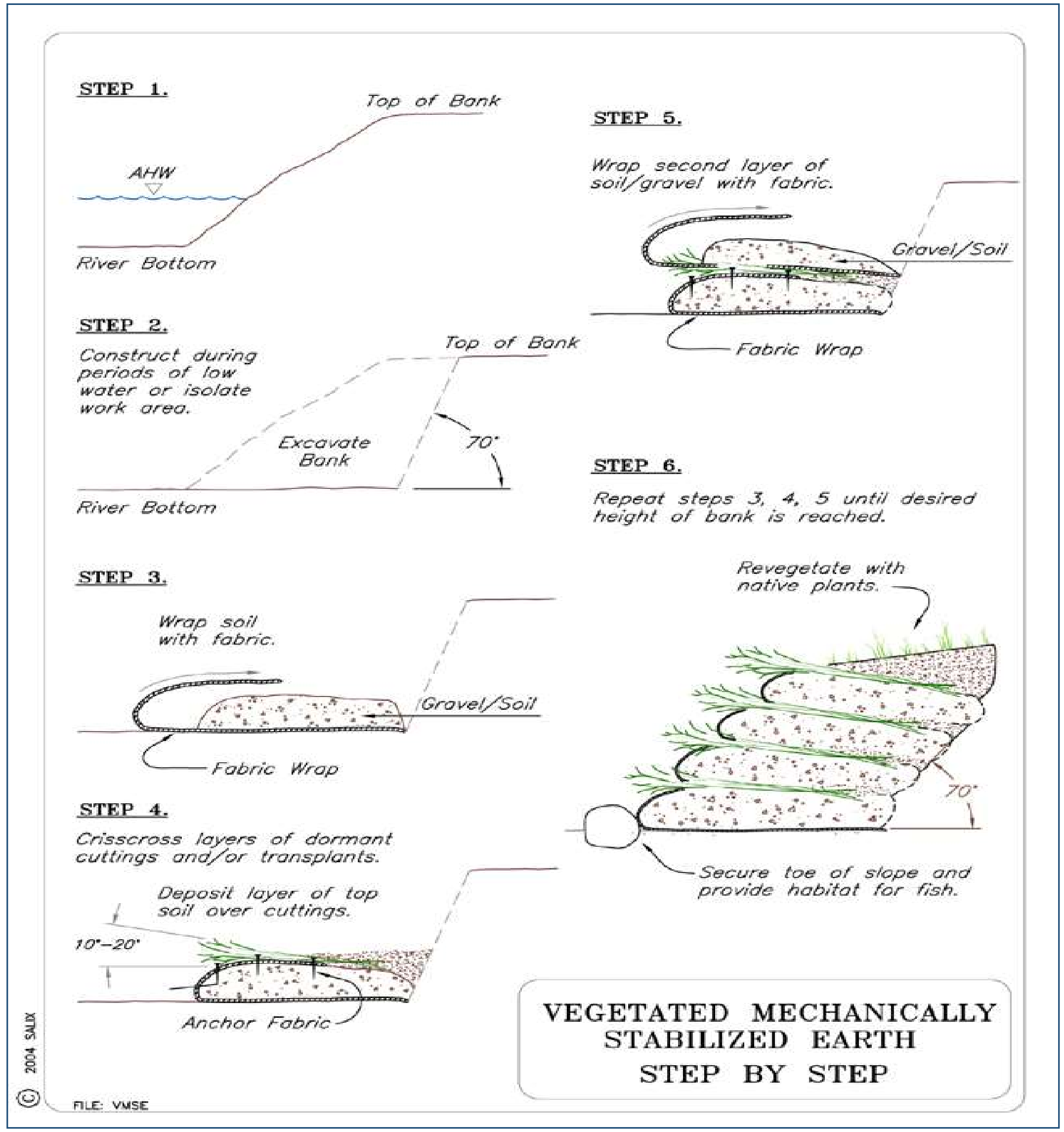


WRAPPED SOIL LIFT DETAIL

NTS

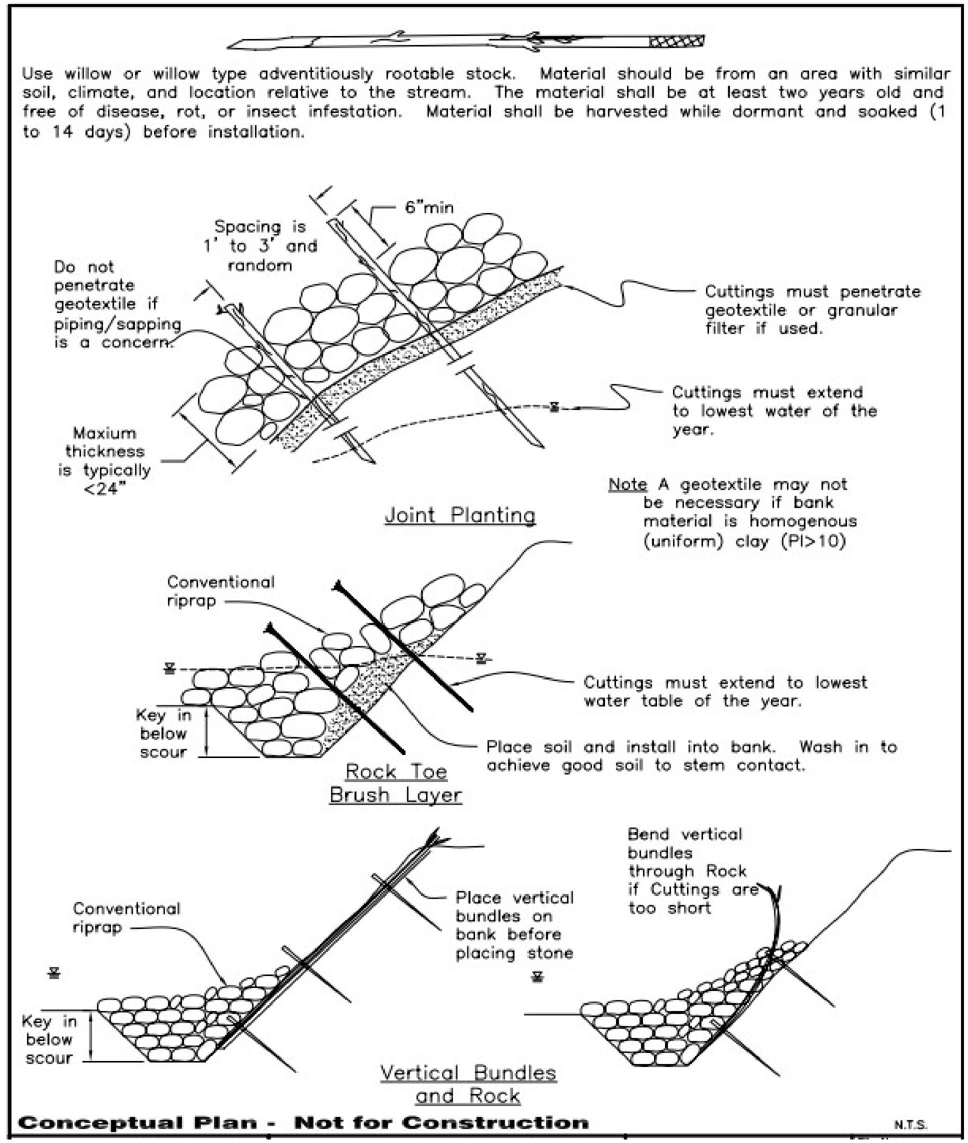
*www.terratechnologies.com

Mechanically Stabilized Earth Structure (MSE)

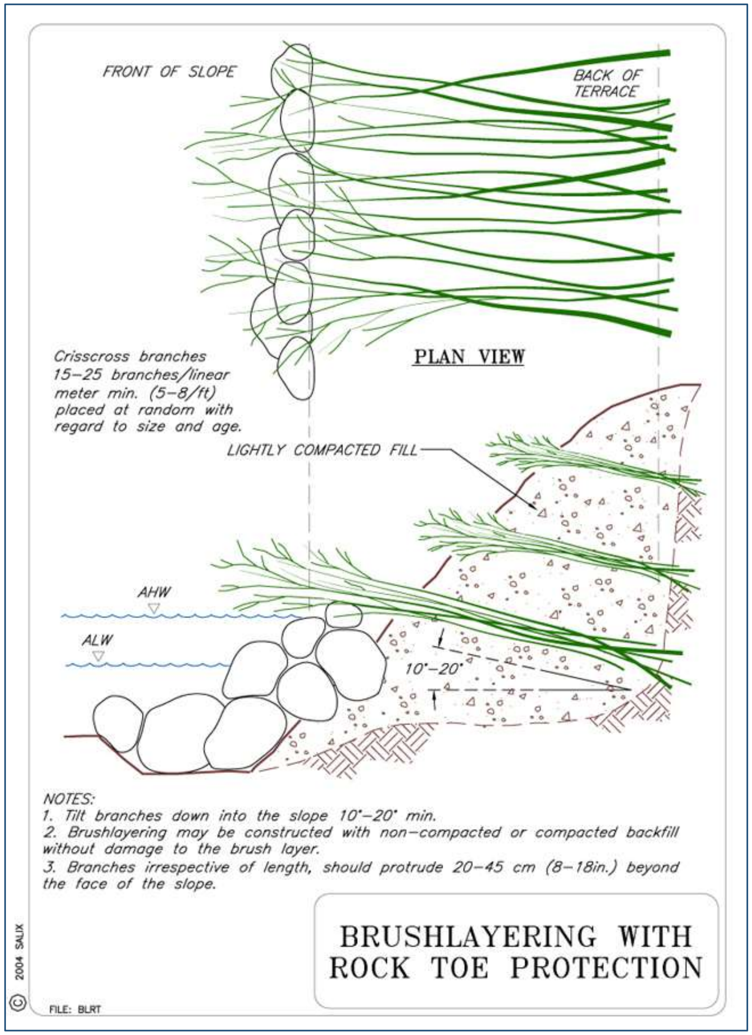


Willow Cuttings and Rock/Riprap Variations:

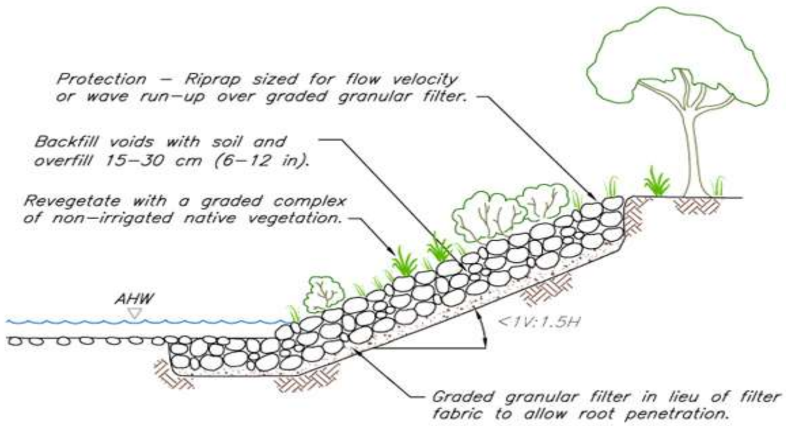
- Joint Planting
- Rock Toe Brush Layer
- Vertical Bundles



Brush Layering with Rock Toe Protection



Soil-Choked Riprap



NOTES: CLASS 2 PERMEABLE MATERIAL

Permeable material for blankets or other subdrainage purposes shall consist of hard, durable, clean sand, gravel or crushed stone and shall be free from organic material, clay balls, or other deleterious substances.

Class 2 permeable material shall have a Durability Index of not less than 40 and a Sand Equivalent value of not less than 75.

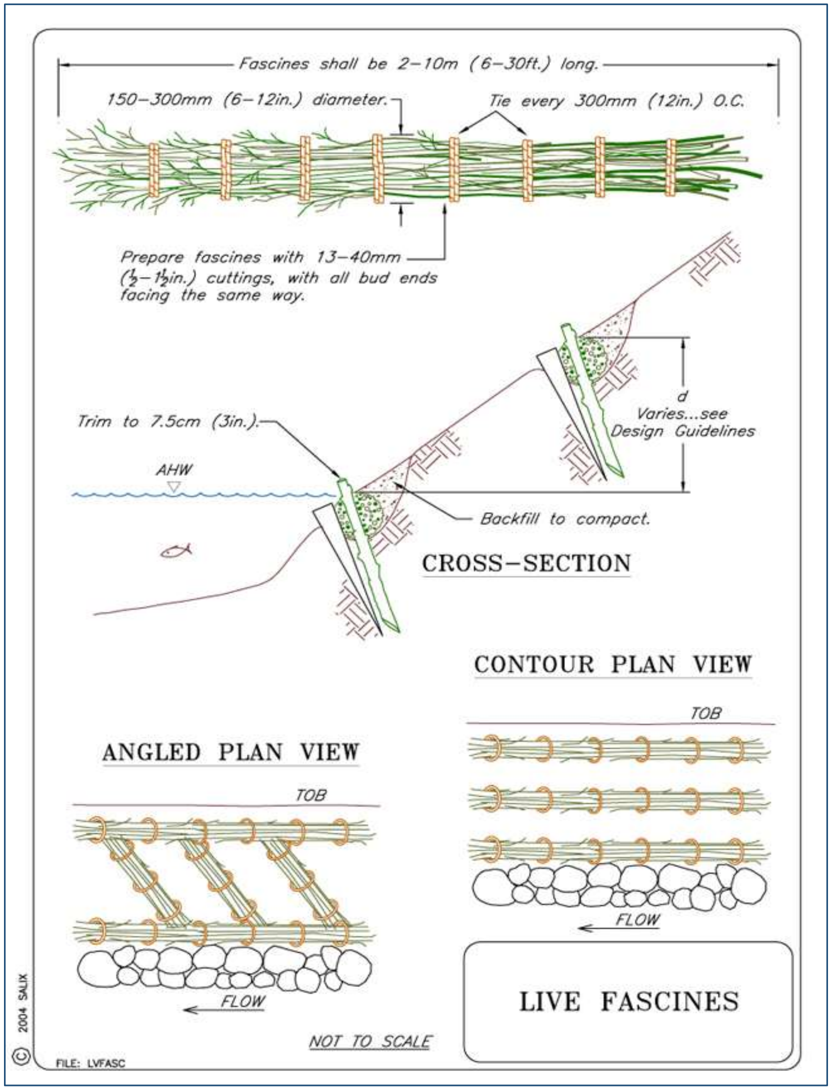
SIEVE SIZES	PERCENTAGE PASSING
1–Inch	100
3/4–Inch	90–100
3/8–Inch	40–100
No. 4	25–40
No. 8	18–33
No. 30	5–15
No. 50	0–7
No. 200	0–3

RIPRAP
W/ SOIL AND GRASS
OR GROUND COVER

FILE: RRSG

Soil Choked Riprap with plantings

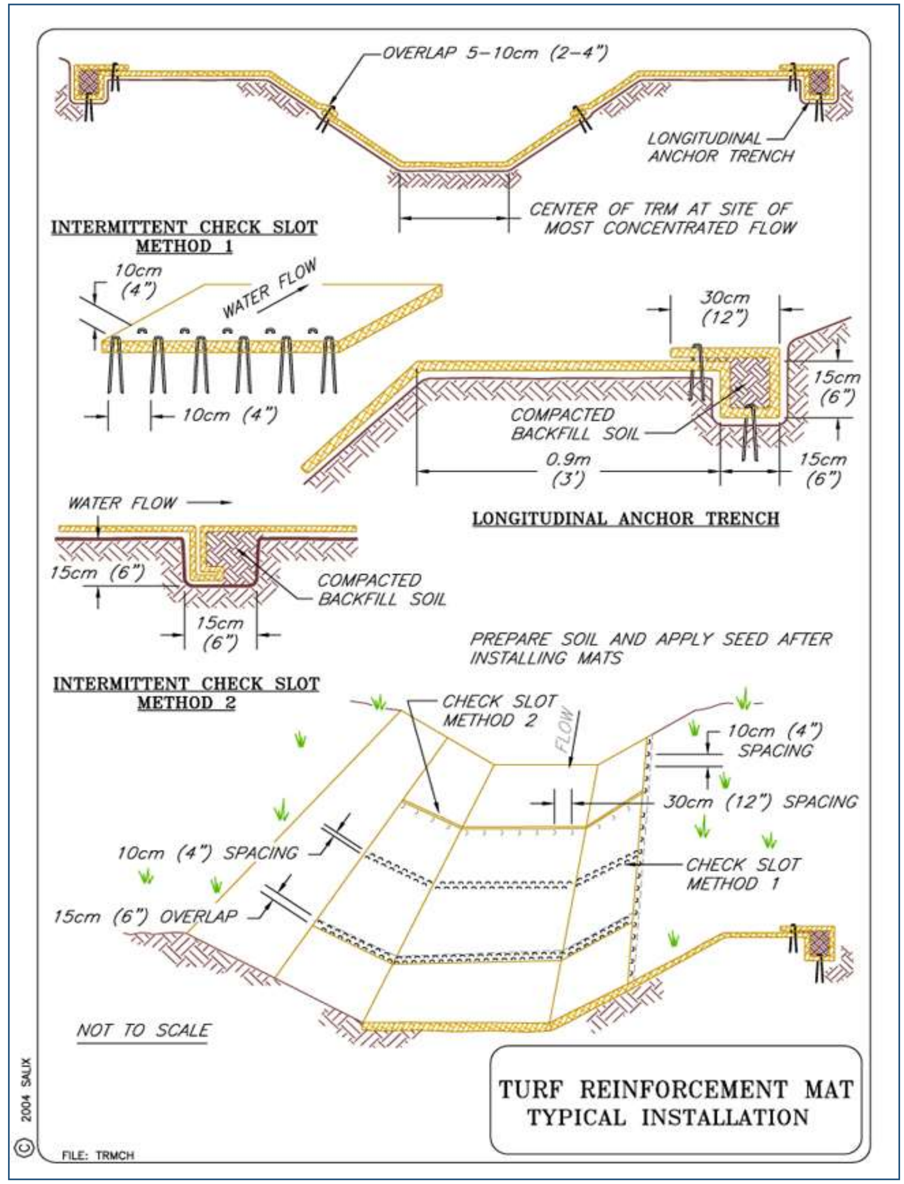
After 1 year



Live Fascines

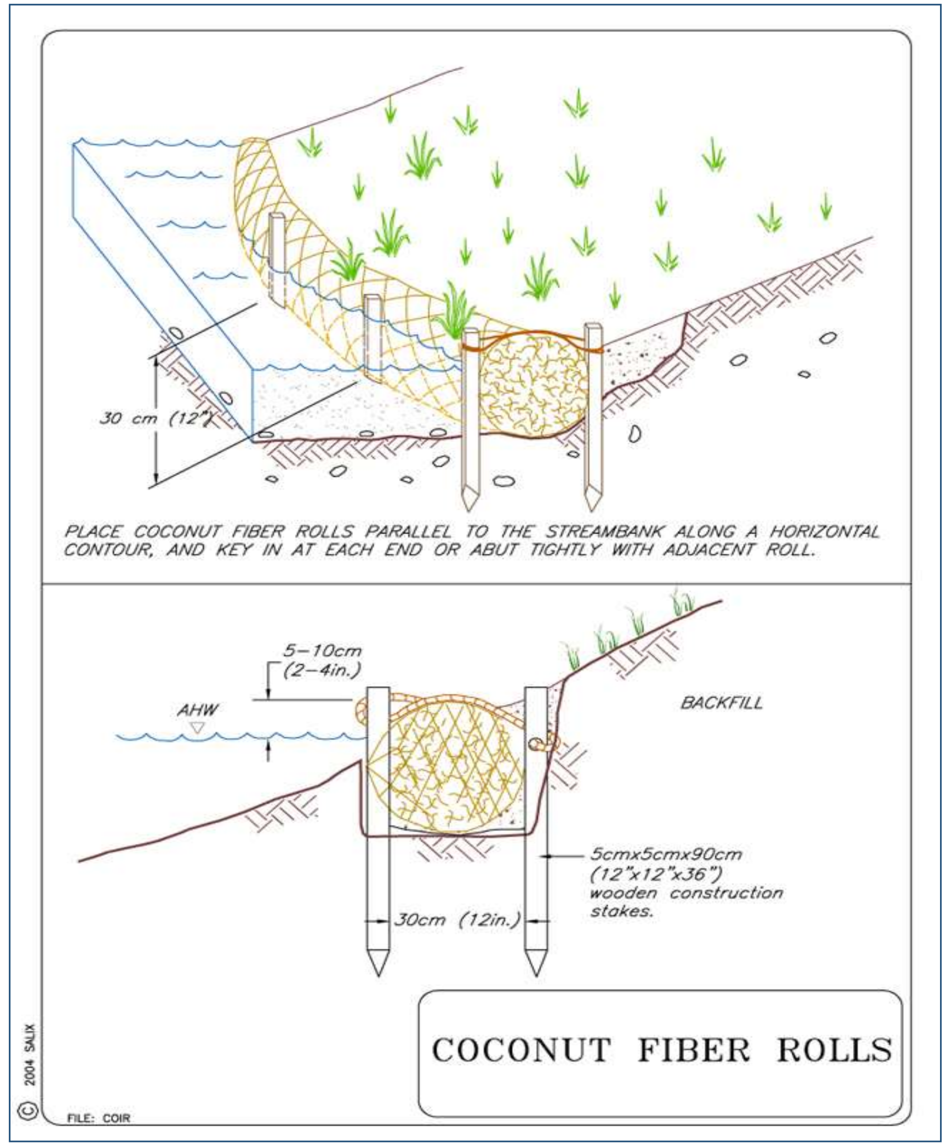
Always placed on a slope, branches in fascine bundle are all oriented in the same direction, tips angled upslope, butt ends positioned downslope.

Turf Reinforced Mats



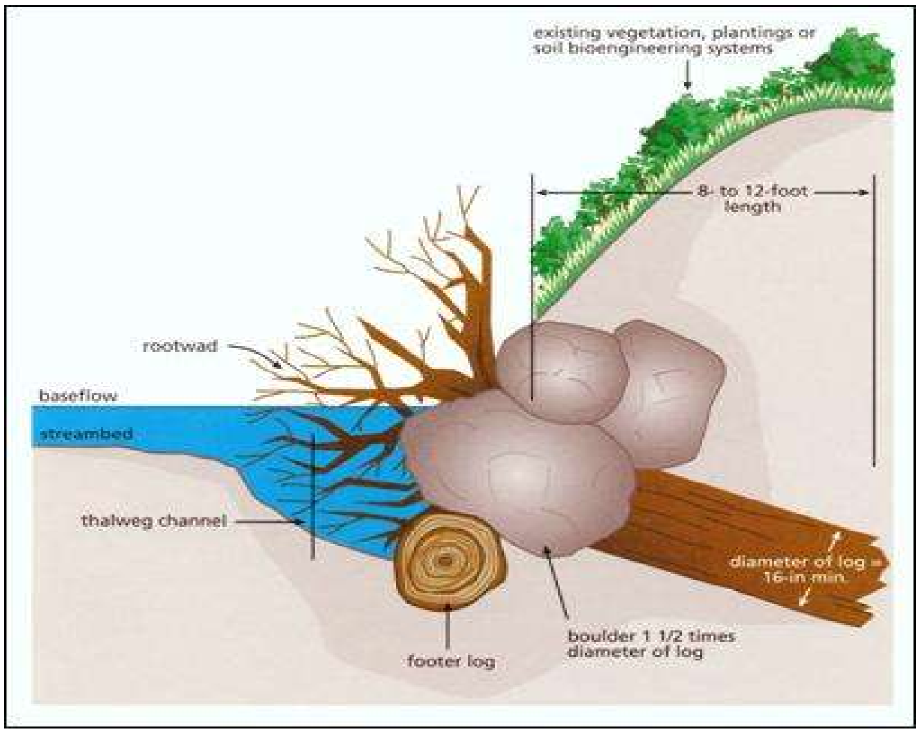
Coir (Coconut) Fiber Rolls for Toe Protection

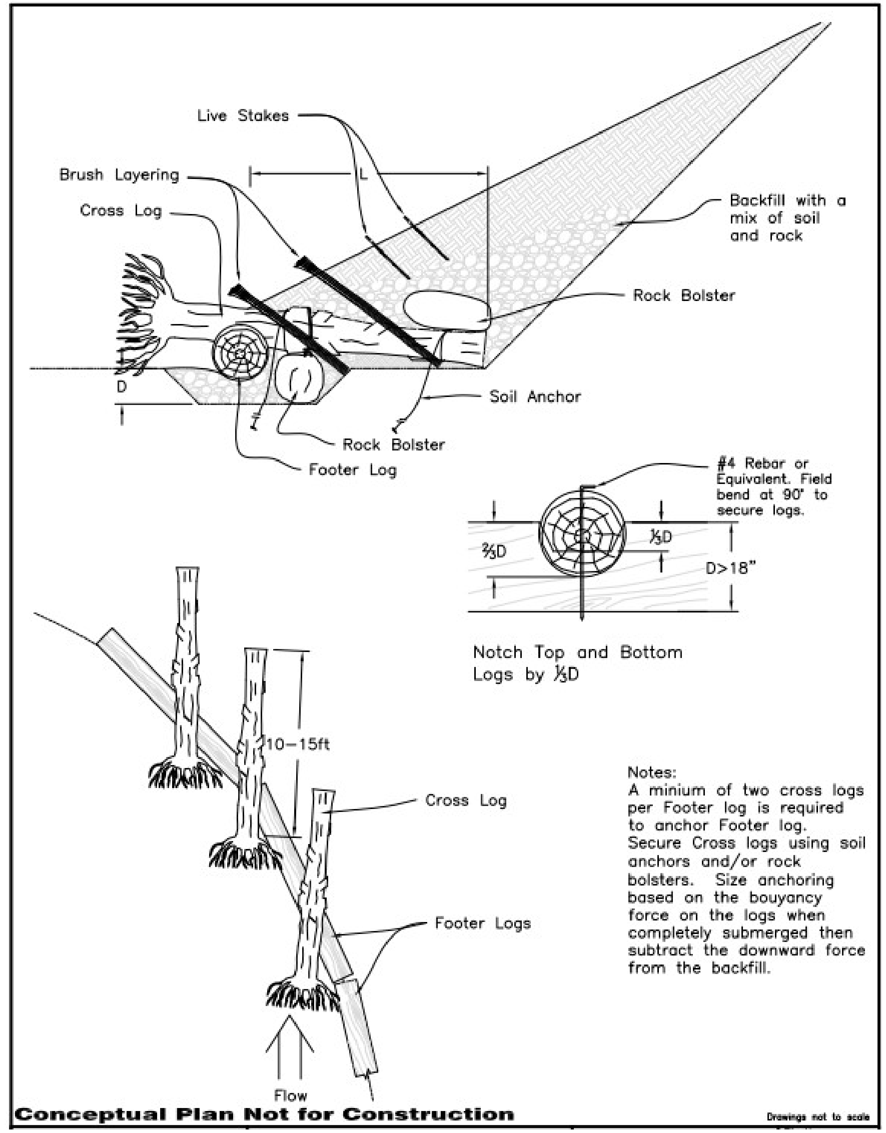
Note: For slow streams and minimal toe scour depths



Root Wads

- Great for Aquatic Habitat
- Natural Channel Bank Stabilization
- Protects Toe





Root Wads Used for
Toe Protection & Water Deflection

Be Aware of Vegetative Maintenance Regulations

- COE ETL 1110-2-571: Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures (2009)

- State and Local Regulations

Suggested Criteria for Use of Various Methods for Streambank Protection

Method	Description	*Bank erosion problem	Stream velocity	Stream depth	Bank slope	Bank height	Constr. cost	Maint. cost
Riprap	Layer of various-sized rocks used to protect a streambank from erosion.	1, 2, 3, 4	>3 ft/sec	Any	<6:1 & >6:1	<4 ft & >4 ft	High	Low
Jetty system	Dike-like structure from the streambank out into the streambed.	1, 3, 4	>3 ft/sec	Any	<6:1 & >6:1	>4 ft	High	Low
Iowa vanes	Vanes placed in the eroding streambed that cause the flow to be redirected and result in the recollection of sediment on the bank.	1, 4	>3 ft/sec	Any	<6:1 & >6:1	>4 ft	Medium	Low
Vegetated geogrids	Combination of geotextiles, rock fills, and live materials.	1, 3, 4	>3 ft/sec	Any	<6:1	>4 ft	High	Low

*Bank Erosion Problem: 1 = Fast flowing streams with erodible soils 3 = Fill structure for holes in streambank
2 = Extensive toe- and stream-level erosion 4 = Resistance to occasional heavy flows

Method	Description	*Bank erosion problem	Stream velocity	Stream depth	Bank slope	Bank height	Constr. cost	Maint. cost
Seeding of streambank	Planting of grasses on a streambank to reinforce a bare streambank.	1, 4	0-3 ft/sec	Any	>6:1	<4 ft & >4 ft	Medium	Low
Live stakes	Placement of woody plant and tree cuttings on a graded bank to grow and stabilize the bank by the formation of roots and above-ground growth.	1, 2, 4	0-3 ft/sec & >3 ft/sec	Any	<6:1	<4 ft & >4 ft	Medium	Medium
Joint planting	Combination of covering a streambank with rock and live stakes.	2, 3, 4	>3 ft/sec	Any	<6:1	>4 ft	High	Low
Live fascine	Placement of bundles of branches in trenches to slow over-bank erosion and establish structural soil stability.	4	0-10 ft/sec	Any	>6:1	>4 ft	High	Low
Brush-mattress	Combination of riprap, live fascine, live stakes, and brush to form a covering over the entire slope.	1, 2, 4	>3 ft/sec	Any	<6:1	>4 ft	High	High
Live cribwall	Combination of timbers, live branches, soil, rocks, and logs to fill a bank and eventually establish a root network.	1, 2, 3	>3 ft/sec	Any	<6:1	>4 ft	High	Low
Branch-packing	Layering of live branch cuttings and compacted soil to fill small holes and slumps of a streambank.	3	>3 ft/sec	Any	<6:1	>4 ft	High	High

*Bank Erosion Problem: 1 = Fast flowing streams with erodible soils 3 = Fill structure for holes in streambank
2 = Extensive toe- and stream-level erosion 4 = Resistance to occasional heavy flows

	holes and slumps of a streambank.							
Coconut fiber rolls	Cylindrical structures made of coconut husk fibers bound together with coconut husk twine.	1, 2, 4	0-10 ft/sec	Any	>6:1	<4 ft	Medium	Medium
Log, rootwad, and boulder revetment	Logs are placed in the stream and held in place by boulders. The rootwads are then placed around the boulders to slow the flow of the stream, protect the bank, and provide habitats for fish and wildlife.	1, 3, 4	>3 ft/sec	Any	<6:1	<4 ft & >4 ft	High	Low
Tree revetment	Placement of trees along the eroding streambank.	1, 3, 4	>3 ft/sec	Any	<6:1	>4 ft	High	Medium
Dormant post planting	Placement of medium-sized trees in the slope next to the stream.	1, 2, 4	>3 ft/sec	Any	>6:1	<4 ft & >4 ft	Medium	High
Piling with wire or geotextile fencing	Single or double row of pilings with mesh, wire, or geotextile on the streamside of the fence.	1, 3, 4	>3 ft/sec	Any	<6:1 & >6:1	>4 ft	Medium & High	Medium

*Bank Erosion Problem: 1 = Fast flowing streams with erodible soils 3 = Fill structure for holes in streambank
2 = Extensive toe- and stream-level erosion 4 = Resistance to occasional heavy flows

Summary

Last Session

- Streambank Zones
- Total Scour at Streambank Toes
- Causes of Local Streambank Instability
- Basics of Toe and Bank Protection
- Design Considerations for Toe Protection

This Session

- Redirective Methods
- Resistive Methods
- Bioengineering / Vegetative Methods
- Criteria for Use of Various Bioengineering/ Vegetative Methods