WISCONSIN SUPPLEMENT
ENGINEERING FIELD HANDBOOK
CHAPTER 16
STREAMBANK AND SHORELINE PROTECTION

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Streambank Protection

Shoreline Protection

WISCONSIN SUPPLEMENT
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ANATOMY OF A HEALTHY STREAMBANK

A healthy streambank is an extravagant ecosystem, the consummate source of food, shelter and of course, water, for a diverse mix of plants and animals. There are several components to a healthy streambank, starting with the riparian zone. The riparian zone of a stream is a natural transition place from land to water, a kind of mud room before runoff enters the stream. It is ideal if it is 30 feet or wider, although narrower strips of land with a variety of vegetation can be adequate. Within healthy stream corridors, the riparian zone acts as a buffer between the damaging pollutants carried in runoff and the stream's water. It can also help to stave off erosion. The vegetative mix in a healthy streambank can include:

- tall grass, ferns, plants, flowers, vines and mosses.
- bushes — short conifers or deciduous shrubs less than 15 feet high.
- evergreen trees (conifers) — cone bearing trees that do not lose their leaves in winter.
- hardwood trees (deciduous) — trees that help to stabilize the riparian zone and soak up runoff.

For more information on appropriate vegetative plantings, consult with your Biologist or Resource Conservationist.

Shape of Stream Channel is Important

The cross section shape of the stream channel is important to healthy functions both within the stream and on the banks. Deep, cool water is ideal game fish habitat and is needed for fish to survive over the winter months. Stream beds free of excess sediment are needed for fish to reproduce. As a channel is distorted and widened either by straightening, erosion due to land use changes in the watershed, or some other reason, various components of the stream habitat begin to suffer. For example, the streambed fills up, creating warmer, shallower waters. Changing the aquatic environment will eventually change the kinds of aquatic species living there. These changes usually point back to evidence of certain land uses in the watershed. Nearby urban areas with many impervious surfaces, for example, increase the velocity and amount of stormwater runoff. This increased runoff can erode the streambank and alter the shape of the stream channel, often changing it from deep and narrow to wide and shallow.

A stable channel has the ability to transport the flows and sediment of its watershed while maintaining the dimensions, pattern and profile of the stream without either aggrading (building up) or degrading (downcutting).

For more information on fish habitat consult with a Fisheries Manager, Biologist or Resource Conservationist. For more information on stream channel shape, consult with a Geologist or someone trained in fluvial geomorphology.

The natural resource professional needs first to determine that there is a problem and if so, find out if the problem is local or system-wide. Good observation skills and detective work are needed. It is important to look at more than one site to see if there is a problem just at a particular site or reach or if the entire system is unstable. The following pages contain more information on clues of instability and problem identification.

STREAM STABILITY PROBLEM IDENTIFICATION

People living next to streams often request assistance to stabilize stream banks. The resource professional must look beyond the eroding stream bank to identify the true cause of the problem. Streambanks naturally erode. The question to answer is whether the rate is excessive. Generally, bank erosion rates are excessive when overhanging vegetation dominates the top of the bank, trees fall into the stream annually, or soil slips and slumps are common. Excessive bank erosion (lateral instability or widening) and downcutting are indicators of unstable streams. Excessive sediment deposition in a stream (formation of central bars or a braided stream) is also an indicator of instability. Bank protection problems fall into two categories: those that correct the problem (stream restoration) and those that compensate for it (streambank protection). Many projects compensate for a problem instead of correcting the fundamental cause. The scope of the problem may be the largest reason streambank protection is chosen over stream restoration.

When examining natural streams, certain stream types are stable in certain geomorphic settings. A "natural" stream is one that has not been modified or constructed (refer to local history). Rosgen (1994) has developed a stream classification system for natural rivers. The "A", "B", "C", and "E" types are usually stable. The "D", "F", and "G' stream types usually indicate instability. Excessive rates of sediment deposition and bank erosion are symptoms of instability associated with "D" stream types. Downcutting is the typical indicator of instability in "G" stream types and widening is usually occurring in "F" types.

So stream classification is usually the first step in defining a stream stability problem. In disturbed or constructed channels, determining the stage of channel evolution (Schumm 1984) is the first step in defining stream stability. Stages I and V are stable, Stage II indicates downcutting is occurring, Stage III indicates widening is occurring, and Stage IV is in the process of stabilizing.

The extent and sequence of different stream types, or stages of evolution, occurring upstream and downstream of the "problem" site helps identify whether the landowner's bank erosion "problem" is a local situation or is part of a system- wide instability. Some examples of local instabilities include bridge pier scour, trees or other debris blockages deflecting flows into banks, or uncontrolled drainage flowing over the streambank. If the "problem" is determined to be local in nature, the resource professional can proceed to the inventory and evaluation procedures outlined below for streambank protection. If a system-wide instability is indicated, additional investigation beyond that landowner's property is warranted. Vertical instability can be detected by surveying a longitudinal profile. If the low bank height diverges from the average bankfull slope and the average water surface slope, this indicates vertical instability. Longitudinal profile instructions can be found in Companion Document 580-8.

After establishing whether the banks or bottom of the stream are stable, becoming unstable, or are presently unstable, the cause of that problem must be identified. Downcutting typically occurs when the slope of a channel is steepened. Decreasing the length of the channel by straightening will increase its slope. Slope will also increase in an upstream reach above a point where the channel bottom elevation is lowered (by downcutting).

However, changes in runoff and sediment loads can also initiate downcutting due to an imbalance between a stream's energy and its resisting forces. For example, downcutting is typical below reservoirs due to the decreased amount of bed load in the stream. Downcutting is also typical in streams draining urbanized areas. The stream may actually fill with sediment initially during development, but as the area is built out, increased runoff and decreased sediment load usually initiates downcutting.

Lateral instability, widening, or excessive bank erosion often occurs after a stream has downcut and created higher banks. Once the critical height of a streambank is exceeded, it will fail through mass wasting (bank sloughing). Excessive buildup of sediment on the floodplain (resulting from excessive upland erosion) can also increase the height of streambanks to a point that they become unstable.

Another typical cause of streambank erosion is the removal of bank and riparian corridor vegetation. Roots increase the erosion resistance of streambank soils and vegetative cover also helps to protect the banks. Widening can also result when a channel downcuts to a resistant layer. The excess energy in the stream results in bank erosion. If a central bar, or some other channel blockage, begins forming in a channel, the diverted flow generally accelerates bank erosion. Central bars indicate the sediment load in the stream is exceeding the stream's capacity to move sediment. This is a precursor to the formation of a braided stream.

The stream instabilities described above are generally tied to changes in runoff and sediment load from a watershed or to physical changes in the riparian corridor or in the stream itself, or the instability is due to a combination of these situations. The true cause of the instability must be identified before alternative solutions can be developed and analyzed.

Ideally, the cause of the stream instability should be removed before any stream modification is attempted. However, local sponsors may not have the authority or ability to fix the true cause of stream instability. In many situations, local sponsors may not want to attempt to implement solutions due to social unacceptability. These situations can result in plans and designs of stream modifications that require taking into account the predicted runoff and sediment loads from the disturbed system.

More detailed, onsite inventories occur after problems have been identified, alternative solutions analyzed, and local sponsors have decided on a course of action. The two levels of inventory and evaluation described on the following pages become applicable if the local sponsors select solutions that involve bank stabilization or channel reconstruction.

STREAMBANK PROTECTION DESIGN

Inventory and Evaluation Needed When Using a Geomorphic Approach

I. Surveys

A. Plan form

1. Minimum length of 20 times the bankfull channel width (normally at least one meander upstream and one meander downstream).
2. Alignment of top of both banks (for determining sinuosity and meander geometry [radius of curvature, belt width, and meander wavelength]).
3. Elevations to determine channel slope.
4. Cultural features.
5. Reference points/landmarks.

B. Cross sections (as many as needed to represent site)

1. Three bankfull cross-sections for stream classification and hydraulic geometry parameters (width, depth, cross-sectional area, and slope) should be made at crossover areas between outside bends of meanders (riffles).
2. Record bank soils, water table, and vegetation pattern for at least one cross section. (attachment).
3. Dominant grain size of bed material (pebble count – Wisconsin Job Sheet 810).

II. Stream classification (Rosgen, 1994)

III. Stage of channel evolution (Schumm, 1984 or Simon, 1989)

IV. Riparian corridor condition

A. Soil layers in banks (Unified Soil Classification System)

B. Existing vegetation condition and potential

C. Land use and level of management

D. Availability of bank protection materials (inert or organic)

E. Terrestrial and aquatic habitat suitability

F. Water quality (pH and EC)

V. Hydrology

A. Plot flow frequency distribution using the 1, 2, 5, 10, 25, 50 and 100-year recurrence interval storms

B. Identify base flow

C. Determine annual water table fluctuation (high and low points)

VI. Hydraulics

A. Bankfull depth of flow (this is average depth)

B. Bankfull velocity

C. Manning's "n" value

STREAM CHANNEL RESTORATION DESIGN

Inventory and Evaluation Needed When Using a Geomorphic Approach

I. Surveys (in addition to those required for streambank protection)

   A. Plan form

      1. Establish a baseline
      2. 1-foot contour map of valley floor

   B. Typical cross-sections of pool and riffle areas

   C. Enough elevation information to plot longitudinal profile of valley floor and channel bottom throughout project area

II. Stream classification (Rosgen, 1994)

   A. Identify site's geomorphic setting

   B. Identify stable stream types for that geomorphic setting (may be located outside of subject drainage basin)

   C. Select stable stream type for project site

   D. Inventory stable stream types in area (use forms)

      1. Survey reference reaches of stable stream types to help select design parameters for reconstructed channel
      2. Adjust design parameters for drainage area
      3. Select appropriate cross-section, longitudinal profile, and plan forms design parameters for reconstructed channel. For a list of average values which can help with design, see Companion Document 580-15.

         a. width/depth ratio (pools, riffles, runs, glides)
         b. cross-section area
         c. slope (valley, channel, pools, riffles, runs, glides)
         d. confinement (floodplain dimensions)
         e. D_{50} of bed material
         f. sinuosity
         g. radius of curvature
         h. meander wavelength
         i. belt width
         j. pool-to-pool spacing
         k check using empirical equations (dimensionless ratios)

III. Stage of channel evolution (Schumm, 1984 or Simon, 1989)

IV. Riparian corridor condition (in addition to those required for streambank protection)

   A. Area-wide resource management plan (watershed level with landscape considerations included)

   B. Biological investigations

      1. Current and potential riparian and upland plant species composition and distribution

2. Current and potential terrestrial habitat assessment
3. Current and potential aquatic habitat assessment
4. Macroinvertebrate assay
5. Threatened and endangered species

C. Cultural resources

D. Geotechnical investigation

1. Surface soils

   a. map
   b. grain size distribution, plasticity index, and USCS
   c. fertility (pH, nutrients, salinity, restrictive layers)

2. Subsurface soils

   a. profiles parallel and perpendicular to proposed alignment
   b. identify salvage and waste areas
   c. grain size distribution, plasticity index, and USCS
   d. undisturbed samples at proposed depths of reconstructed channel for dry density, shear strength, dispersion potential, plasticity index, and grain size distribution

3. Bank stability analysis

   a. qualitatively assess the height and slope of stable banks in reference stream reaches to support design
   b. do a slope stability analysis if questions cannot be resolved based on field observations
   c. identify locations
   d. identify appropriate practices (consider other objectives in addition to stability)

4. Depth to ground water maps for wet and dry parts of the year (ground water flow paths and annual fluctuation)

5. Surface and ground water quality (pH, TDS, EC, DO, BOD, heavy metals, fecal coliform, pesticides, and temperature)

V. Hydrology

A. Climate data (rainfall [amount and time of year], snowfall and snowmelt, ET, growing degree days [growing season], temperature extremes)

B. Gaged sites

1. Annual peak flow frequency distribution plot
2. Flow duration table
3. Determine base flow and bankfull discharge
4. Frequency of inundation of present floodplain and constructed floodplain
5. Obtain USGS Form 9-207 (Summary of Discharge Measurement Data) data far each gage site for constructing graphs relating width and cross-sectional area to discharge (for use in helping select design parameters for bankfull channel)
6. Obtain expanded rating table for gages to identify peak flow that fills bankfull channel at each gage (use flow frequency distribution plot to determine frequency of this bankfull discharge)

C. Ungaged sites

1. Complete items 1-3 from the gauged site list using TR-55 or regional equations.
2. Complete item 4 from the gauged site list using TR-20.
3. Construct hydraulic geometry graphs from stable stream types in area.

VI. Hydraulics

A. Select stable slope (use stream type and relationships between valley floor slope, channel slope, and sinuosity of reference reaches on other stable stream types)

B. Locate channel centerline

1. Start with appropriate meander belt width and adjust based on required sinuosity (slope) and meander geometry
2. Fit to existing terrain (property lines, right of way, minimize cut and fill)

C. Consider grade control options to maximize fit of new channel with existing terrain

D. Develop water surface profile (WSP) to check width, depth, and velocity of flow through reconstructed channel

E. If D_{50} is gravel or cobble-size, do tractive stress analysis to check on size limits of particles moved during bankfull flow

F. If sand bed channel, use other tools, such as Chang, 1988 (pp. 277-281), to check on stability

G. If channel boundaries are cohesive soils, check stability by establishing a relationship between the width/depth ratio and the percent of silt and clay in the channel boundaries and compare with Schumm's $F = 255\ M^{-1.08}$ (1960) relationship

H. Sediment transport analysis to determine potential for scour and deposition through new channel and in downstream reaches (may need a sediment budget to quantify bedload introduced into new channel from upstream sources)

I. CHECK that high frequency flow fits designed, bankfull cross-section and that lower frequency flows access the floodplain

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SUGGESTED SURVEY POINTS FOR STREAMBANK WORK

A. From top of bank out into floodplain for a minimum distance of two bankfull channel widths.
B. Top of bank.
C. Change in soils or type of vegetation.
D. Breaks in slope.
E. Water table or point of groundwater discharge (seeps or wet areas).
F. Channel bottom (minimum of three points including the deepest).
G. Left and right water line on the date of survey (low flow channel).
H. Top of sand or gravel bar.
I. Edge of permanent vegetation (top of bankfull channel).
J. Cultural features near banks (roads, fences, power poles, etc.).
K. OHWM ordinary high water mark elevation (bankfull channel elevation).
L. Flood prone width and elevation (at 2 times the maximum depth at bankfull).

*Bankfull channel width = width of stream at Q = 1.2 years, which is identified by the first flat depositional surface, break in bank slope or top of sediment deposits.

The estimate of bankfull stage and corresponding discharge is a key to properly:

1. Classify stream types.
2. Establish dimensionless ratios. Dimensionless ratios are used so stream sites can be compared to each other even if they vary widely in drainage area. For example, rather than talking about the radius of curvature of a bend in a stream, we can talk about the radius of curvature/bankfull width. The radius of curvature/bankfull width will likely be the same for a small stream or river of the same stream type.
3. Perform a departure analysis. Departure analysis is simply the comparison of a stable reference reach to a potentially impaired stream.

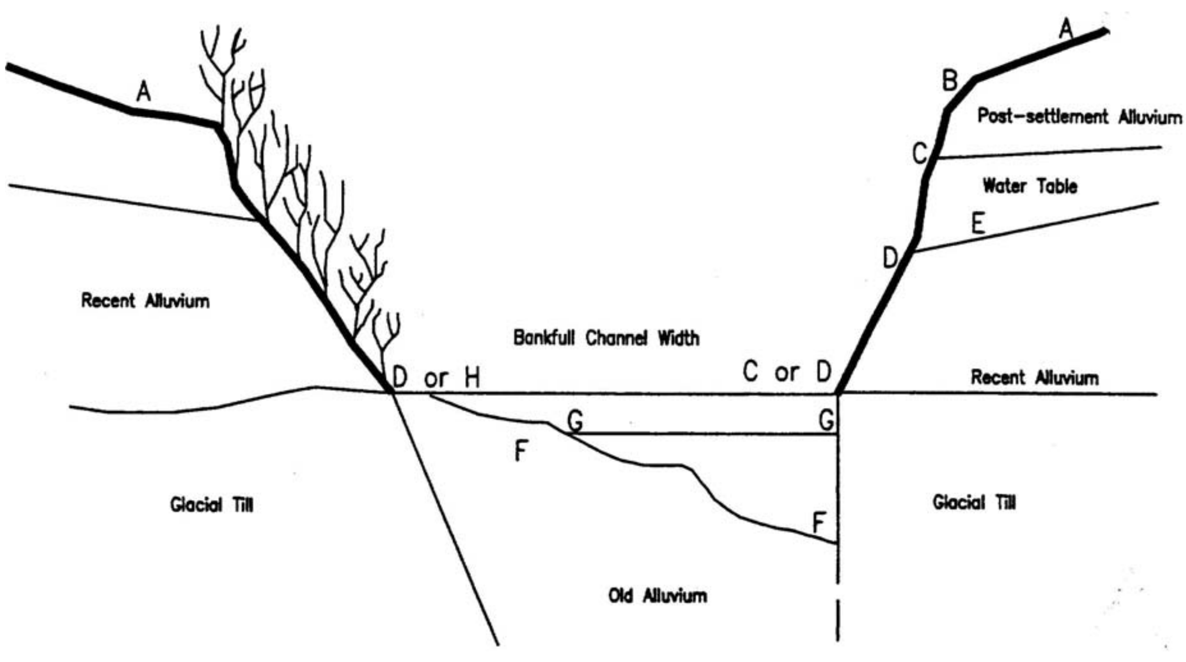


Figure WI-16-1: Suggested survey points.

INVESTIGATIONS

Additional things to investigate and document before treatment is started are:

1. Stage of Channel Evolution. Refer to the Channel Evolution Model (Schumm, Harvey, Watson, 1984) sketches in Companion Document 580-7.

2. The stream reach classification by Rosgen's Classification System (Companion Document 580-5).

3. An evaluation of the stream cross section and meander relationships for the reach in question.

4. An evaluation of the channel stability visual indicators to help decide if stabilization is required. Some erosion and deposition occurs in stable streams. Excessive erosion or deposition are signs of an unstable system. A longitudinal profile survey will show if the stream bed is degrading (downcutting), aggrading (building up), or stable. Instructions for completing a longitudinal profile survey are given in Companion Document 580-8.

5. When the bed of a stream is degrading, or is expected to occur, the grade of the channel must be analyzed before a streambank protection project is planned.

   Four visual indicators of channel degradation are:

   a. headcuts or knickpoints in the channel bottom.
   b. lack of sediment deposits in the channel.
   c. the presence of a vertical face or scarp at the toe of the channel banks.
   d. the exposure of the foundations of cultural features or the undercutting of cultural features.

   An evaluation for evidence of excessive deposition. This can be indicated by:

   a. extremely high or wide point bars relative to the stream's width and depth.
   b. the formation of central bars - bars that build up in the middle of a channel instead of at its edges.
   c. vegetation buried in sediment.
   d. reduced bridge clearance.

6. An evaluation of streambank erodibility indicators such as (see Companion Document 580-4 for a diagram of streambank erodibility factors):

   a. the bank height above the base flow.
   b. the bank angle above the base flow.
   c. the density of roots and amount of bank surface protection.
   d. the soil layering in the bank to identify the weak soils.
   e. the soil particle sizes in the bank.
   f. the water table elevation and slope in the streambank.
   g. the thalweg is near the bank.

METHODS OF EVALUATION

Two methods or approaches can be used to evaluate a material resistance to erosion. These methods are:

1. Permissible velocity

   The permissible velocity approach focuses on a computed velocity for the geometry of the channel.

   The channel particle, or treatment system is assumed stable if the computed velocity (mean [V_{avg}] or impingement [V_s]) is lower than the maximum permissible velocity. The impingement velocity (on outside bends directly in line with the centerline) may be assumed to be 33% greater than the average stream velocity (V_s.= V_{avg} * 1.33).

2. Permissible tractive force (Shear Stress)

   The tractive force approach focuses on stresses developed at the interface between the flowing water and the materials forming the channel boundary. The boundary is assumed stable if the computed (proportioned) shear stress is less than the allowable shear stress.

Velocity and shear stress data should be collected in a crossover riffle cross section.

VELOCITIES IN STREAMS

Velocities in streams can be calculated using Manning's Equation. The Wisconsin Streambank Protection spreadsheet can be used to simplify the computation. Channel hydraulics, Manning's Equation, and Manning's "n" values are further discussed in the EFH, Chapters 3 and 14. Methods to determine Manning's "n" is in a Wisconsin supplement to EFH, Chapter 3.

The design depth at which the velocity is determined for stability must be compatible with the design procedures for site risks and for the selected bank protection treatment.

In some cases, the design storm elevation may be to the out-of-bank flow. When there is a low bank or flood record data showing that a stream goes out of bank (across the flood plain) frequently, the designer should consider design velocities for this stream stage. A stream with at least one low bank is not entrenched. The maximum stream velocity will occur as the water spreads-out across the floodplain, unless another terrace is encountered.

In other cases, the design storm elevation may be a selected depth or a particular storm return period. If a 100-year frequency storm is contained within the channel banks, the designer may wish to design using the velocity for this depth or for a lesser storm frequency.

EFH Chapter 2, TR-55, and the USGS publication, “Flood Frequency Characteristics of Wisconsin Streams,” can be used to determine runoff discharge.

STREAMBANK PROTECTION BASED ON PERMISSIBLE VELOCITY

<u>Sizing Rock Riprap</u>

The equivalent spherical stone diameter, D_{50}, shall be selected from Figure WI-16-2 using the impingement velocity of the stream. The D_{50} is defined as the rock size of which 50 percent is smaller by weight.

Rock riprap material that will be predominantly cubical in shape may be designed using a D_{50} stone size that is 80 percent of the equivalent spherical stone size obtained from Figure WI-16-2.

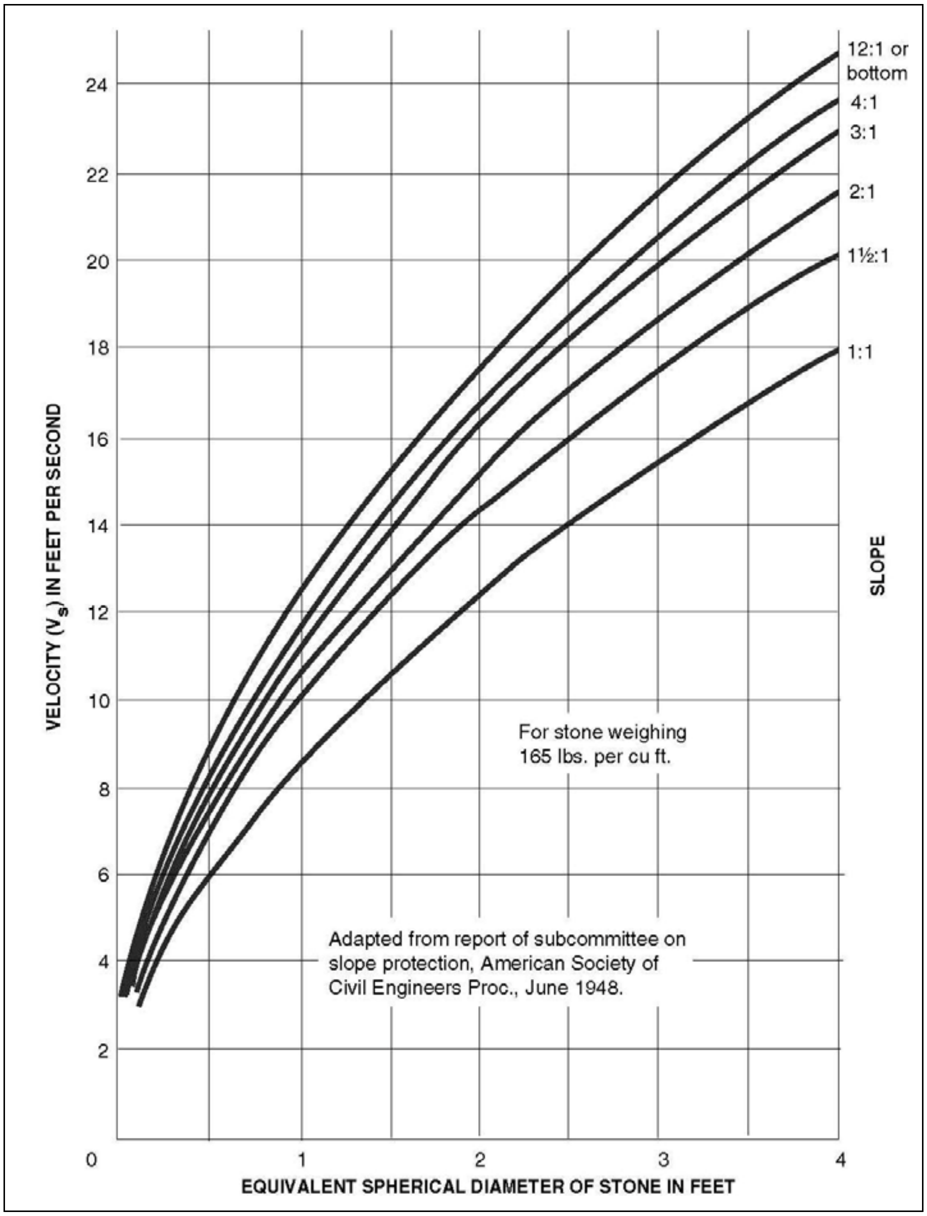


Figure WI-16-2

Equation for Figure WI-16-2: $Log\ D_{50} = (\log V_s - \boldsymbol{B}) / \boldsymbol{M}$

Table 1
Constants for Figure WI-16-2 Equation

Side Slope	B	M
3:1	0.470	0.443
2:1	0.332	0.526
1.5:1	.0271	0.57
**Range1.5-4.0:1	$0.470 + (\frac{3-z}{.5}) * (-.08433)$	$0.443 + (\frac{3-z}{.5}) * (.04233)$

**Approximate D_{50} for side slopes ranging from 1.5-4.0:1

STREAMBANK PROTECTION BASED ON PERMISSIBLE TRACTIVE FORCE (SHEAR STRESS)

Shear Stress

Critical shear stress is defined as the shear force that moves a given size particle that makes up a channel boundary (bed and bank). The maximum shear stress occurs on the bed and depends on the width-to-depth ratio and side slopes. Since most NRCS streambank protection work occurs on streams which are wider than deep and side slopes steeper than 4:1 (H:V), the maximum shear stress can be estimated to be:

$$\tau_{\text{Bed Max Straight}} = 1.5 * \gamma * R * S$$

Where: τ = shear Stress (lbs/ft^2)
γ = unit weight of fluid (62.4 lbs/ft^3)
R = hydraulic radius (ft)
S = energy slope (ft/ft)

NRCS published a Watershed and Stream Mechanics document dated March 1980. Figure 8-2 (Maximum unit tractive stress) is reproduced here. The figure shows how shear stress is distributed between the bed and banks of a trapezoidal channel. It is approximated that the bank shear is 80 % of the maximum shear.

$$\frac{\tau_{\text{Bank Max Straight}}}{\tau_{\text{Bed Max Straight}}} = 0.8$$

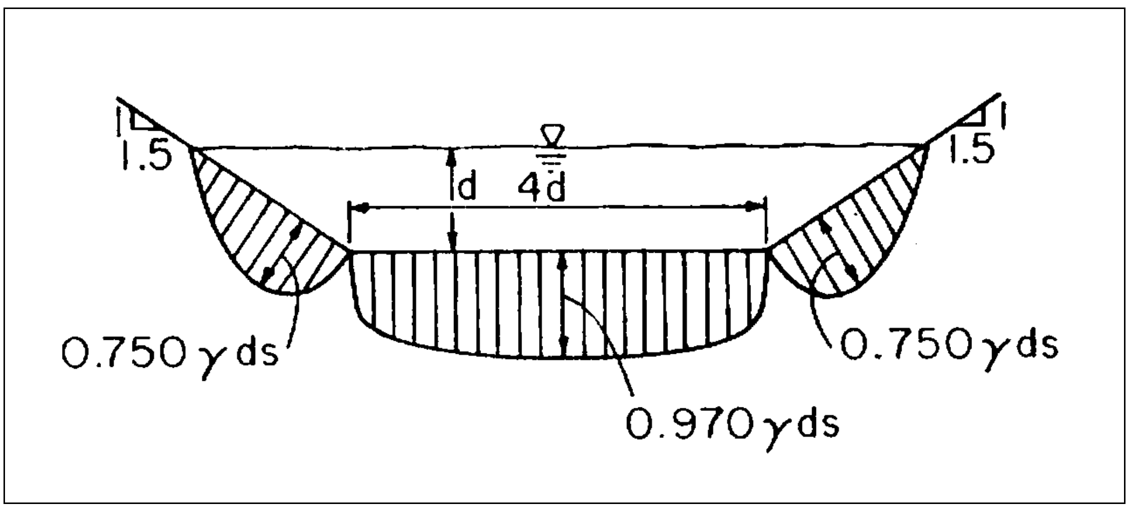
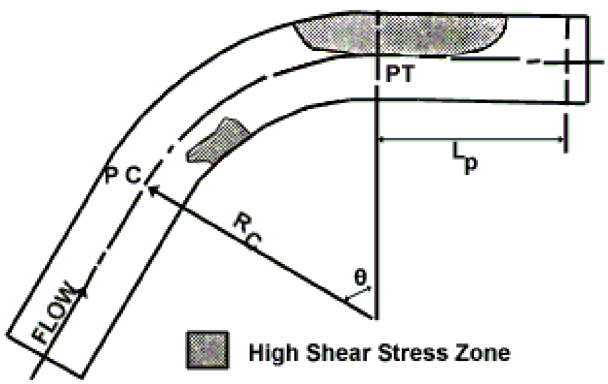


Figure WI-16-3: Shear Stress Distribution Diagram



PC = point of curvature
PT = point of tangency
R_c = radius of curvature
Θ = angle
L_p = length of protection

Figure WI-16-4

<u>Shear Stress in a Channel Bend</u>

Shear stress in a channel's curve is greater than in a straight reach. Secondary currents develop in channel bends. The maximum shear stress is near the middle of the channel as a curve begins and drifts to the outer bank as the flow leaves the curve. The sharper the curve, the greater the shear stress on the bank. The method for calculating shear in a bend is to take the maximum bed shear and multiply it by a bend factor K_b which is a function of the radius of the bend (R_c) and the width of the water surface at bankfull flow (B).

$$\tau_{\text{Bed Max Bend}} = K_b * \tau_{\text{Bed Max Straight}}$$

$$K_b = 2.4(e)^{-.0852\frac{Rc}{B}}$$

After shear stress is calculated, this information can be used to pick treatment strategies on the proposed bank. Integrated bank treatments can be designed, with less vigorous measure higher on the bank (bank zone vs. toe zone) because shear stress will be reduced higher on the bank. Hard armoring is not required from the anticipated scour bottom to the top of the bank on all channels. Shear on the bank in a channel bend (λ_x) can be estimated using the following:

$$\tau_x = C * \tau_{\text{Bed Max Bend}}$$

Table 2

Top of Channel	**Ratio of stream depth(x)**	**Coefficient (C)**
	1.0	0
	0.9	0.14
	0.8	0.27
	0.67	.041
	0.6	0.54
	0.5	0.68
	0.4	0.79
	0.33	0.8
	0.2	0.8
	0.1	0.8
Bottom of Channel	0.0	0.8

Give a reach cross section, the shear on the bank on a straight reach and bend can now be distributed by elevation. The Streambank Protection spreadsheet will plot a distribution.

DESIGN EXAMPLE - ENTRENCHED CHANNEL

The following data was entered in to Wisconsin's Streambank Protection Spreadsheet to illustrate the capability of the design tool.

D50 required = 11.4 inches
Water surface elevation = 101.8 (out-of-bank elevation)

The velocity and capacity of the reach is 7.5 feet/second and 5754 CFS respectively.

STREAMBANK RIPRAP DESIGN USING COORDINATE METHOD Ver 4-2008

CLIENT:	Example site #1	County		DATE:	
DSN BY:	anyone	CHK by:		DATE:	
COMMENT	Water Surface at 101.8				

UPSTREAM W.S. STATION (ft)	UPSTREAM W.S. ELEV (ft)	DOWNSTREAM W.S. STATION (ft)	DOWNSTREAM W.S. ELEV (ft)	Design Storm Elev. (ft)	COMPUTED SLOPE (%)	SELECTED SLOPE (%)	MANNINGS "n"
0+00	95.69	12+00	90.59	101.8	0.42	0.42	0.04

ROCK STATIONS START (ft)	ROCK STATIONS END (ft)	SLOPING STATIONS START (ft)	SLOPING STATIONS END (ft)	SLOPING LENGTH (ft)	SIDE SLOPE
7+50	9+15	7+50	9+15	165	1.5

ROCK HEIGHT (ft)	ROCK LENGTH (ft)	ROCK TYPE CU=1 SP=2	D50 USED (in)	D50 MIN (in)	OHWM Elev (ft)
4	165	1	12	11.4	94.6

FILTER OPTION TABLE	FILTER OPTION CODE	KEYWAY BOTTOM WIDTH (ft)	DEPTH BELOW SCOUR (ft)	THICKNESS (in) ROCK	THICKNESS (in) FILTER
1 = 2 X D50 & FILTER					
2 = 3 X D50 & NO FILTEF					
3 = 2 X D50 & GEOTEXTII	2			36	
4 = 2 X D50 & FILTER & GEO.		2	2		

Above Keyway Rock Vol/Ft	Keyway Rock Vol/ft	VOLUME/FT (cy/ft) ROCK	VOLUME/FT (cy/ft) FILTER	TOTAL ROCK (cy)	TOTAL FILTER (cy)
0.801234	0.3333333	1.135		187	0

VELOCITY (fps)	Q (cfs)	AREA (sq ft)	p (ft)	r (ft)		Feet
					T =	3.0
					X =	5.4
7.5	5754	767.4	139.6	5.50	Y =	3.6

Design Q or Out of BANK Q (cfs)	Design Q or Out of BANK V (fps)	ENGR JOB Class	GEOTEXT (sq yd)	END DISTS	W.S.EL
				63	101.80
5754	7.5	VI	0	199	101.80

SITE ID:	0+01
CROSS SECTION DISTANCE	CROSS SECTION ELEV
0	102.3
60	102.2
80	99.6
100	98.9
120	94.6
140	94.6
160	93.7
172	91.9
173	91.7
183	91.7
199	101.8
242	101.9

RIPRAP GRADATION

% PASSING (by wt)	ROCK SIZE (in)
100	24
60-85	18
25-50	12
5-20	6
0-5	2

NOTES

1. Use only elevations for cross-sections
2. Accepts up to 24 cross section pairs
3. Seclect any W.S. elevation
4. Use side slopes of 1.5:1 - 4.0:1
5. X-section shown on WI-404A - WI-404A-ET - WI-404A-LT
6. Rock and filter thicknesses can be computed or entered.
7. First and last cross-section points must be high than adjacent points.

Ver 7.97 - DEVELOPED BY J. H. MARTER, WISCONSIN NRCS, 9/93. REVISED 5/97.
Ver 3-2007 Revised bv S. Mueller

D50 required = 5.7 inches
Water surface Elevation = 97.1 (chosen to the match the 10-year, 24-hour storm)

The velocity and capacity of the reach is 5.0 feet/second and 1296 CFS respectively.

STREAMBANK RIPRAP DESIGN USING COORDINATE METHOD Ver 4-2008

CLIENT:	Example site #1	County		DATE:	
DSN BY:	anyone	CHK by:		DATE:	
COMMENT	Water Surface at 97.1				

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UPSTREAM W.S. STATION (ft)	UPSTREAM W.S. ELEV (ft)	DOWNSTREAM W.S. STATION (ft)	DOWNSTREAM W.S. ELEV (ft)	Design Storm Elev. (ft)	COMPUTED SLOPE (%)	SELECTED SLOPE (%)	MANNINGS "n"
0+00	95.69	12+00	90.59	97.1	0.42	0.42	0.04

ROCK STATIONS START (ft)	ROCK STATIONS END (ft)	SLOPING STATIONS START (ft)	SLOPING STATIONS END (ft)	SLOPING LENGTH (ft)	SIDE SLOPE
7+50	9+15	7+50	9+15	165	1.5

ROCK HEIGHT (ft)	ROCK LENGTH (ft)	ROCK TYPE CU=1 SP=2	D50 USED (in)	D50 MIN (in)	OHWM Elev (ft)
4	165	1	6	5.7	94.6

FILTER OPTION TABLE	FILTER OPTION CODE	KEYWAY BOTTOM WIDTH (ft)	DEPTH BELOW SCOUR (ft)	THICKNESS (in) ROCK	THICKNESS (in) FILTER
1 = 2 X D50 & FILTER					
2 = 3 X D50 & NO FILTEF					
3 = 2 X D50 & GEOTEXTII	2			18	
4 = 2 X D50 & FILTER & GEO.		2	2		

Above Keyway Rock Vol/Ft	Keyway Rock Vol/ft	TOTAL VOLUME/FT (cy/ft) ROCK	TOTAL VOLUME/FT (cy/ft) FILTER	TOTAL ROCK (cy)	TOTAL FILTER (cy)
0.400617	0.3333333	0.734		121	0

VELOCITY (fps)	Q (cfs)	AREA (sq ft)	p (ft)	r (ft)		Feet
5.0	1296	257.5	85.2	3.02	T =	1.5
					X =	2.7
					Y =	1.8

Design Q or Out of BANK Q (cfs)	Design Q or Out of BANK V (fps)	ENGR JOB Class	GEOTEXT (sq yd)	END DISTS	W.S.EL
1296	5.0	IV	0	108	97.10
				192	97.10

SITE ID: 0+01

CROSS SECTION DISTANCE	CROSS SECTION ELEV
*********	********
0	102.3
60	102.2
80	99.6
100	98.9
120	94.6
140	94.6
160	93.7
172	91.9
173	91.7
183	91.7
199	101.8
242	101.9

RIPRAP GRADATION
~~~~~~~~~~~~~~~~

% PASSING (by wt)	ROCK SIZE (in)
100	12
60-85	9
25-50	6
5-20	3
0-5	1

NOTES
~~~~~

1. Use only elevations for cross-sections
2. Accepts up to 24 cross section pairs
3. Seclect any W.S. elevation
4. Use side slopes of 1.5:1 - 4.0:1
5. X-section shown on WI-404A - WI-404A-ET - WI-404A-LT
6. Rock and filter thicknesses can be computed or entered.
7. First and last cross-section points must be high than adjacent points.

Ver 7.97 - DEVELOPED BY J. H. MARTER, WISCONSIN NRCS, 9/93. REVISED 5/97.
Ver 3-2007 Revised by S. Mueller
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D50 required = 8.3 inches
Water surface elevation = 99.2 (chosen to the match the 100-year, 24-hour storm)

The velocity and capacity of the reach is 6.3 feet/second and 2805 CFS respectively.

STREAMBANK RIPRAP DESIGN USING COORDINATE METHOD Ver 4-2008

CLIENT:	Example site #1	County		DATE:	
DSN BY:	anyone	CHK by:		DATE:	
COMMENT	Water Surface at 99.2				

UPSTREAM W.S. STATION (ft)	UPSTREAM W.S. ELEV (ft)	DOWNSTREAM W.S. STATION (ft)	DOWNSTREAM W.S. ELEV (ft)	Design Storm Elev. (ft)	COMPUTED SLOPE (%)	SELECTED SLOPE (%)	MANNINGS "n"
0+00	95.69	12+00	90.59	99.2	0.42	0.42	0.04

ROCK STATIONS START (ft)	ROCK STATIONS END (ft)	SLOPING STATIONS START (ft)	SLOPING STATIONS END (ft)	SLOPING LENGTH (ft)	SIDE SLOPE
7+50	9+15	7+50	9+15	165	1.5

ROCK HEIGHT (ft)	ROCK LENGTH (ft)	ROCK TYPE CU=1 SP=2	D50 USED (in)	D50 MIN (in)	OHWM Elev (ft)
4	165	1	10	8.3	94.6

FILTER OPTION TABLE
1 = 2 X D50 & FILTER
2 = 3 X D50 & NO FILTER
3 = 2 X D50 & GEOTEXTILE
4 = 2 X D50 & FILTER & GEO.

FILTER OPTION CODE	KEYWAY BOTTOM WIDTH (ft)	DEPTH BELOW SCOUR (ft)	THICKNESS (in) ROCK	THICKNESS (in) FILTER
2	2	2	30	

Above Keyway Rock Vol/Ft	Keyway Rock Vol/ft	TOTAL VOLUME/FT (cy/ft) ROCK	TOTAL VOLUME/FT (cy/ft) FILTER	TOTAL ROCK (cy)	TOTAL FILTER (cy)
0.667695	0.3333333	1.001		165	0

VELOCITY (fps)	Q (cfs)	AREA (sq ft)	p (ft)	r (ft)
6.3	2805	447.0	106.3	4.21

	Feet
T =	2.5
X =	4.5
Y =	3.0

Design Q or Out of BANK Q (cfs)	Design Q or Out of BANK V (fps)	ENGR JOB Class
2805	6.3	V

GEOTEXT (sq yd)	END DISTS	W.S.EL
	91	99.20
0	195	99.20

SITE ID: 0+01

CROSS SECTION DISTANCE	CROSS SECTION ELEV
0	102.3
60	102.2
80	99.6
100	98.9
120	94.6
140	94.6
160	93.7
172	91.9
173	91.7
183	91.7
199	101.8
242	101.9

RIPRAP GRADATION

% PASSING (by wt)	ROCK SIZE (in)
100	20
60-85	15
25-50	10
5-20	5
0-5	2

NOTES

1. Use only elevations for cross-sections
2. Accepts up to 24 cross section pairs
3. Seclect any W.S. elevation
4. Use side slopes of 1.5:1 - 4.0:1
5. X-section shown on WI-404A - WI-404A-ET - WI-404A-LT
6. Rock and filter thicknesses can be computed or entered.
7. First and last cross-section points must be high than adjacent points.

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Ver 3-2007 Revised by S. Mueller

USGS's Flood Frequency Characteristics of Wisconsin Streams was used to find the 100-year, 24-hour runoff rate of 2762 CFS, a rate which is exceeded with a reach water surface of 99.2. The 100-year storm is contained within the surveyed cross section.

FLOOD FREQUENCY CHARACTERISTICS OF WISCONSIN STREAMS (ver 1-2005)

USGS Water Resources Investigations Report 03-4250

Wisconsin Flood Frequency Area1 Note 1.

Clear Data Entry Cells

Project: Example Site 1
County: SW WI
By: Date:
Checked By: Date:

Watershed Area (square miles)	8.646
Main-channel length (miles)	4.046
Enter Elevation 0.4046 miles upstream from point of interest	948
Enter Elevation 3.4391 miles upstream from point of interest	1120
Enter Forest Cover (% of Basin Area)	10
Enter 25-yr, 24-hr Precipitation (in.) Note 5.	5.29

Area	A	8.646	sq miles
Forest	FOR Note 2.	11	%+1
Slope	S	56.7	feet/mile
Intens	I_{25} Note 4.	1.1	inches

Peak Flood Discharge with n-year recurrence interval Note 3.

Q_2	424	cfs
Q_5	828	cfs
Q_{10}	1268	cfs
Q_{25}	1808	cfs
Q_{50}	2256	cfs
Q_{100}	2762	cfs

Note 1. For is indicated by Figure 3 of above report
Note 2. FOR is Forest Cover in basin area consisting of woodland cover +1, in percent of total basin area.
Note 3. Flood frequency equations from Table 2, equations 1-1 to 1-6 of above report.
Note 4 INTENS is 25-year, 24 hour precipitation minus 4.2 as defined in Table 1 of above report.
Note 5. As indicated by Figure 1. of above report

The required riprap size varied from 11.4 to 5.7 inches with the various discharges. The current streambank protection standard allows the designer to use less than the out-of-bank flow rate if the minimum design flow rate is achieved at a lower stage. This reach is an example of that concept. The out-of-bank flow exceeds the 100-year storm event.

The designer chose to extend riprap from the thalweg elevation to an elevation 1.1 feet above the low bank elevation (Elev. 95.7). The spreadsheet plots the reach's cross section, the design water surface and the riprap cross section, based on the entered toe dimensions. The riprap cross section can be placed on the reach cross section by entering and adjusting the location of the upper back face of the section.

Print Area

Clear Data Input Cells

Starting point riprap.
Use these input cells to change the starting point of the riprap on the plot.

Left Bank

PLOT INPUTS plot with toe Coordinates	
x	y
6.0	-4.0
9.0	-6.0
11.0	-6.0
13.0	-4.0
10.5	-4.0
4.5	0.0
0.0	0.0

PLOT INPUTS plot w/OUT toe Coordinates	
x	y
0.0	0.0
6.0	-4.0
10.5	-4.0
4.5	0.0
0.0	0.0

Right Bank

PLOT INPUTS plot with toe Coordinates	
x	y
190.0	95.7
184.0	91.7
181.0	89.7
179.0	89.7
177.0	91.7
179.5	91.7
185.5	95.7
190.0	95.7

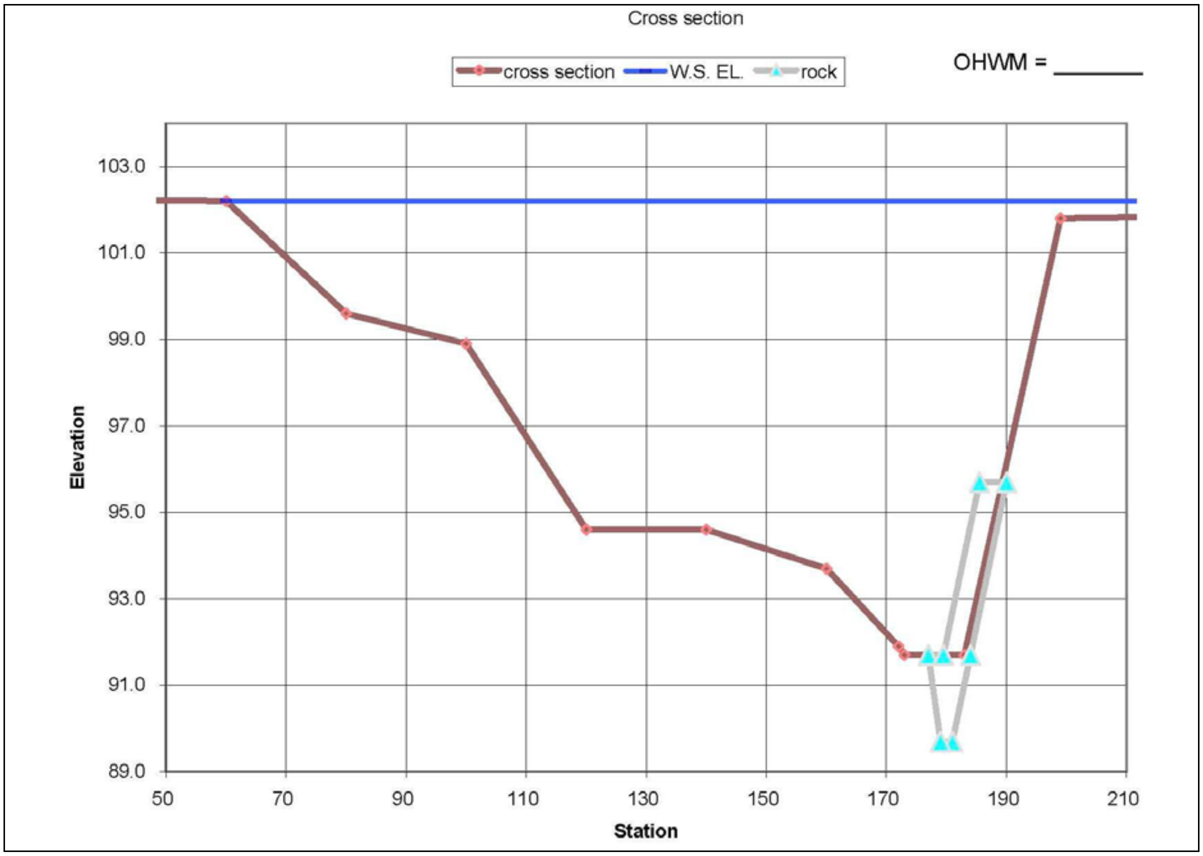
PLOT INPUTS plot w/OUT toe Coordinates	
x	y
190.0	95.7
184.0	91.7
179.5	91.7
185.5	95.7
190.0	95.7

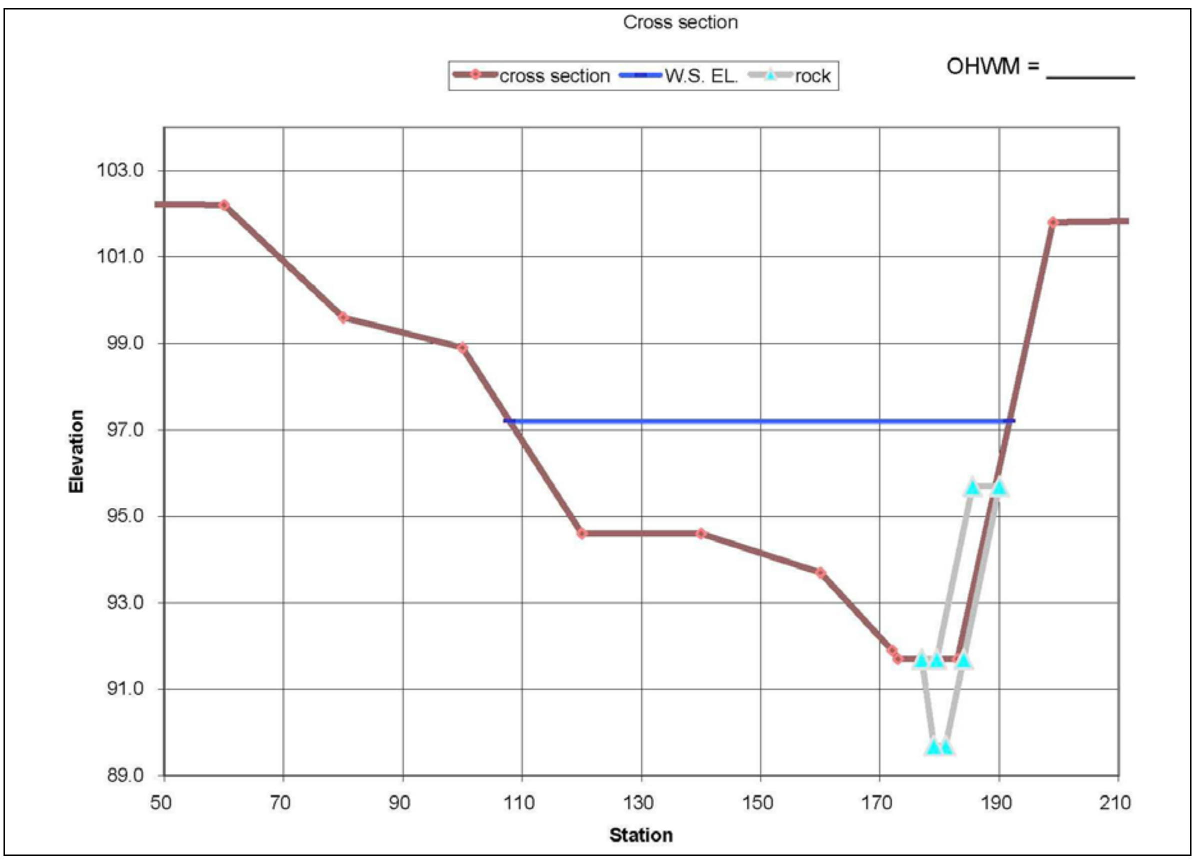
Rock Riprap for est. quantities page	
Above Keyway	Keyway
Cu Yds/ft	Cu Yds/ft
0.67	0.33333
Cu Yds	Cu Yds
110.17	55

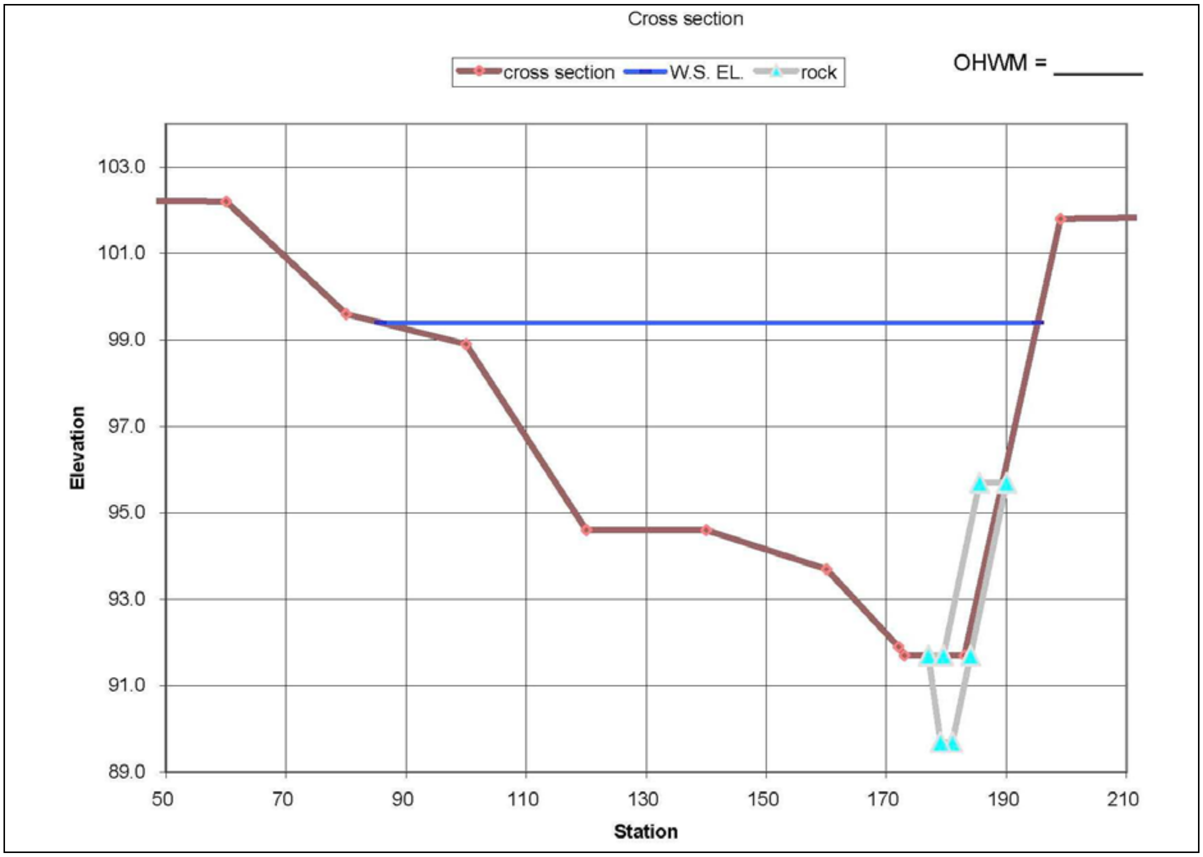
Start	End
2x thickness Vol - 5 Ft	
3.33847	3.33847

Keyway Bottom Width	
Poss.	Range RR Thickness
2	<30in
4	>30<42 in
6	>42 in

The following plotted cross sections were plotted from the previous example site 1 data with different design water surfaces. They give the designer a chance to preview the cross sections before they are manually plotted or drawn with ACAD.

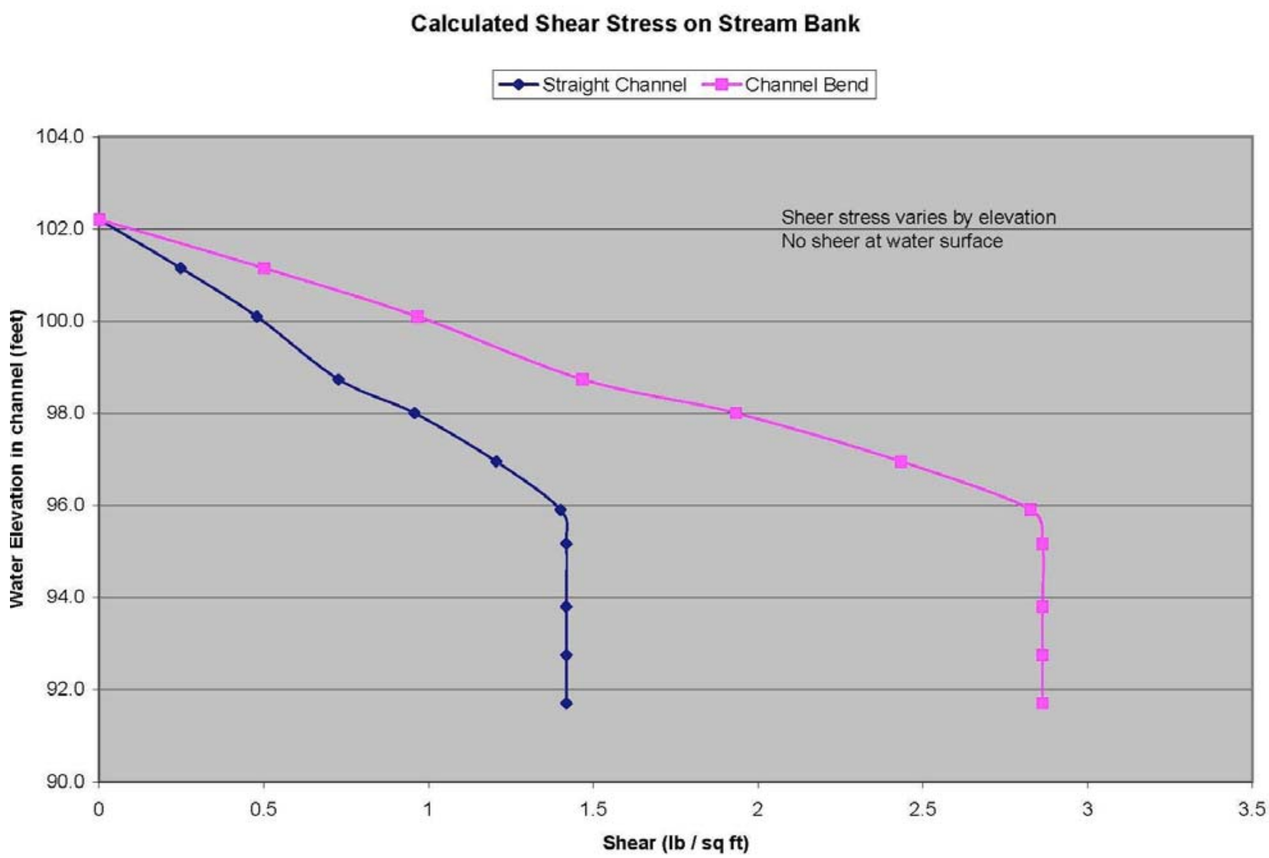

Cross section
cross section
W.S. EL.
rock
OHWM = ________
103.0
101.0
99.0
97.0
95.0
93.0
91.0
89.0
Elevation
50
70
90
110
130
150
170
190
210
Station

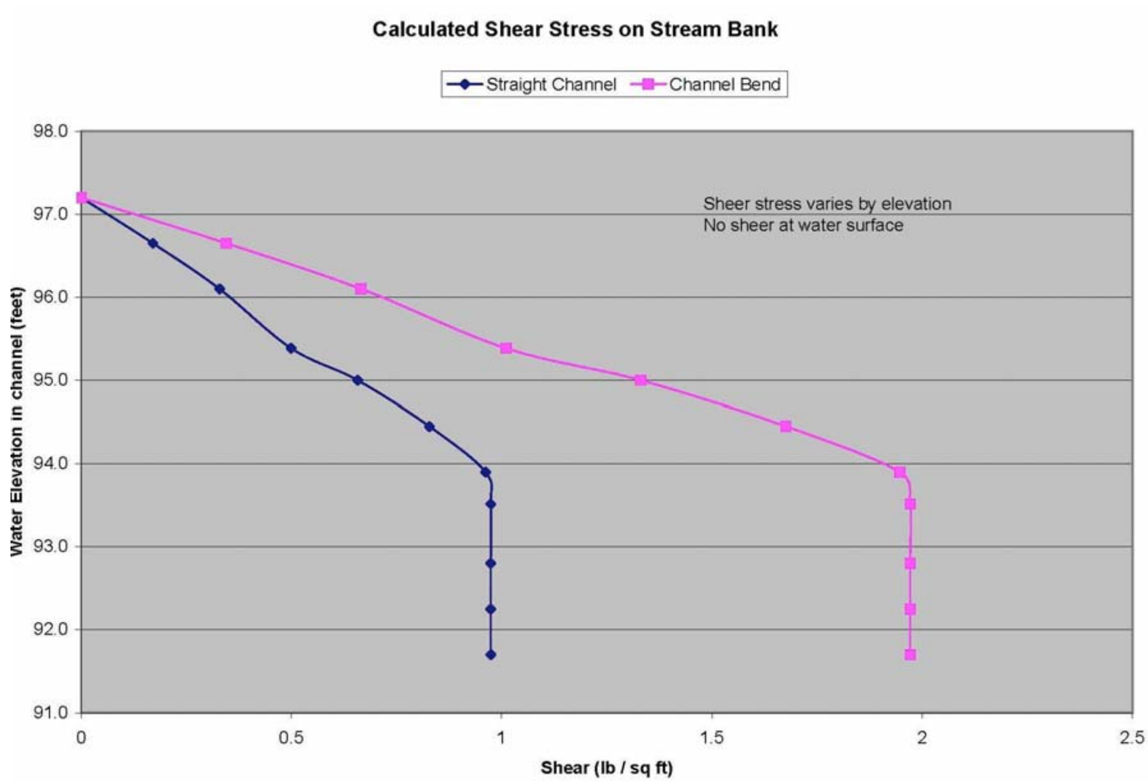

Cross section
cross section
W.S. EL.
rock
OHWM = ________
103.0
101.0
99.0
97.0
95.0
93.0
91.0
89.0
Elevation
50
70
90
110
130
150
170
190
210
Station

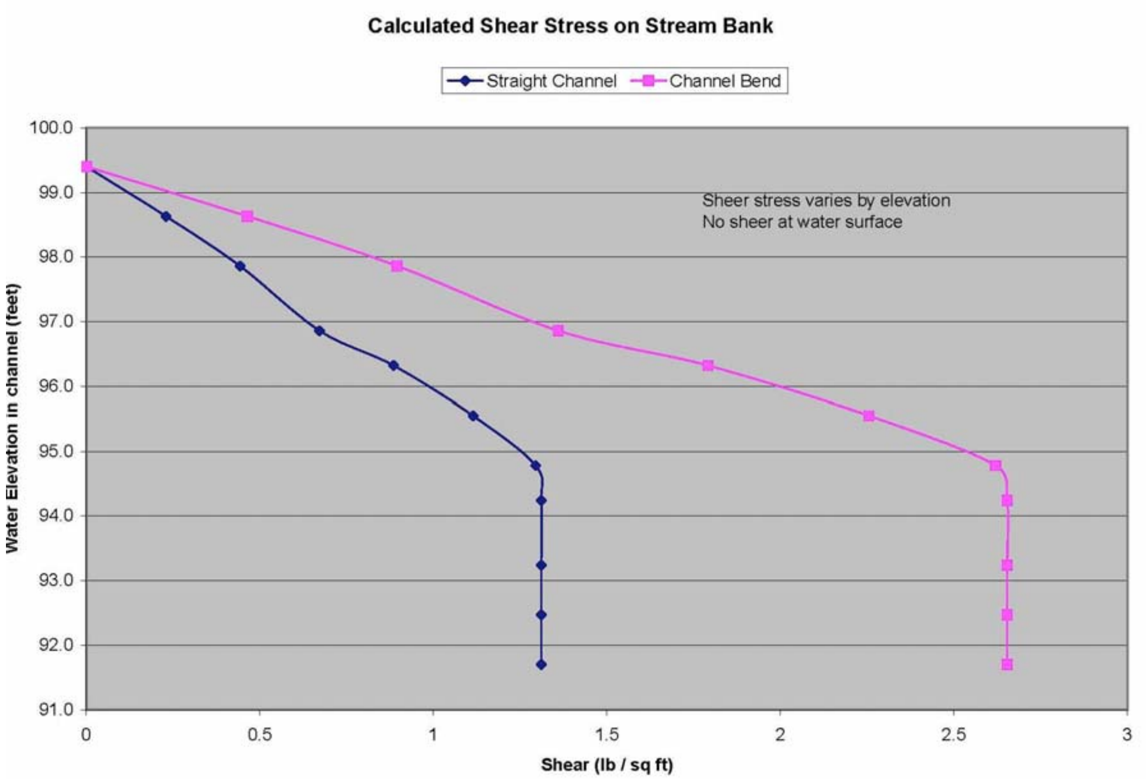


The streambank protection spreadsheet also calculates and plots the shear stress in the design reach cross section. The plots below show the distributed shear on the channel bank for the previous example site 1 data with different design water surfaces. Higher water surfaces create greater stresses on the bank. It is important to pick the minimum design flow or greater and the matching water suface elevation.

Companion Document 580-10 contains techniques that can be used to protect the eroding bank based on the distributed shear plot. A structural toe must be used with vegetative and bioengineering measures. Using the third plot, with a design water surface of 99.2, riprap (D50 = 10 inches) could be used from the toe to elevation 95.7 with live willow stakes above that elevation (allowable shear = 2.1-3.1). Any technique with an allowable shear above 2.1 could be used on the upper bank.


Calculated Shear Stress on Stream Bank
Straight Channel
Channel Bend
Sheer stress varies by elevation
No sheer at water surface
Water Elevation in channel (feet)
104.0
102.0
100.0
98.0
96.0
94.0
92.0
90.0
0
0.5
1
1.5
2
2.5
3
3.5
Shear (lb / sq ft)


Calculated Shear Stress on Stream Bank
Straight Channel
Channel Bend
Sheer stress varies by elevation
No sheer at water surface
Water Elevation in channel (feet)
98.0
97.0
96.0
95.0
94.0
93.0
92.0
91.0
0
0.5
1
1.5
2
2.5
Shear (lb / sq ft)


Calculated Shear Stress on Stream Bank
Straight Channel
Channel Bend
Sheer stress varies by elevation
No sheer at water surface
Water Elevation in channel (feet)
Shear (lb / sq ft)
100.0
99.0
98.0
97.0
96.0
95.0
94.0
93.0
92.0
91.0
0
0.5
1
1.5
2
2.5
3

DESIGN EXAMPLE – NON-ENTRENCHED CHANNEL

The following data was entered in to Wisconsin's Streambank Protection Spreadsheet to illustrate the capability of the design tool.

D50 required = 6.4 inches
Water surface Elevation = 47.3. Out-of-bank Elevation = 48.6

STREAMBANK RIPRAP DESIGN USING COORDINATE METHOD

Ver 4-2008

CLIENT:	Example site #2	County		DATE:	
DSN BY:	anyone	CHK by:		DATE:	
COMMENT	Water Surface at 47.3				

UPSTREAM W.S. STATION (ft)	UPSTREAM W.S. ELEV (ft)	DOWNSTREAM W.S. STATION (ft)	DOWNSTREAM W.S. ELEV (ft)	Design Storm Elev. (ft)	COMPUTED SLOPE (%)	SELECTED SLOPE (%)	MANNINGS "n"
0+00	8.4	14+39	0	47.3	0.58	0.58	0.036

ROCK STATIONS START (ft)	ROCK STATIONS END (ft)	SLOPING STATIONS START (ft)	SLOPING STATIONS END (ft)	SLOPING LENGTH (ft)	SIDE SLOPE
0+00	2+00	0+00	2+00	200	2

ROCK HEIGHT (ft)	ROCK LENGTH (ft)	ROCK TYPE CU=1 SP=2	D50 USED (in)	D50 MIN (in)	OHWM Elev (ft)
5.5	200	2	8	6.4	44.6

FILTER OPTION TABLE	FILTER OPTION CODE	KEYWAY BOTTOM WIDTH (ft)	DEPTH BELOW SCOUR (ft)	THICKNESS (in) ROCK	THICKNESS (in) FILTER
1 = 2 X D50 & FILTER					
2 = 3 X D50 & NO FILTER					
3 = 2 X D50 & GEOTEXTILE	3			16	
4 = 2 X D50 & FILTER & GEO.		2	2		

Above Keyway Rock Vol/Ft	Keyway Rock Vol/ft	VOLUME/FT (cy/ft) ROCK	VOLUME/FT (cy/ft) FILTER	TOTAL ROCK (cy)	TOTAL FILTER (cy)
0.607327	0.3703704	0.978		196	0

VELOCITY (fps)	Q (cfs)	AREA (sq ft)	p (ft)	r (ft)		Feet
5.3	446	83.9	38.1	2.20	T =	1.3
					X =	3.0
					Y =	1.5

Design Q or Out of BANK Q (cfs)	Design Q or Out of BANK V (fps)	ENGR JOB Class	GEOTEXT (sq yd)	END DISTS	W.S.EL
446	5.3	III	439	24	47.30
				61	47.30

SITE ID:	0+01
CROSS SECTION DISTANCE	CROSS SECTION ELEV
*********	********
-40	48.6
0	47.8
22.6	47.6
38.5	44.6
45.6	43.9
53.5	43.5
93.7	63.5

RIPRAP GRADATION

% PASSING (by wt)	ROCK SIZE (in)
100	16
60-85	12
25-50	8
5-20	4
0-5	2

NOTES

1. Use only elevations for cross-sections
2. Accepts up to 24 cross section pairs
3. Seclect any W.S. elevation
4. Use side slopes of 1.5:1 - 4.0:1
5. X-section shown on WI-404A - WI-404A-ET - WI-404A-LT
6. Rock and filter thicknesses can be computed or entered.
7. First and last cross-section points must be high than adjacent points.

Ver 7.97 - DEVELOPED BY J. H. MARTER, WISCONSIN NRCS, 9/93. REVISED 5/97.
Ver 3-2007 Revised by S. Mueller

USGS's Flood Frequency Characteristics of Wisconsin Streams was used to find the 10-year, 24-hour runoff rate of 434 CFS, a rate which is exceeded with a reach water surface of 47.3.

FLOOD FREQUENCY CHARACTERISTICS OF WISCONSIN STREAMS (ver 3-2007)

USGS Water Resources Investigations Report 03-4250

Wisconsin Flood Frequency Area 2[Note 1.]

Clear Data Entry Cells

Project: Example Site #2 NW area
County: NW WI
By: Date:
Checked By: Date:

Watershed Area (square miles)	6.64
Main-channel length (miles)	5.8
Enter Elevation 0.58 miles upstream from point of interest	850
Enter Elevation 4.93 miles upstream from point of interest	1000
Enter Soil Permeability, (inches/hr) [Note 2.]	1.65

Area	A	6.64	sq miles
Soil Perm	SP	1.65	in/hr
Slope	S	34.5	feet/mile

Peak Flood Discharge with n-year recurrence interval [Note 3.]

Q_2	195	cfs
Q_5	336	cfs
Q_{10}	434	cfs
Q_{25}	572	cfs
Q_{50}	676	cfs
Q_{100}	780	cfs

Slope valid between 3.6 - 96 FT/MI

Note 1. For is indicated by Figure 3 of above report
Note 2. Soil permeability from Plate 2 of above report
Note 3. Flood frequency equations from Table 2, equations 2-1 to 2-6 of above report.

The designer chose to extend riprap from the thalweg elevation to an elevation 0.4 feet above the low bank elevation. (Elev. 48.6) The spreadsheet plots the reach's cross section, the design water surface and the riprap cross section, based on the entered toe dimensions. The riprap cross section can be placed on the reach cross section by entering and adjusting the location of the upper back face of the section.

Print Area

Clear Data Input Cells

Starting point riprap.
Use these input cells to change the starting point of the riprap on the plot.

Left Bank

PLOT INPUTS plot with toe Coordinates	
x	y
11.0	-5.5
15.0	-7.5
17.0	-7.5
19.0	-5.5
14.0	-5.5
3.0	0.0
0.0	0.0

PLOT INPUTS plot w/OUT toe Coordinates	
x	y
0.0	0.0
11.0	-5.5
14.0	-5.5
3.0	0.0
0.0	0.0

Right Bank

PLOT INPUTS plot with toe Coordinates	
x	y
64.0	49.0
53.0	43.5
49.0	41.5
47.0	41.5
45.0	43.5
50.0	43.5
61.0	49.0
64.0	49.0

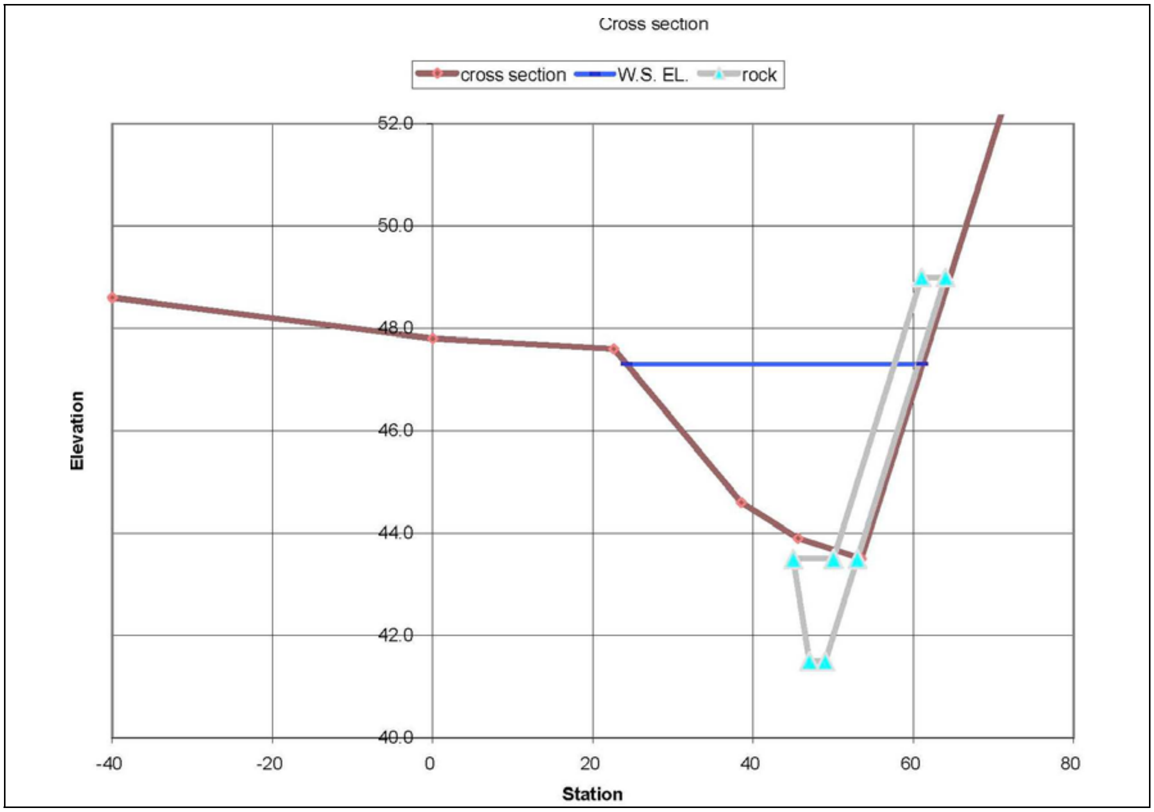
PLOT INPUTS plot w/OUT toe Coordinates	
x	y
64.0	49.0
53.0	43.5
50.0	43.5
61.0	49.0
64.0	49.0

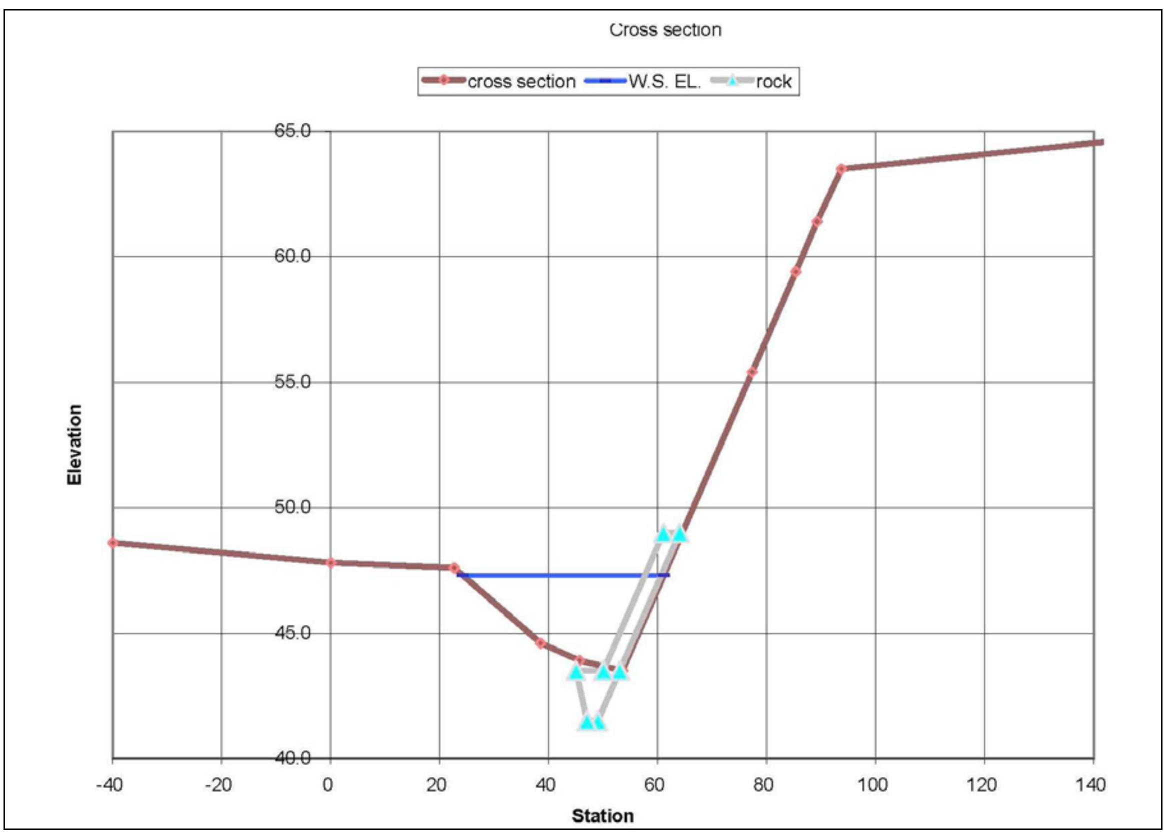
Rock Riprap for est. quantities page	
Above Keyway	Keyway
Cu Yds/ft	Cu Yds/ft
0.61	0.37037
Cu Yds	Cu Yds
121.465	74.0741

Start	End
2x thickness Vol - 5 Ft	
3.03664	3.03664

Keyway Bottom Width	
Poss.	Range RR Thickness
2	<30in
4	>30<42 in
6	>42 in

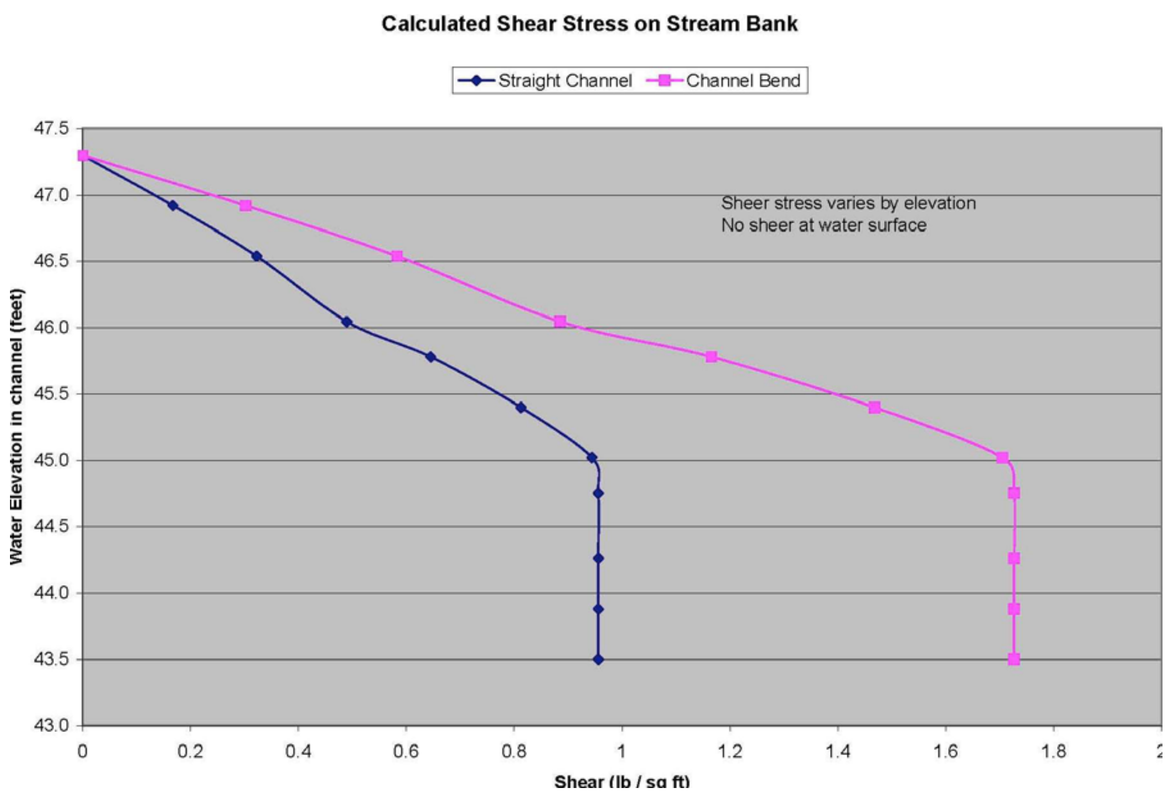
The following plotted cross sections were plotted from the previous example site 2 data. They give the designer a chance to preview the cross sections before they are manually plotted or drawn with ACAD. The second cross section had additional data entered to create the taller bank.


Cross section
cross section
W.S. EL.
rock
52.0
50.0
48.0
46.0
44.0
42.0
40.0
Elevation
-40
-20
0
20
40
60
80
Station


Cross section
cross section
W.S. EL.
rock
65.0
60.0
55.0
50.0
45.0
40.0
Elevation
-40
-20
0
20
40
60
80
100
120
140
Station

The streambank protection spreadsheet also calculates and plots the shear stress in the design reach cross section. The plot below shows the distributed shear on the channel bank for the previous example site 2 data.

Companion Document 580-10 contains techniques that can be used to protect the eroding bank based on the distributed shear plot. A structural toe must be used with vegetative and bioengineering measures. Using the plot, with a design water surface of 47.3, riprap (D50 = 8 inches) could be used from the toe to elevation 49.0 with seeding above that elevation. No shear exists above elevation 47.3 in a 10-year, 24-hour storm, so the seeding on the bank would be for erosion control.



ROCK RIPRAP TESTING AND GRADATION

Wisconsin Construction Specification 9, Rock Riprap, requires most rock to be tested for soundness using a modified ASTM-C-88 procedure. Sodium sulfate tests from rock riprap sources with loss less than 20 percent are considered passing. The design D_{50} size can be increased for sources exceeding 20 percent loss.

Rock with sodium sulfate test losses over 28 percent shall not be used.

The rock gradation for streambank revetments shall be determined using the following criteria.

Table 3

Percent Passing by Weight	Size in Inches (round to the nearest inch)
100	2 x D_{50}
60-85	1.5 x D_{50}
25-50	D_{50}
5-20	0.5 x D_{50}
0-5	0.2 x D_{50}

LEACHING PROTECTION OF BASE SOILS PROTECTED WITH ROCK RIPRAP

For bank soils with no significant seepage pressures, leaching of the bank base material through the riprap must be prevented. Leaching can be controlled by one of the following methods.

1. The thickness of the riprap is increased to 3 times the D_{50} stone size. $T_{riprap} = 3*D_{50}$
2. The riprap gradation is small enough (bedding) such that the rock material meets the leaching protection requirements for the bank base material. $T_{riprap} = 2*D_{50}$
3. A protective layer of intermediate sized material (bedding) meeting the leaching protection criteria is placed between the riprap and base material. $T_{riprap} = 2*D_{50}$
4. A geotextile is placed between the riprap and base material. It must meet the criteria for Class I or II woven or non-woven geotextiles contained in Wisconsin Construction Specification 13, Geotextiles and the guide for the use of Wisconsin Construction Specification 13, Geotextiles, in Chapter 17, Engineering Field Handbook.

<u>Leaching Protection Requirements (Bedding) Gradation Design</u>

The gradation of the underlying material must meet the following criteria for rock riprap.

$$D_{15}(B) > \frac{D_{15}(\text{riprap})\,\text{max.}}{40} > 0.42\,\text{mm (No. 40 sieve)}$$

$$D_{15}(B) < \frac{D_{15}(\text{riprap})\,\text{min.}}{5}$$

$$D_{85}(B) > \frac{D_{15}(\text{riprap})\,\text{max.}}{5}$$

$$D_{50}(B) > \frac{D_{50}(\text{riprap})\,\text{max.}}{40}$$

The D_{15}, D_{50}, or D_{85} (B) is the size of the soil base or bedding material of which the designated percentage is smaller by weight.

Note that the maximum and minimum values refer to the ranges shown in the gradation limits for the riprap.

When comparing the plotted gradation curves of the riprap and bedding, the bedding gradation curve should be approximately parallel to the rock riprap curve or have a flatter slope.

FILTER MATERIAL DESIGN

A filter is required when seepage pressures in the sides or bottom of a channel could cause detachment of soil particles and move them out through protective layers.

A sand-gravel filter will be designed using criteria contained in National Engineering Handbook (NEH), Part 633, Chapter 26, Gradation Design of Sand and Gravel Filters.

<u>Geotextile Filter Design</u>

Refer to the guide for the use of Wisconsin Construction Specification 13, Geotextiles, in Chapter 17, Engineering Field Handbook.

ROCK RIPRAP SECTION DIMENSIONS

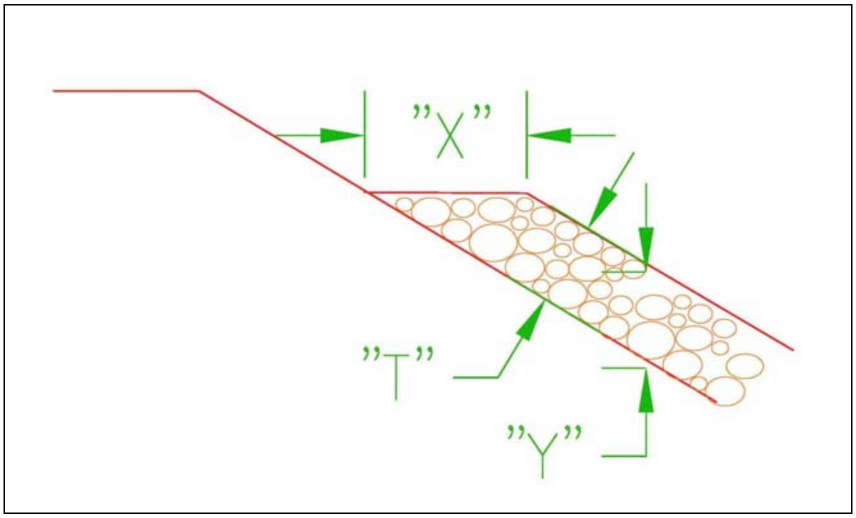


Figure WI-16-5

Table 4

Rock Thickness "T" inches	1.5:1 side slope		2.0:1 side slope		3.0:1 side slope	
	"X" (ft)	"Y" (ft)	"X" (ft)	"Y" (ft)	"X" (ft)	"Y" (ft)
12	1.8	1.2	2.2	1.1	3.2	1.0
15	2.3	1.5	2.8	1.4	4.0	1.3
18	2.7	1.8	3.4	1.7	4.7	1.6
24	3.6	2.4	4.5	2.2	6.3	2.1
27	4.1	2.7	5.0	2.5	7.1	2.4
30	4.5	3.0	5.6	2.8	7.9	2.6
36	5.4	3.6	6.7	3.4	9.5	3.2
42	6.3	4.2	7.8	3.9	11.1	3.7
48	7.2	4.8	9.0	4.5	12.7	4.2
54	8.1	5.4	10.1	5.0	14.2	4.7
60	9.0	6.0	11.2	5.6	15.8	5.3
72	10.8	7.2	13.4	6.7	19	6.3

Rock Thickness

The minimum riprap thickness shall be 12 inches, as thick as the maximum stone diameter, or the thickness required to meet leaching control criteria, whichever is greater.

VOLUME COMPUTATIONS

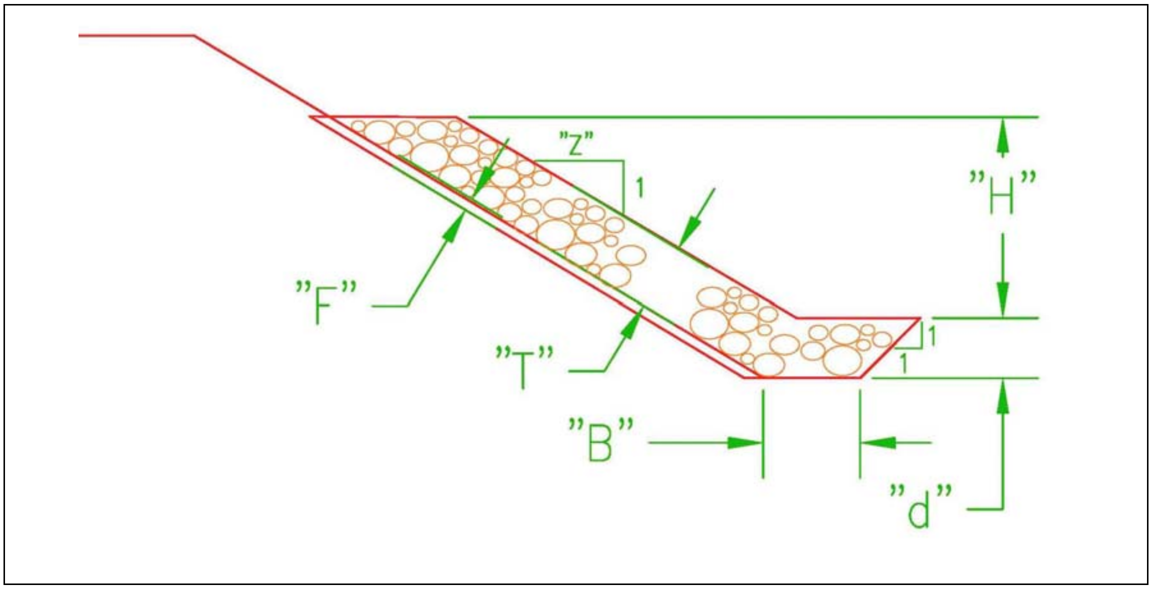


Figure WI-16-6

<u>Formulas</u>
H = Constructed height above keyway (ft)
T = Thickness of rock (ft)
F = Thickness of filter (ft)
B = Bottom width of keyway (ft)
d = Depth of keyway (ft)
Z = Constructed side slope (Z:1)
V = Volume per liner foot of protection (yd^3/ft)

Rock Volume above Keyway

$$V = \frac{\sqrt{Z^2 + 1} * H * T}{27}$$

Rock Volume in Keyway

$$V = \frac{d * B + \frac{Z * d^2}{2} + \frac{d^2}{2}}{27}$$

Filter Volume

$$V = \frac{\sqrt{Z^2 + 1} * (H + d) * F}{27}$$

<u>Thickness of Filter of Bedding Layer</u>

A sand-gravel filter or bedding shall be at least 1/3 the thickness of the rock riprap but not less than 6 inches nor greater than 12 inches.

TOE PROTECTION

The undermining of toe protection is one of the primary mechanisms of streambank failure. In the design of bank protection, estimates of the anticipated bottom scour are needed so that the protective measure is placed sufficiently low in the streambed to prevent undermining.

Grade control of the stream reach may be needed. Grade control of the channel depends on many factors, such as hydraulic conditions, sediment size and loading, channel morphology, flood plain and valley characteristics, and ecological objectives. These factors must all be evaluated before grade control of a stream is planned.

Three toe configurations are presented below. The 580 standard requires the toe to be placed at least to the minimum depth of anticipated bottom scour.

The anticipated bottom scour must consider channel degradation as well as natural scour and fill processes. Channel degradation is a morphologic change in a river system.

Excavated Keyway

The toe of the riprap may be designed as illustrated in Figure WI-16-7. The toe material should be placed in a keyway along the entire length of the riprap blanket.

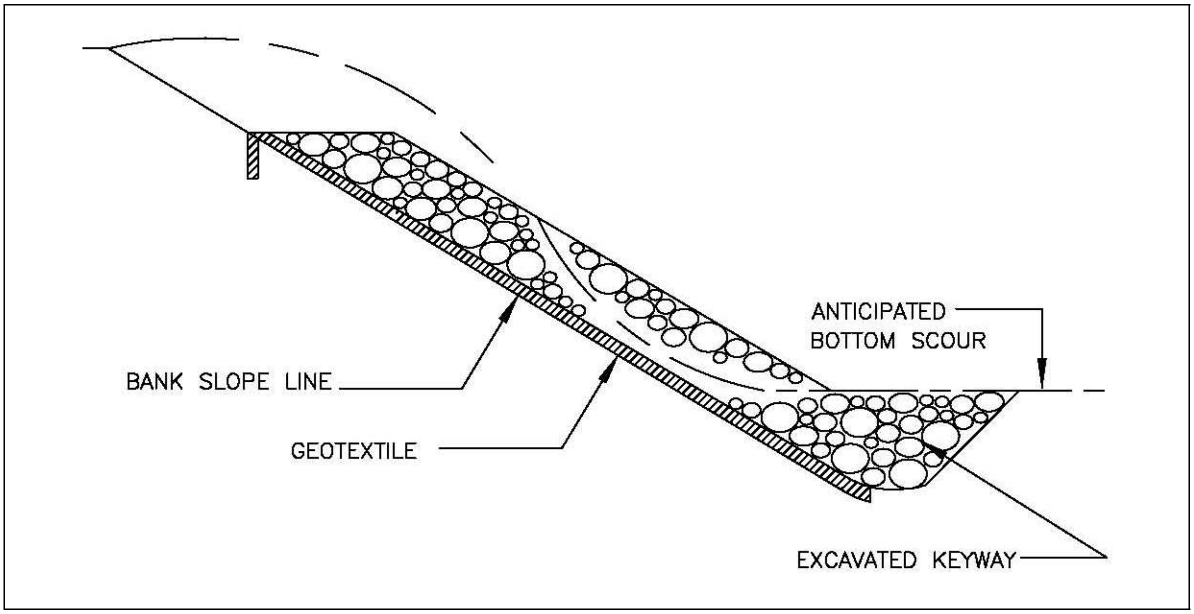


Figure WI-16-7

Launchable Toe

If the keyway is anticipated to be undermined, a launchable toe can be designed. The size of the launchable toe is controlled by the anticipated depth of scour along the revetment. As scour occurs, the stone in the toe will launch into the eroded area as illustrated in Figures WI-16-8a and 8b.

The volume of rock required for the toe must be equal to or exceed one and one-half times the volume of rock required to extend the riprap blanket (at its design thickness and on a slope of 1V:2H) to the anticipated bottom scour.

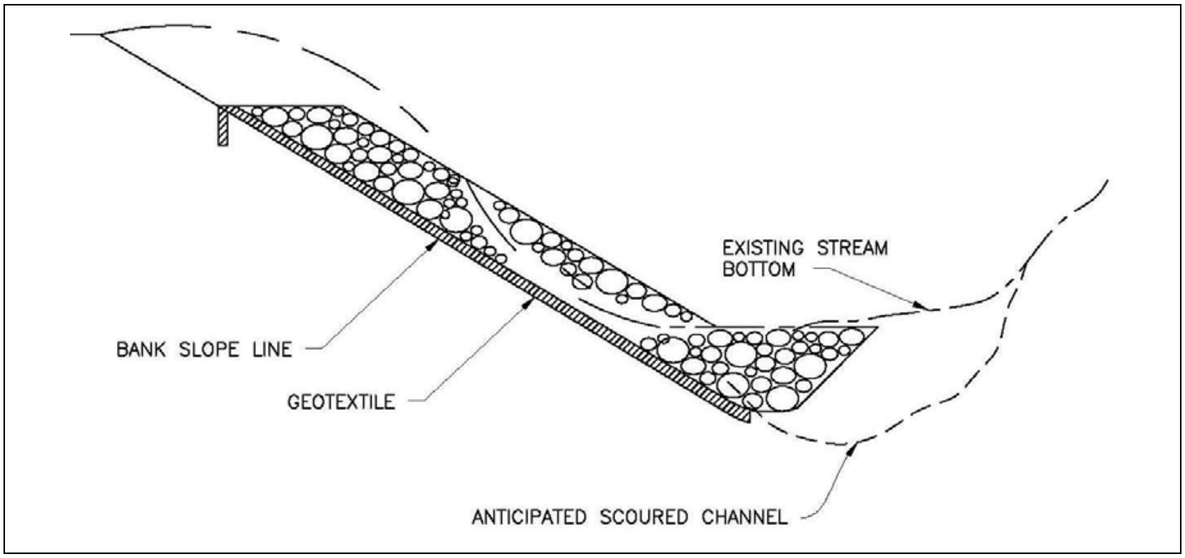


Figure WI-16-8a (as-built)

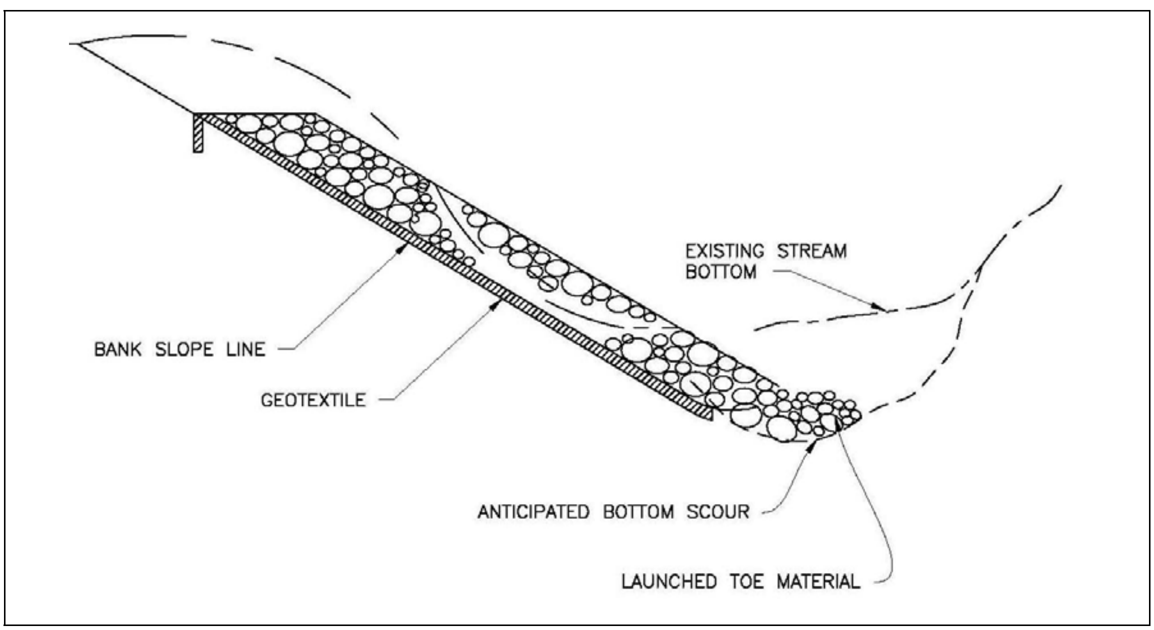


Figure WI-16-8b (after launching)

Excavated Toe

Where a keyway is not excavated, the riprap blanket should terminate at the anticipated bottom scour (Figure WI-16-9).

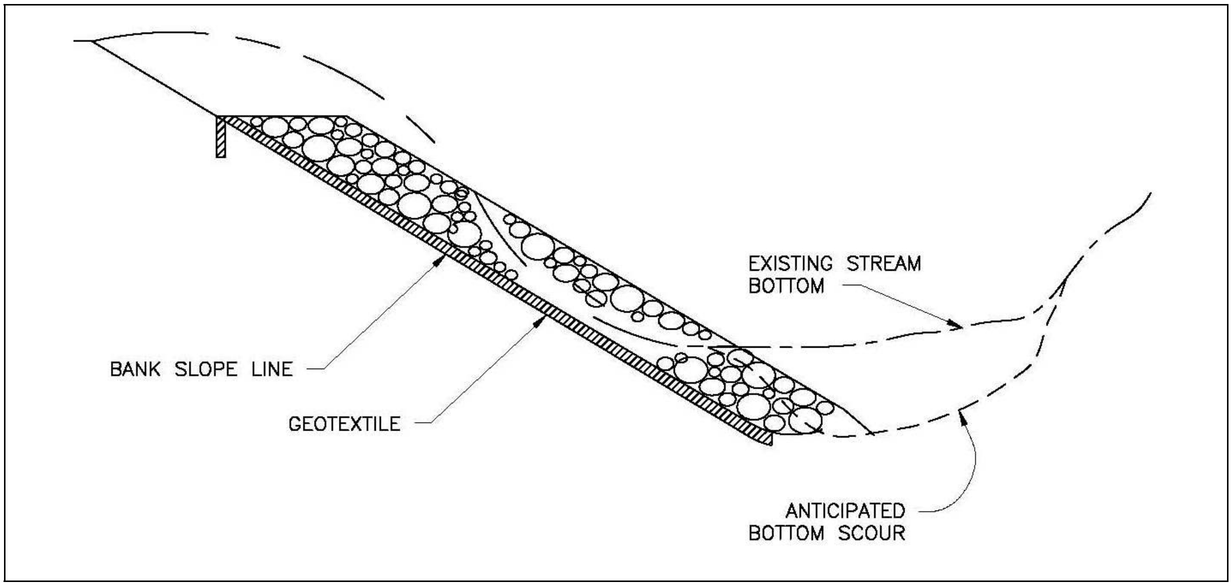


Figure WI-16-9

Care must be taken during the placement of the all toe configurations to ensure that the material does not mound and form a low dike; a low dike along the toe could result in flow concentration along the revetment face which could stress the revetment to failure. In addition, care must be exercised to ensure that the channel's design capability is not impaired by placement of too much riprap in a toe mound.

LENGTH OF GEOTEXTILE NEEDED (FEET) EXCLUDING OVERLAP

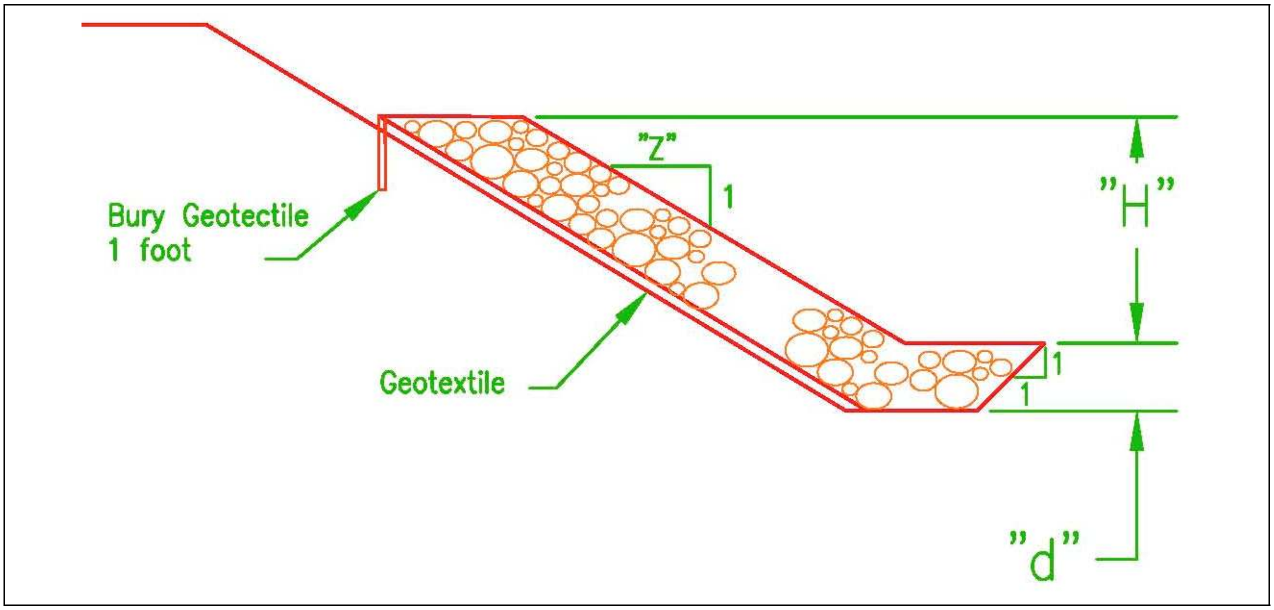


Figure WI-16-10

Table 5

"H"	"Z"		
	1.5:1	**2.0:1**	**3.0:1**
2.0	4.6	5.5	7.2
3.0	6.4	7.7	10.4
4.0	8.2	9.9	13.6
5.0	10.0	12.2	16.8
6.0	11.8	14.4	20.0
7.0	13.6	16.7	23.1
8.0	15.4	18.9	26.3
9.0	17.2	21.1	29.5
10.0	19.0	23.4	32.6
For Additional "d" = 0.5 feet	0.9	1.1	1.6

Length includes 1 foot buried in anchor trench.

Values were computed by $L = 1 + \sqrt{(H+d)^2 + [(H+d)*Z]^2}$ with d assumed to be 0.0 feet. The length needed to be increased for "d" below the top of the toe.

Increase the length by 1.5 feet for each roll side overlap needed to cover the slope length.

REVETMENTS BLOCKS

Revetment blocks are manufactured blocks of various shapes and sizes. These generally are made with concrete, but other materials have been used. Interlocking or a tight butt fit provides resistance to displacement.

Design

Refer to the manufacture's design procedures for these systems. Maximum allowable velocities will vary by manufacturer because of different abilities of the block systems to resist detachment or displacement from flood events. Independent studies are the best source for allowable velocity data.

GABION AND MATTRESS REVETMENTS

Gabion and mattress revetments are systems of wire baskets laced together and filled with rock of a predetermined size(s). Basket thickness, length, and width are of various dimensions. Baskets one foot or less in thickness are often called a mattress.

Combinations of baskets and mattresses can provide needed stability. Main uses of these linings are:

- control of bank seepage,
- improved stability of banks,
- protection from erosion, and
- meeting a predetermined value of Manning's "n".

In narrow confined sites, gabions can be stacked with a nearly vertical face or wall.

Design

Primary design parameters that must be evaluated are:

- foundation,
- seepage and drainage needed behind them,
- velocity,
- stability of the stream bed (degrading), and
- hydraulic capacity.

Refer to the manufacturer's design procedures for these systems. Maximum allowable velocities will vary by basket thickness and manufacturer.

CELLULAR CONFINEMENT SYSTEMS

A cellular confinement system is generally a heavy-duty polyethylene that is delivered in a collapsed position. When pulled into the expanded shape, they are panels 4 or 8 inches thick, 8 feet wide, and 20 feet long. When expanded, there is a honeycomb appearance to the cell pattern. The cells are filled to give erosion control. They can be placed on the streambed and banks. Refer to the manufacturer's design recommendations for details of design and construction.

There are five infill materials that could be used for streambank protection.

- Topsoil and vegetation on upper portion of side slopes.
- Sand and pit-run only for low flows. Use surface sealer recommended.
- Gravel, maximum 3-inch size, for low to moderate velocities.
- Crushed stone, maximum 3-inch size, for low to moderate velocities.
- Concrete or soil cement for moderate to very high velocities.

Design

Primary design parameters that must be evaluated are:

- foundation,
- seepage and drainage needed behind them,
- velocity,
- stability of the stream bed (is it down cutting?), and
- hydraulic capacity.

Allowable maximum velocities used for design needs to be based on reliable hydraulic studies for the material.

Leaching Protection of Base Soils Protected with Revetment Blocks and Other Systems

For bank soils with no significant seepage pressures, leaching of the bank base material through the revetment blocks must be prevented. Leaching can be controlled by one of the following methods.

1. A protective layer of intermediate sized material (bedding) meeting the leaching protection criteria is placed between the blocks and base material. See the manufacturer's design criteria.

2. A geotextile is placed between the blocks and base material.

WISCONSIN DESIGN FOR STREAM BARBS

Stream barbs are low rock sills projecting out from the bank and across the thalweg of a stream for the purpose of redirecting the stream flow away from an eroding bank. Flow passing over the barb is redirected such that flow leaving the barb is perpendicular to the barb centerline. The thalweg is defined as the thread of the deepest portion of the channel.

Application and Effectiveness

- Experience is increasing. The range of application has not been tested.
- Stable streambed required.
- Effective in control of bank erosion on streams.
- Less rock than jetties.
- Can be less rock than revetments.
- Environmentally more acceptable.
- Effective in controlling erosion while establishing vegetation on intervening bank.

Design and Construction Guidelines

Materials - large rock, geotextile, or gravel bedding material.

Design and Construction:

1. Rock Size, D_5 - Select the larger size of the two methods shown below. One is based on velocity. The other is based on d_{100} size of the streambed material.

   - Method 1.

     Compute the low bank velocity. The spreadsheet, "Streambank Riprap," is suggested. Determine a D_{50} rock size using EFH Figure 16-WI-4, or use the D_{50} MIN size shown on the spreadsheet calculation. For stream barb design, the D_{50} size determined by either of these methods is the D_5 gradation size for the rock used in the stream barb. Rename D_{50} to D_5 rock size for stream barb design for this use. The velocity shall be determined using the design storm or out-of-bank flow.

   - Method 2.

     The d_{100} streambed material is from the stream pebble count. D_5 for rock in the stream barb cannot be less than d_{100} of the streambed material.

Table 6
Rock Sizes and Gradation for Both Methods

Percent Passing by Weight	Size (in.)
100	4 x D_5
25 - 50	2 x D_5
0 - 5	D_5

2. Key the barb into the streambed a depth, D, approximately D_{100} or at least one foot below the channel bottom.

3. The minimum elevation of the barb top projecting into the stream is at the typical base flow elevation. An option is to slope the top of the projecting section down from the bankfull flow elevation to the base flow elevation at the end of the barb. The option should be used on sites with highly erosive

soils and on sites were streambanks between the barbs will not be sloped. NOTE: Permitting agencies may not allow the latter option. Then use a level top throughout its length.

4. Barb top width, TW, should be at least equal to 3 times the D_{100}, but not less than 3 feet. If equipment must travel on top of the barb for construction, use 8 to 10 feet.

5. The acute angle between the barb and the upstream bank will typically range from 50 degrees to 80 degrees. Alignment should be based on the flow off the barb assuming flow perpendicular to the centerline of the barb.

6. The length of the barb, L, generally must be long enough to cross the stream thalweg. A barb length of 1.5 to 2 times the distance from the bank to the thalweg has proven satisfactory on most projects. Avoid lengths longer than ½ of the stream base flow top width. Generally, no additional barbs are needed after the thalweg position is at least ½ the stream width toward the opposite side (see Figure WI-16-11a, 11b, and 11c).

7. The spacing of barbs is dependent on the stream flow path leaving the barb. Evaluate the position of this flow path within the stream and in comparison to the opposite bank. Typically, barb spacing is 4 to 5 times the barb length. Start placement with the upstream barb. Install sequentially from here. The additional barbs should be placed upstream from the point where the stream flow intersects the bank again. Observations made during construction will help determine the position of each barb in sequence.

8. Design Proportions and Construction Notes.

   a. "T" dimension is from EFH Figure WI-16-5.
   b. "X" dimension is from EFH Figure WI-16-5.
   c. The bottom width of the barb is equal to the top width, TW, plus 3 times the rock height, H.
   d. The minimum height of rock on the bank should be the lesser of the top of low bank height or 1.0 foot above the bankfull flow (1.0 to 2 year frequency event).
   e. Place Class I (Wisconsin Construction Specification 13) geotextile under the bank rock. If d_{100} is less than or equal to 1 inch, extend the geotextile into the trench for the barb rock. When the barb is added to a rock riprap revetment and the riprap design does not require geotextile, geotextile is not required for the barb site.
   f. Keyway (embed) the barb into the bank 2 times "X" or 6-foot minimum, whichever is greater.

9. Revetment riprap can butt stream barbs on either or both sides.

<u>Definitions</u>

D_{100} is the stream barb rock material size of which 100 percent is smaller by weight. It is also the depth the barb is keyed into the streambed below the thalweg elevation and the channel bottom. When D_{100} is less than one foot, keyway (embedment) depth is to be one foot.

D_{50} is the stream barb rock material size of which 50 percent is smaller by weight.

D_5 is the stream barb rock material size of which 5 percent is smaller by weight.

d_{100} is the streambed material by which 100 percent is smaller by weight. It is typically determined from the in-stream pebble count.

H, height of the projecting portion of the stream barb is from the depth of embedment to the top of the barb.

Thalweg is the main flow portion of the stream and is generally the deepest part of the stream channel cross section along this flow. It often changes from side to side as it goes through meanders.

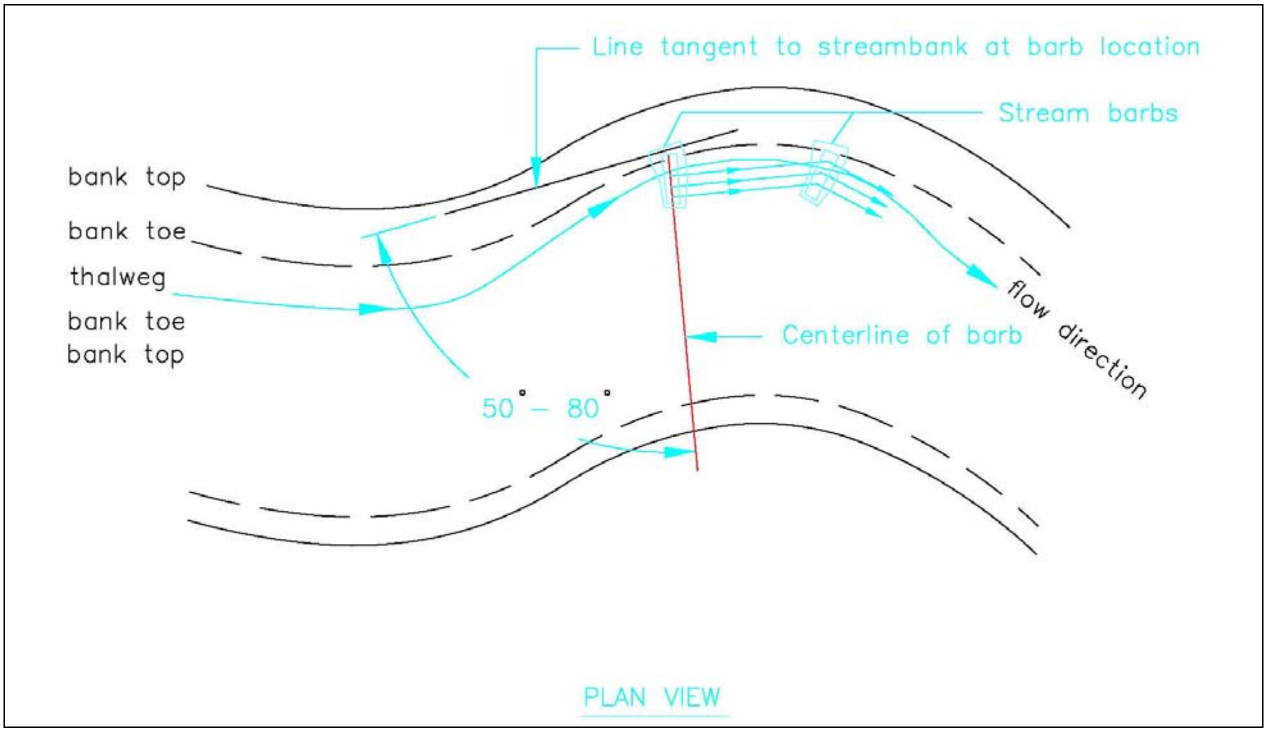


Figure WI-16-11a

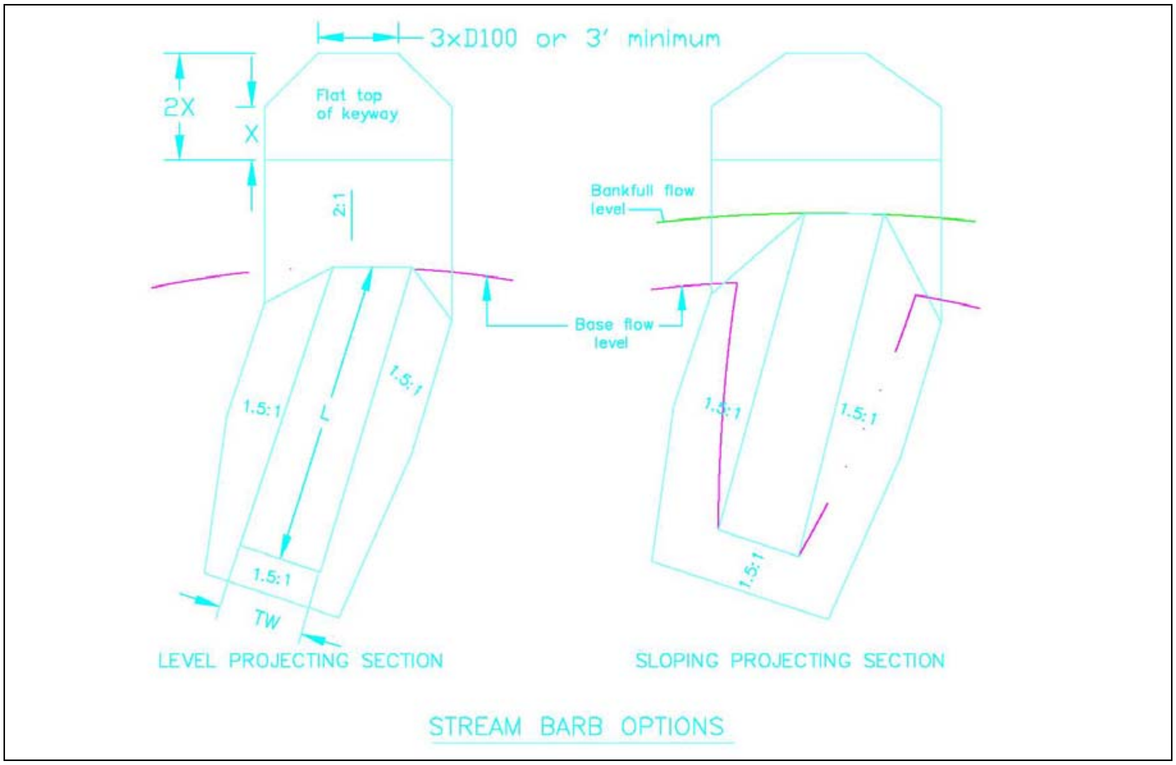


Figure WI-16-11b

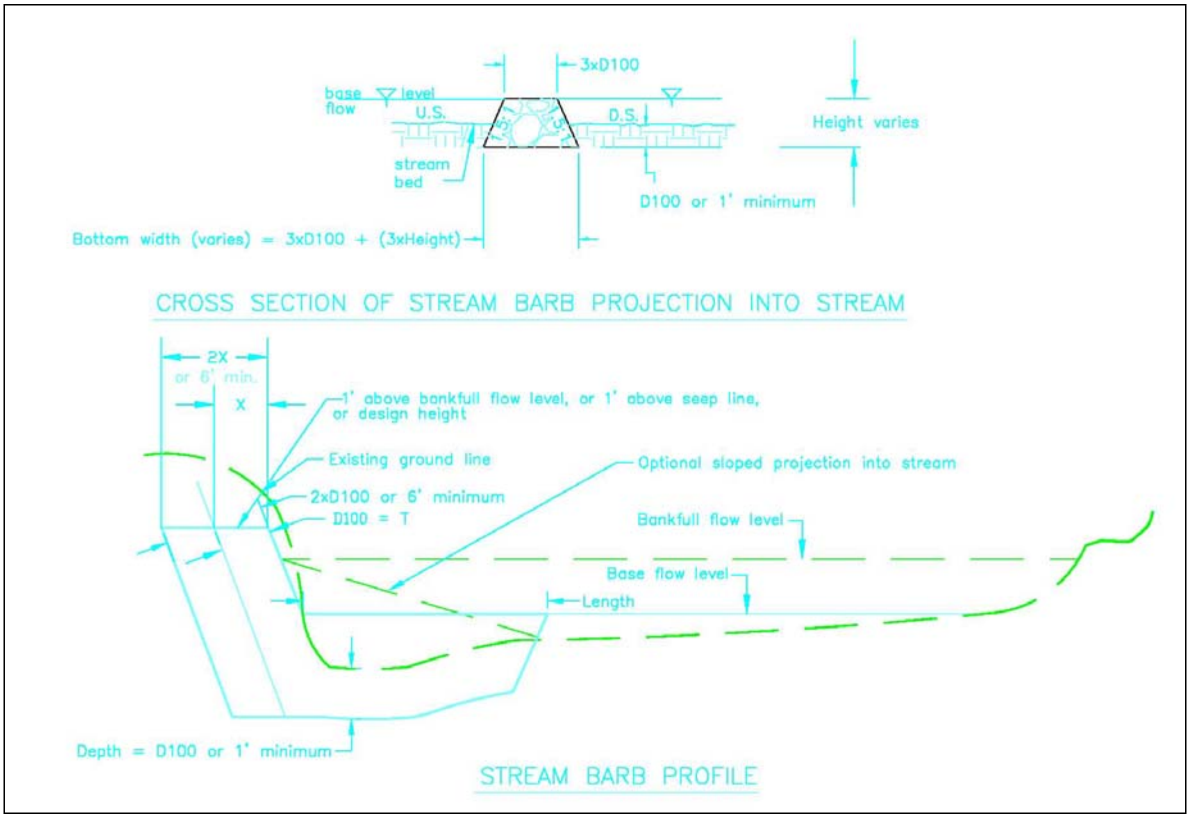


Figure WI-16-11c

FLOOD GATE AND WATERING FACILITY

Where a livestock stream crossing must be fenced on one or both sides, a flood gate may be more desirable than the fencing.

Panels must be constructed with materials that will meet the need for durability and strength. Panel lengths and number of panels must be adapted to the stream width.

Where to Locate a Fence Crossing on a Waterway

Site selection for construction of a fence across a waterway needs careful consideration. Incorrect location or alignment of the fence can initiate or accelerate channel erosion. The fence should always be built along a straight section of the river or at the crossover point in the middle of a meander where the main flow is naturally directed to the center of the channel. The fence should never be constructed on a meander bend as the flow typically accelerates around the outside of the meander and can cause bank scouring.

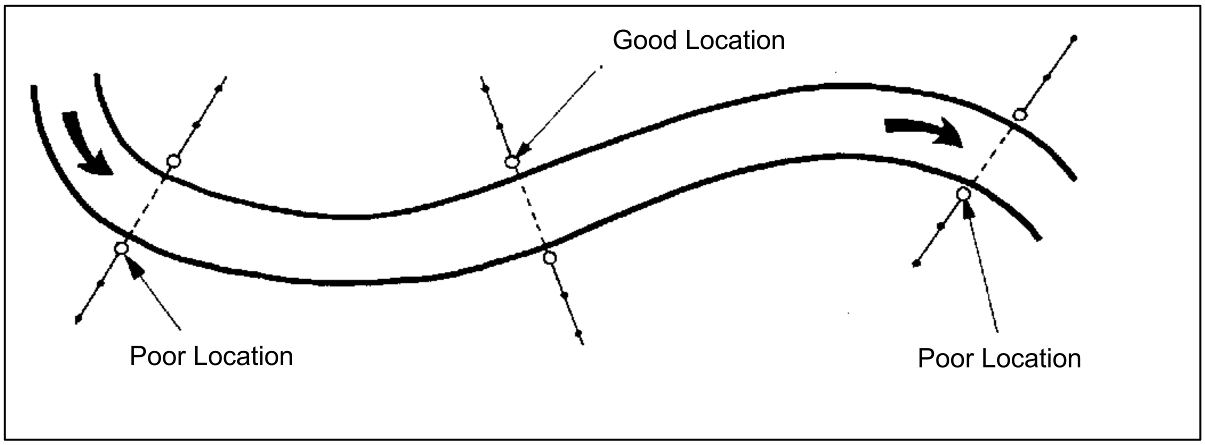


Figure WI-16-12

Suspended Cable Fences

A successful design for a flood gate is the suspended cable fence. A steel cable or chain can be suspended across the waterway between two secured posts. From the cable a fence made of galvanized chain, chain mesh, galvanized mesh, or prefabricated fencing or netting is attached. The suspended cable remains taut during the flood while the flood gate fence remains flexible and will rise with the flow. Some variations of the flood gate fence have foam or plastic floats at the bottom of the fence to aid flotation on the surface of the flood flow. With all suspended fences, it is preferable to have as few vertical supporting posts across the floodway as possible. Debris can get trapped against the post and cause extra pressure on the fence during flooding. It is necessary to ensure that the bottom of the fence hangs into the water to reduce the chance of stock getting under the fence when the river dries up or the water level recedes. It is also important that vegetation such as creepers, vines, and grasses do not become entangled in the fence and restrict the ability of the fence to swing up in a flood. Sediment or debris may also hold the fence down. For this reason suspended fencing needs to be checked and maintained each summer.

Hinged Flood Gate

A variation of the cable fence is to have a conventional wire fence across the waterway. A cable is strung between the base of the posts on either side of the river. A wooden or welded steel frame is hung from the cable so that it is hinged and will move up in the flow. This flood gate design is only suitable if the flood flows are generally within the channel and do not normally rise above the flood gate. In floods higher than the gate, there is the risk that debris will build up on the conventional wire fence and obstruct the flow.

Fixed Frame Hinged Flood Gate

A variation of the suspended cable for smaller waterways is to have a fixed frame across the waterway on which the flood gate fence can swing. The supporting frame needs to be well secured to the bank and if possible above the 100-year flood level. The land manager should be aware that, in high flows, debris may get caught on the fixed frame.

The following consideration should be made when designing a flood gate or watering facility.

Design Considerations

- Site conditions (i.e., stream size, volume of flow, velocities, soil type, and stability of both the bed and banks of the stream).
- Type of existing (or planned) fencing system (i.e., electric, wood, or barb wire).
- Producers needs.
- Livestock type.
- Durability of system.
- Quality of materials.
- Ease of repair or replacement.
- Simplicity of system.
- Economics.
- Posted warning to the public (i.e., signage that would give advance notice to water craft user of flood gate system or warnings to the public of electric fencing used in a flood gate system).
- Local, state, and federal permits.

Function

- Ability to open during flood events and close after flood water recede.
- Restrict livestock from opening, passing through, or going under.
- Ease of cleaning debris from flood gate system.
- Opportunity for public this pass under or portage around in a safe manner (i.e., canoes, kayaks, fishermen, and hikers).

Operation and Maintenance

- Periodically inspect the system, and inspect system after high water events.
- Periodically replace stone, clean sediment from the access ramps of the system.
- Clean all debris from fencing and flood gate system.
- Replace broken or damaged components when necessary.

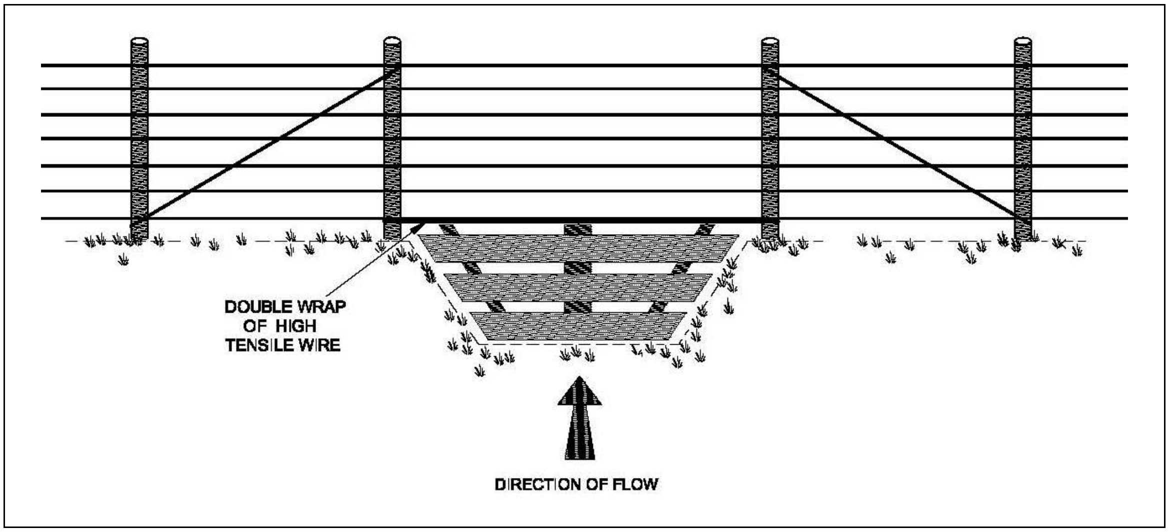


Figure WI-16- 13a: Fixed Framed Hinged Flood Gate

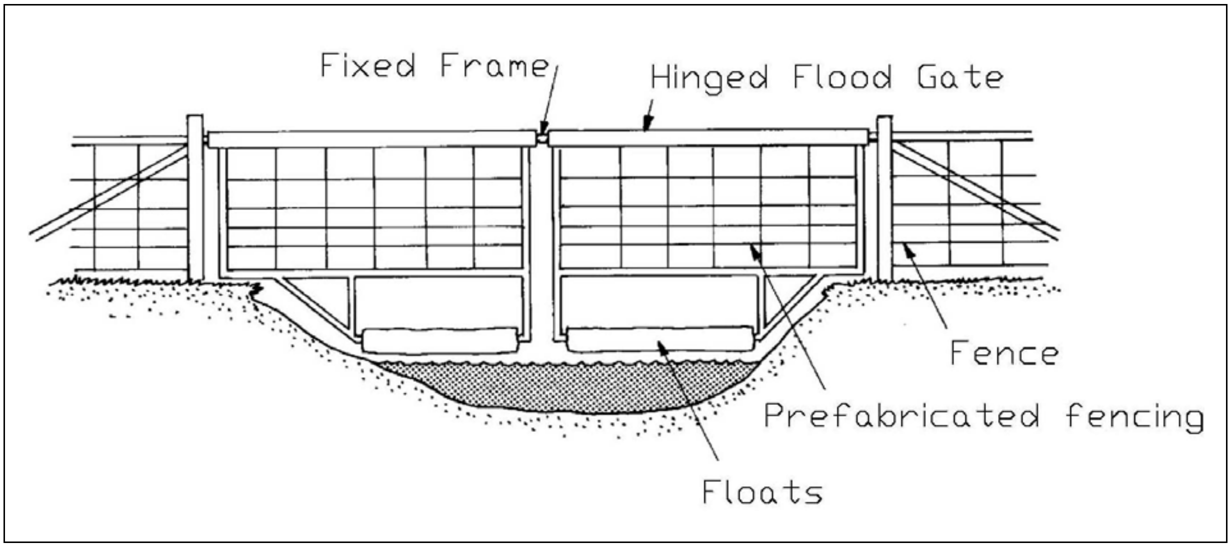


Figure WI-16-13b

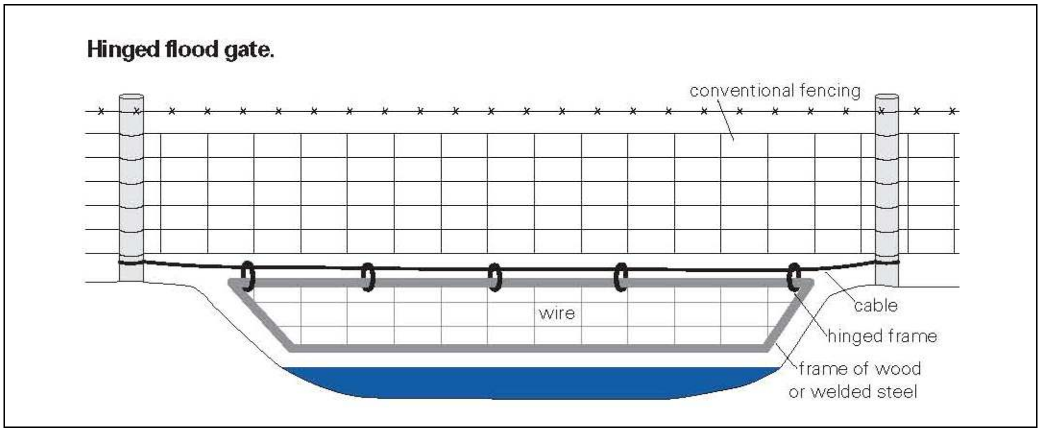


Figure WI-16-13c

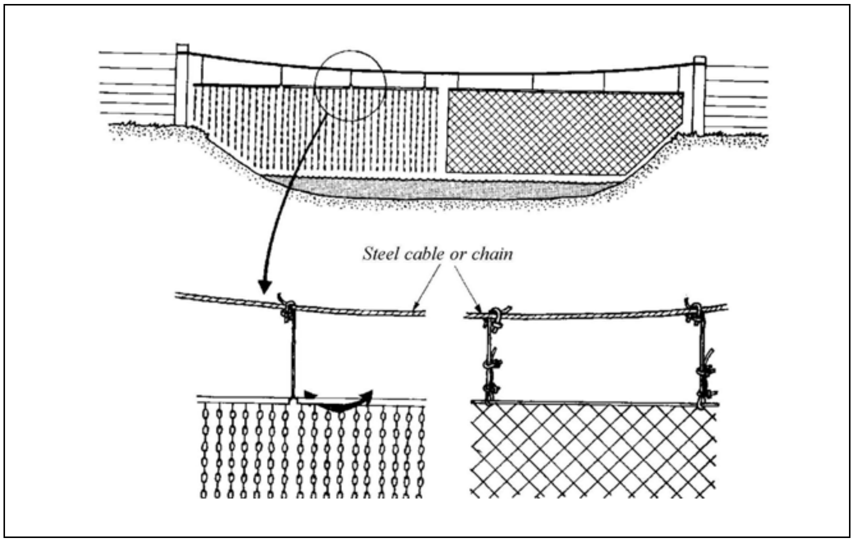


Figure WI-16-13d: Suspended Cable Fence

LIVESTOCK STREAMBANK WATERING RAMP

Livestock streambank watering ramps need a ramp slope safe for the cattle to walk on in most seasons of the year. A slope of 4:1 or flatter has proven to work. The ramp side slopes should be 2:1 or flatter. The ramp surface for the end that is in the stream should be placed at the stream bottom elevation or lower. Recess the ramp from the edge of the stream bottom into the bank.

Ramp surfacing shall be as specified for livestock stream crossings in Practice Standard 587, Stream Crossing, Section IV, Field Office Technical Guide, NRCS.

The sides and bottom end of the ramp should be fenced to limit cattle access.

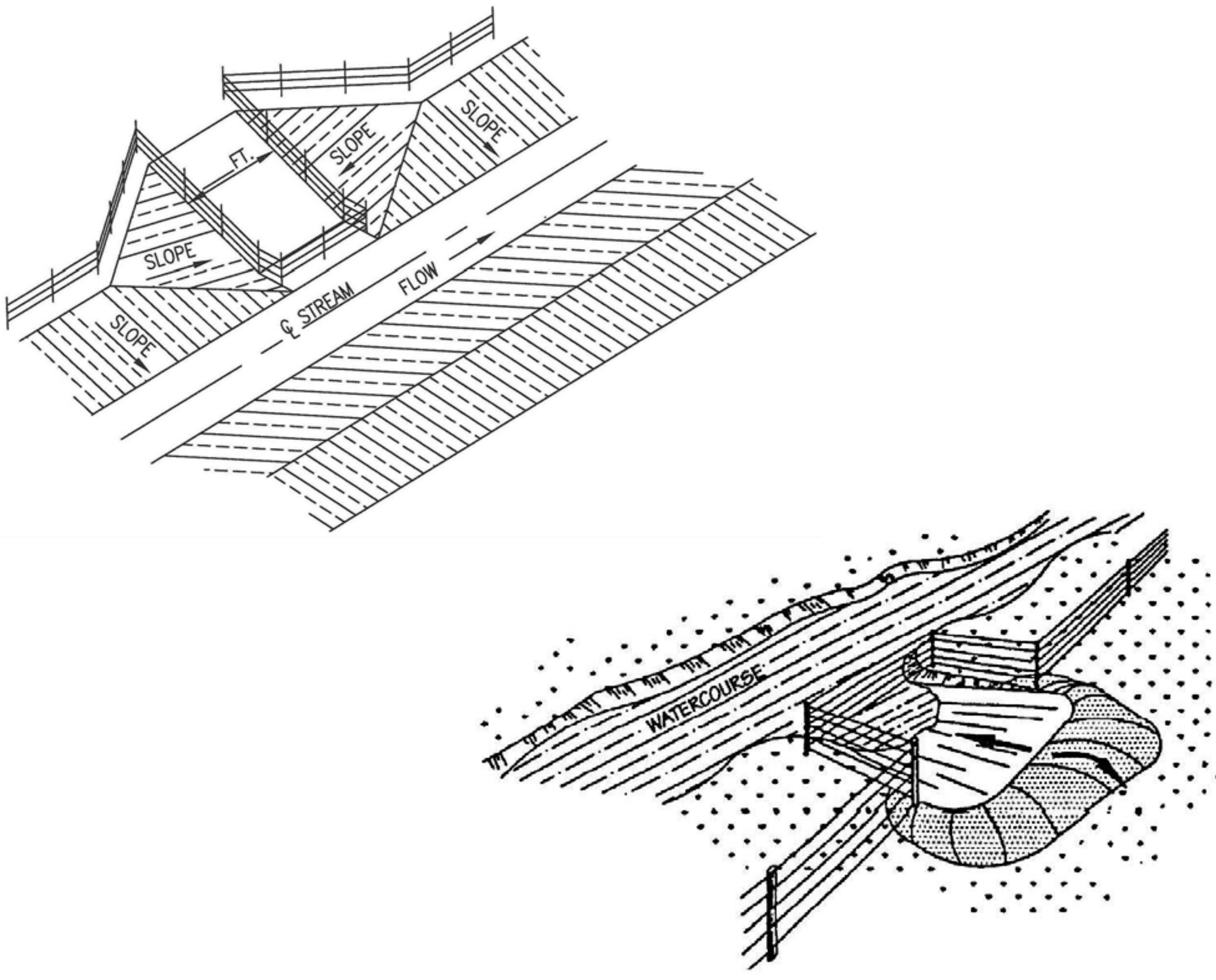


Figure WI-16-14

ALTERNATIVE TECHNIQUES FOR STREAMBANK PROTECTION

Introduction

There are many instances where traditional engineering solutions, like rock riprap, are either environmentally undesirable or too expensive. Companion Document 580-9 contains a list of many other techniques other than riprap that can be used to protect the eroding banks. A structural toe shall be used with all vegetative and bioengineering measures. Companion Document 580-10 lists velocities and shear stresses techniques can withstand.

Biotechnical slope protection and soil bioengineering both use applied science that combines mechanical, biological, and ecological concepts to create a living structure for slope stabilization. Adapted woody species are arranged in a specific configuration that provides immediate soil reinforcement. As the plants grow, the roots provide shear strength and resistance to sliding. When properly designed, these techniques not only help to stabilize slopes, they also improve infiltration, filter runoff, transpire excess moisture, moderate ground temperatures, improve habitat, and enhance aesthetics.

“Integrated bank treatment” is recognized in Wisconsin state code and means a streambank protection that combines two separate treatments: structural treatment for toe protection at the base of the bank and biostabilization or seeding on the remaining upper portion of the bank.

Although the entire streambank is made up of different zones (toe, bank, overbank, and upland), it is important that the entire bank be considered as a single entity. Toe protection and vegetative components must be incorporated into a single project with a common boundary. The cross section, plan, and profile view of a project must be integrated in to the design calculations, construction drawings, and specifications. The national NRCS has published reference documents to aid the planner and designer with streambank protection projects.

Some of these documents are:

1. National Engineering Handbook (NEH), Part 650, Engineering Field Manual, Chapter 16, Streambank and Shoreline Protection.

2. National Engineering Handbook (NEH), Part 650, Engineering Field Manual, Chapter 18, Soil Bioengineering for Upland Slope Protection and Erosion Reduction.

3. National Engineering Handbook (NEH), Part 653, Stream Corridor Restoration Principles, Processes, and Practice

4. National Engineering Handbook (NEH), Part 654, Stream Restoration Design

ICE DAMAGE

Ice can affect riprap linings in a number of ways. Moving surface ice can cause crushing and bending forces as well as large impact loadings. The tangential flow of ice along a riprap lined channel bank can also cause excessive shearing forces. Quantitative criteria for evaluating the impact ice has on channel protection schemes are unavailable. Ice attachment to the riprap also can cause a decrease in stability.

For design, consideration of ice forces should be evaluated on a case-by-case basis. In most instances, ice flows are not of sufficient magnitude to warrant detailed analysis. Where ice flows have historically caused problems, a stability factor of 1.2 to 1.5 should be used to increase the design rock size. A general rule found in EM 1110-2-1601 is to increase the thickness of the revetment by 6-12 inches and accompanied by an appropriate increase in stone size (D_{50} increase of 3-6 inches).

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SHORELINE RIPRAP PROTECTION DESIGN PROCEDURE

The following design procedure is taken from the 1984 edition of the "Shore Protection manual" published by the U. S. Army Corps of Engineers.

CALCULATE FETCH:

1. Using an aerial photograph, USGS quad map, or other planimetric view of the lake, locate the site needing protection. Draw a line across the open water of the lake from the design point, in a nearly perpendicular manner from the shoreline, until it intersects the opposite shoreline. This line's direction may be varied within reasonable judgment to reflect long expanses of water which may be key in the production of wind-generated waves.
2. Use the line drawn in step 1 as the central radial. Draw 4 radials on either side of this central radial at angles of 3 degree intervals from the design point.
3. Measure the length of each of the 9 radial lines and average them. This will be the effective fetch length, F_e.

CALCULATE WIND STRESS:

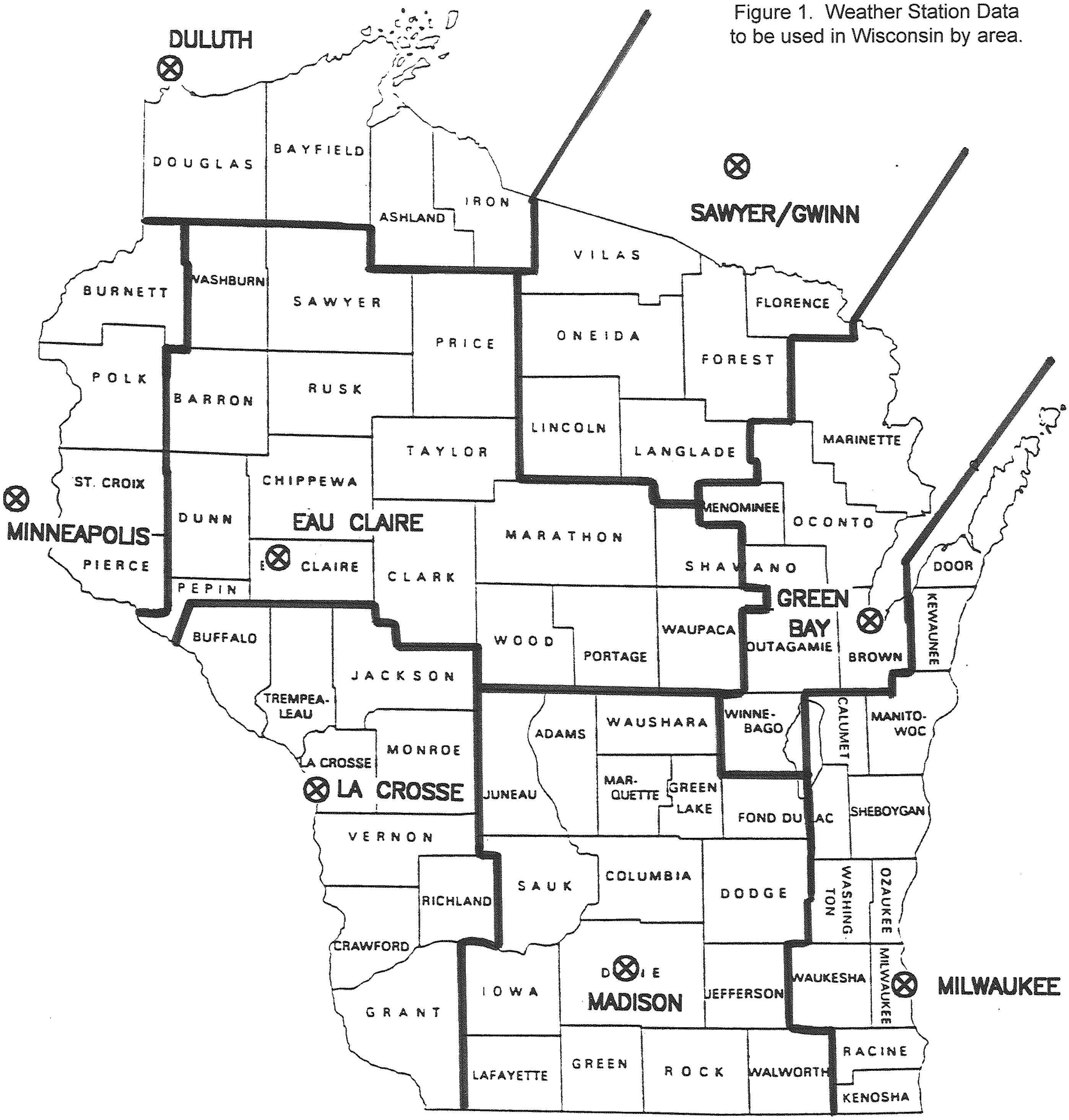
4. The wind data available for Wisconsin has been summarized in Table 1. Using the map in Figure 1, locate the region of the state which contains the design site.

Table 1. Design Wind Stress Factors, (U_a)
For First Order Weather Stations
(in miles per hour)

Compass Point	Duluth	Eau Claire	Green Bay	La Crosse	Madison	Milwaukee	Minneapolis	Sawyer/ Gwinn	Compass Point
N	27	32	32	32	32	39	33	28	N
NNE	30	32	32	30	32	39	34	28	NNE
NE	30	30	33	28	33	38	28	28	NE
ENE	39	30	32	30	32	38	27	28	ENE
E	34	32	30	28	32	35	28	30	E
ESE	28	31	28	28	32	30	28	30	ESE
SE	27	30	30	30	31	30	28	30	SE
SSE	27	30	31	30	32	32	28	28	SSE
S	28	31	32	32	33	38	33	28	S
SSW	28	32	35	32	35	38	28	28	SSW
SW	28	32	35	33	35	39	28	31	SW
WSW	28	32	35	35	38	41	28	31	WSW
W	28	33	33	35	38	38	33	33	W
WNW	28	35	32	35	35	38	33	38	WNW
NW	28	32	32	32	35	35	34	35	NW
NNW	28	32	32	32	34	38	31	31	NNW

WISCONSIN

Figure 1. Weather Station Data to be used in Wisconsin by area.



5. Note the direction of the wind that would affect the site if it blew directly toward the site along the central radial. Find the compass point (1 of 16) from Figure 2 that most nearly corresponds with this direction.

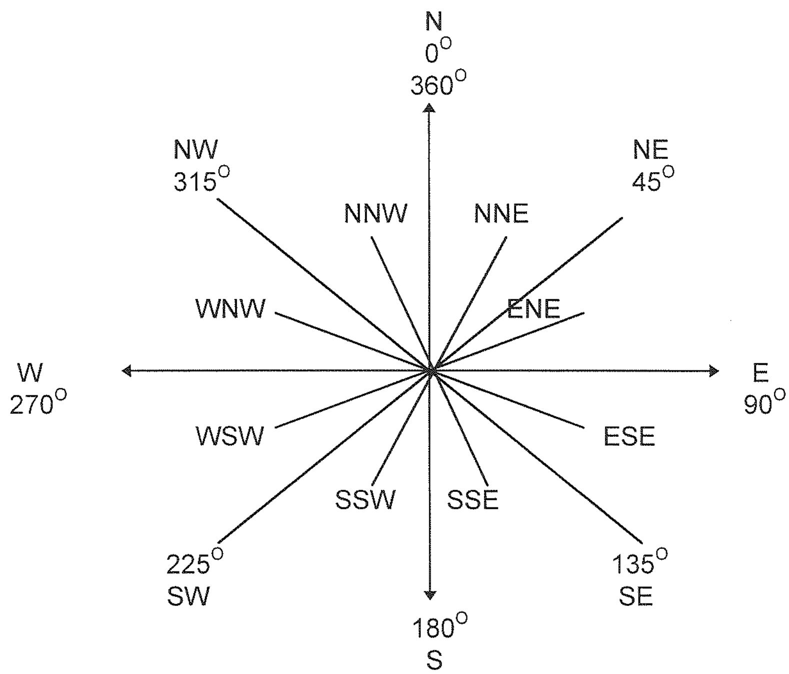


Figure 2. Compass Rose

6. Using the wind data in Table 1 for the region containing the location of the site, find the wind stress factor to be used.

CALCULATE DESIGN WAVE HEIGHT:

7. Use the chart in Figure 3 with the effective fetch (F_e) and the wind stress factor (U_a) to determine the period of the wave (T). Calculate the wave length (L) using the following equation.

$$L = 5.12\ T^2$$

Determine the average lake depth (d) along the central radial using maps, information supplied by the landowner, or other resources. Calculate d/L (lake depth over wave length). Table 2 will identify the type of wave impacting the design site.

Table 2. Classification of Wave Type

Classification	d/L
Deep Water	> 0.5
Transitional	0.04 to 0.5
Shallow Water	<0.04

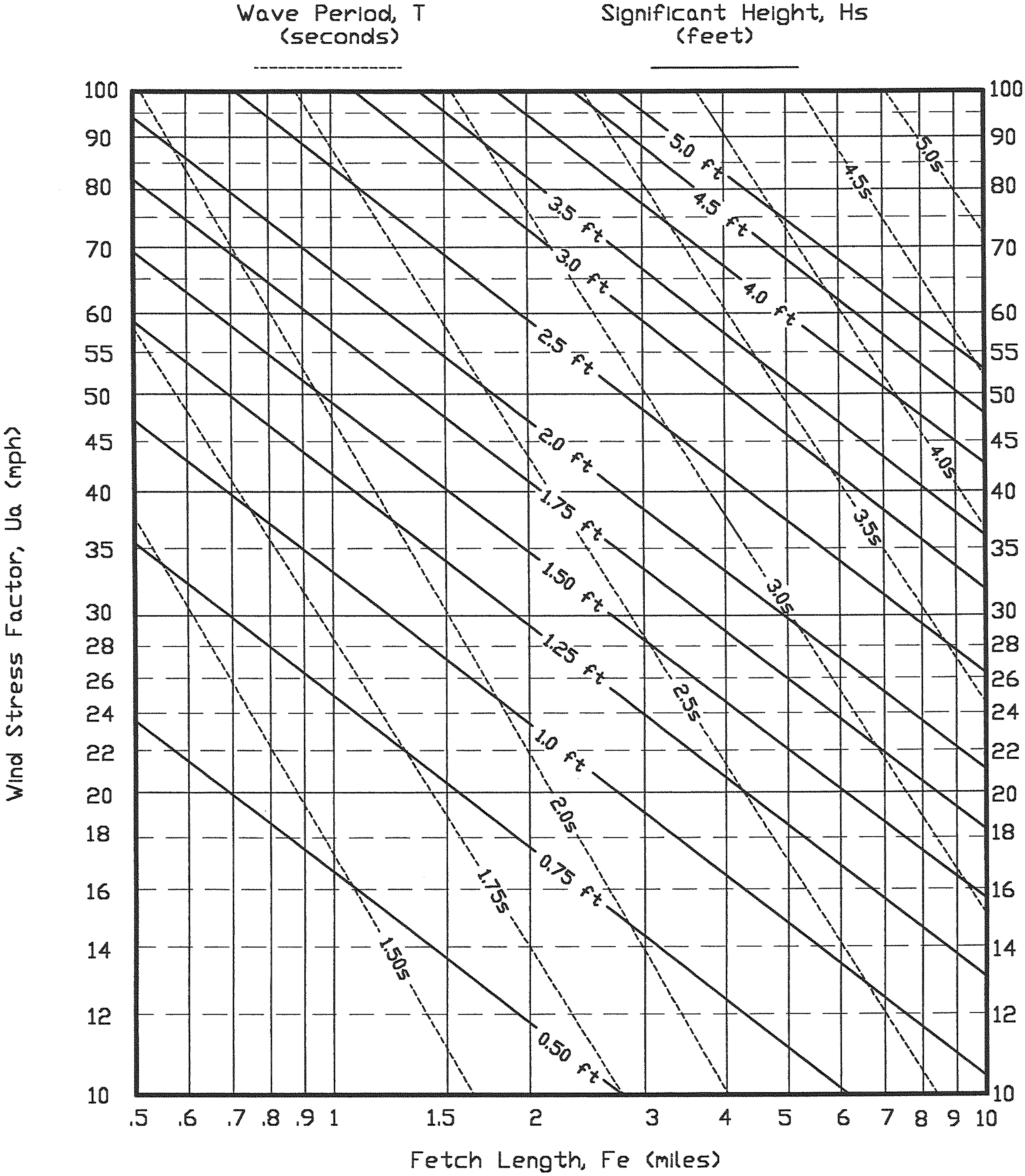


FIGURE 3. Nomograms of deepwater significant wave prediction curves as functions of wind speed and fetch length.

(Adapted from ACOE's Shore Protection Manual)

9. Calculate the significant wave height (H_s) by one of the following methods:

    - If you have a shallow water condition refer to the Army Corp of Engineers' Shore Protection Manual.

    - If you have a deep water or transitional condition, use Figure 3 to determine the significant wave height (H_s) for the calculated effective fetch and wind stress factor.

10. Choose a design frequency for the site from Table 3 and note the corresponding safety design factor(DF_{wph}) from Table 4. Multiply the H_s determined in step 9 by the DF_{wph}, to obtain the design wave height (H_o). Note that these are minimum design factors that may need to be increased for local circumstances. Also, note that the design frequency and resulting safety design factor is different for determining runup and wave protection height (WPH) compared to what is used to determine rock size.

Table 3. Design Frequency Selection

Description	Riprap		Precast Concrete Block or Gabion
	Runup & WPH *	Rock Size	
Low Hazard: Failure of protective measure does not endanger anything of value; distance from shore to anything of value exceeds 40 feet. Raw bank height is less than 5 feet.	H_{10}	H_s	H_{10}
Moderate Hazard: Failure of measure increases threat to something valuable; distance from shore to anything of value exceeds 20 feet. Raw bank height is less than 10 feet.	H_5	H_{10}	H_5
High Hazard: Failure of measure would threaten existence of valuable structure or property; distance from shore to anything of value is less than 20 feet.	H_1	H_{10}	H_1
Note: When H_s is used, some damage may result to the shoreline in extreme events. Where this is unacceptable, or maintenance may be poor, increase the design frequency. Raw bank height may be only the lower portion of the total bank height. Use the two terms with caution. * WPH = Wave Protection Height			

Table 4. Safety Design Factors for Waves and Riprap

Definition	Notation	Factor
Average of highest 1/3 of all waves	H_s	1.0
Average of highest 10% of all waves	H_{10}	1.27
Average of highest 5% of all waves	H_5	1.37
Average of highest 1% of all waves	H_1	1.67

11. Calculate H_0/L (design wave height/wave length). Select a slope ratio of the constructed revetment. Using these two numbers and Figure 5, select the appropriate relative run-up ratio, R/H_0.

12. Determine the run-up (R) of the waves by multiplying the relative run-up ration, R/H_0, by the design wave height, H_0. For revetments other than angular riprap, multiply R by 1.2. This accounts for the smoother surface and the lower weight. The setup (S) is 0.1 times the design wave height (H_0), but no more than 0.5 feet. See Figure 4 below for definition of terms.

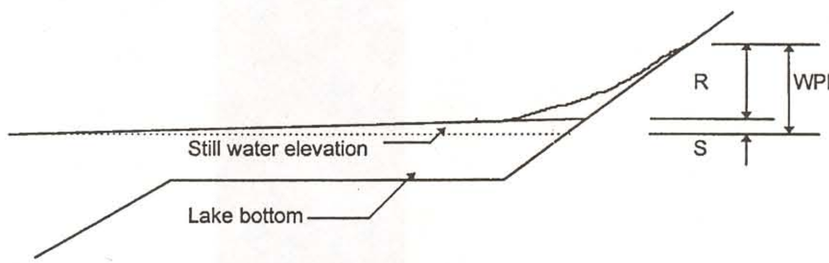


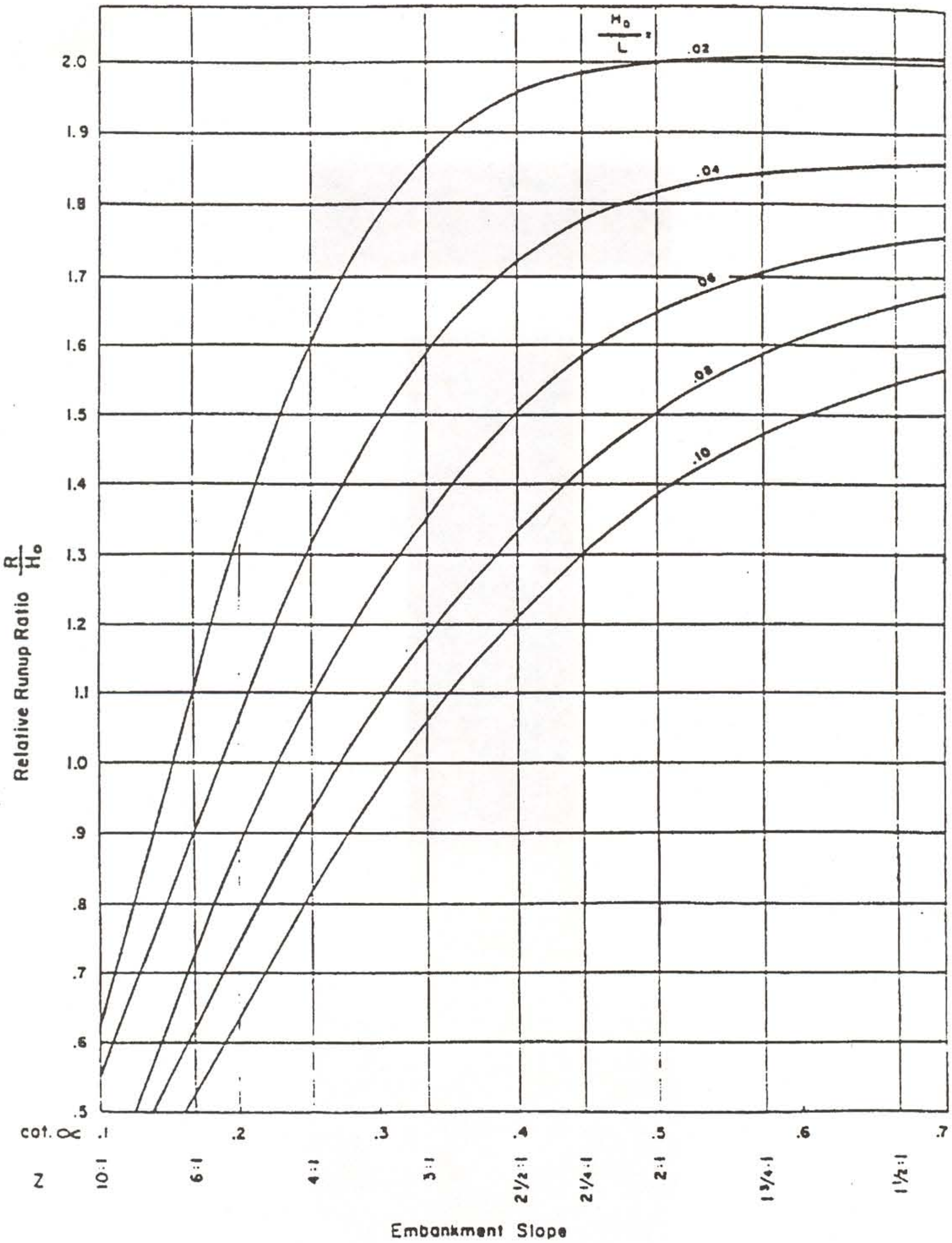
Figure 4. Runup and Setup

CALCULATE PROTECTION LIMITS:

13. The minimum upper and lower design elevations to be protected are:
    - The lower limit for the riprap shall be 1.5 times the design wave height (H_0), below the normal low lake elevation for the year. See Figures 6 and 7 for toe options.
    - The upper limit for the riprap shall be the sum of the wave run-up and the wind setup, R+S, above the Ordinary High Water elevation as defined in Standard 580, Streambank and Shoreline Protection. This sum is also called the wave protection height (WPH).

ROCK SELECTION:

14. <u>Size:</u> The size of rock is determined from relationships of wave heights, wave velocities, and drag on the rock relative to the stable size of the rock needed to resist these forces for a given bank slope. Choose a design frequency for the site from Table 3 and note the corresponding safety design factor (DF_{riprap}) from Table 4. Multiply the H_s determined in step 9 by the DF_{riprap} to obtain a new design wave height (H_{rock}), for rock selection. Note that these are minimum design factors that may need to be increased for local circumstances. Also, note that the design factor is different for determining run-up and wave protection height (WPH) compared to what is used to determine rock size.



Source: National Technical Release #69

FIGURE 5.
WAVE RUNUP RATIO
WNTC ENG. STAFF
PORTLAND, OREGON

For a given site with the design wave height (H_{rock}) and design slope of protection (z) known, determine the proper rock size, W_{50} weight, from the following equations.

Equations for Angular Stone

$W_{50} = 6.234\ H_{rock}^3$ (2:1 slope) (1)

$W_{50} = 4.156\ H_{rock}^3$ (3:1 slope) (2)

$W_{50} = 3.117\ H_{rock}^3$ (4:1 slope) (3)

$W_{50} = 2.078\ H_{rock}^3$ (6:1 slope) (4)

$W_{50} = 1.558\ H_{rock}^3$ (8:1 slope) (5)

$W_{50} = 1.247\ H_{rock}^3$ (10:1 slope) (6)

Equations for Rounded Stone

$W_{50} = 11.428\ H_{rock}^3$ (2:1 slope) (1a)

$W_{50} = 7.619\ H_{rock}^3$ (3:1 slope) (2a)

$W_{50} = 5.714\ H_{rock}^3$ (4:1 slope) (3a)

$W_{50} = 3.810\ H_{rock}^3$ (6:1 slope) (4a)

$W_{50} = 2.857\ H_{rock}^3$ (8:1 slope) (5a)

$W_{50} = 2.286\ H_{rock}^3$ (10:1 slope) (6a)

These equations were derived using a specific gravity, Gs = 2.50. If the specific gravity of the rock to be used is known, W_{50} can be determined by using the following equations.

Angular: $W_{50} = (16.83\ G_s\ H_{rock}^3)/((G_s - 1)^3\ z)$ (7)

Rounded: $W_{50} = (30.86\ G_s\ H_{rock}^3)/((G_s - 1)^3\ z)$ (8)

where

G_s = specific gravity of rock

z = slope of protection (i.e. 2:1 or 3:1)

15. Gradation and Thickness: The recommended gradation and thickness of rock depends somewhat on the rock available. It is necessary to recognize more than one gradation as satisfactory for protection. Riprap consisting of either a well-graded mixture of smaller and larger rock or of uniformly sized material is acceptable. The advantage of uniformly sized rock is that it does not segregate during placement. Riprap with broadly graded material is more effective than uniformly graded rock in preventing leaching of the underlying material. All rock quality shall meet the requirements of Wisconsin Construction Specification 9, Loose Rock Riprap.

    There are two types of rock placement:

    - Type 1 - Dumped (Equipment-Placed) Rock: When placing rock by equipment, the use of a graded rock is necessary. The W_{50} weight of the rock, as determined from Equations 1-6, can be converted to a rock size, d_{50}, using Table 6. Note that Table 6 is for a specific gravity of 2.50. If the actual specific gravity of the rock to be used is known, d_{50} can be determined using the following equation.

      $d_{50} = 0.2902(W_{50} / G_s)^{0.33}$ (9)

Table 6. Stone Weight (W_{50}) and Equivalent Stone Diameters (d_{50})

Weight (lbs)	Dimension (inches)	Weight (lbs)	Dimension (inches)	Weight (lbs)	Dimension (feet)	Weight (tons)	Dimension (feet)
0.025	0.75	5	4.38	100	0.99	1	2.69
0.050	0.94	10	5.52	200	1.25	2	3.39
0.075	1.08	15	6.32	300	1.43	3	3.88
0.100	1.19	20	6.96	400	1.57	4	4.27
0.125	1.28	25	7.50	500	1.70	5	4.60
0.150	1.36	30	7.97	600	1.80	6	4.89
0.175	1.43	35	8.39	700	1.90	7	5.15
0.200	1.50	40	8.77	800	1.98	8	5.38
0.225	1.56	45	9.12	900	2.06	9	5.60
0.250	1.62	50	9.44	1000	2.14	10	5.80
0.5	2.04	55	9.75	1100	2.21	11	5.99
1.0	2.56	60	10.04	1200	2.27	12	6.16
1.5	2.93	65	10.31	1300	2.33	13	6.33
2.0	3.23	70	10.57	1400	2.39	14	6.48
2.5	3.48	75	10.81	1500	2.45	15	6.64
3.0	3.70	80	11.05	1600	2.50	16	6.78
3.5	3.89	85	11.27	1700	2.55	17	6.92
4.0	4.07	90	11.49	1800	2.60	18	7.05
4.5	4.23	95	11.70	1900	2.65	19	7.18
5.0	4.38	100	11.90	2000	2.69	20	7.31

from Chapter 7 of ACOE's Shore Protection Manual

assumes a specific gravity of 2.50 (unit weight = 156 lbs/cubic foot)

The minimum thickness of the rock shall be 2 times the d_{50} size of the rock, but not less than 12 inches. The rock gradation is determined using Table 5 below.

Table 5. Riprap Gradation

Size of Stone	Percent of Total Weight Smaller than the given size
2.0 to 2.5 x d_{50}	100
1.6 to 2.1 x d_{50}	85
1.0 to 1.5 x d_{50}	50
0.3 to 0.5 x d_{50}	15

- Type 2 - Hand-Placed Rock: Riprap that is hand-placed consists of rocks of uniform size carefully placed by hand in a definite pattern with a minimum of voids. The concept calls for angular rock. The rock W_{50} weight, determined from Equations 1-6, is to be converted to a rock size, d_{50}, using Table 6. The dimension obtained from Table 6 is used as the minimum rock size D_{min} for the hand-placed rock. The maximum size of the rock, D_{max}, to be used will be 1.5 times the D_{min} size. It will be necessary to have a well-graded filter material and/or geotextile under the riprap to protect against leaching. The minimum thickness of the rock shall be equal to the D_{max}.

The Shore Protection Manual recommends limiting the use of graded riprap to design wave heights less than or equal to 5 feet.

TOE PROTECTION:

A critical part of the design of shoreline revetments is protection of the toe. The breaking waves will "scrape along the bottom" causing a scour that may undermine the revetment. Three alternate toe protection designs are described below. Each has conditions where it is best suited. Figures 6 and 7 show the three forms of toe protection for riprap with geotextile and riprap with a sand/gravel filter.

- Type A (with either geotextile or a sand/gravel filter) is meant for lakeshores with shallow water (less than 18" + 2*d_{50}) at the shore and a flat lakebed slope. This type can be used where the riprap "lower limit" calculated in step 13 goes below the existing lake bottom. A toe as shown may replace the need to extend the riprap below the lake bottom elevation.
- Type B (with either geotextile or a sand/gravel filter) is meant for lakeshores with deep water (greater than lower limit + 48") at the shore. This type of toe protection stabilizes the bank through a region where the scour is likely to occur. The thickened section of riprap is to be centered around the elevation calculated for the lower limit of the riprap. This type of toe should be used where drop-off occurs within 50 feet of the shore. This may result in the toe being beneath the lake bottom to limit movement of the drop-off.
- Type C (with either geotextile or a sand/gravel filter) is intended for lakes with an intermediate depth (greater than 18" + 2*d_{50}) at the shore. For safety reasons, there must be at least 18" of water depth at the shore after the riprap is installed. This means that the shoreline water depth should be at least 2.5-3 feet before construction. This type also replaces the need to go below the lake bottom elevation as in Type A. This toe may also be easier to install than the Type A toe.

On sites where ice damage is a concern, larger rock can be placed in the toe area as shown in Figure 8. The rocks shall have a minimum weight of 360 pounds or a minimum diameter of 18 inches. They will be placed beginning at the water-soil intersection and continue into the lake for a distance of at least one rock diameter. The top of the rocks shall be set at an elevation equal to or greater than the Ordinary High Water elevation, which means that the rocks will have to be trenched into the lakebed in most instances. The rocks shall be placed over geotextile covered with a designed granular filter as directed in the filter materials section.

TOP AND END PROTECTION:

Other critical portions of a revetment requiring protection are the top of the slope and ends of the bank protection. Figure 9 shows possible configurations to protect the top and ends. When the computed wave protection height reaches an elevation higher than the top of the existing bank, protection of the revetment top must include an overflow apron. This should be 6 feet horizontally for every foot of wave protection height above the existing top of bank, but not less than 3 feet in any case. See Figure 9 for an illustration of this.

The revetment end is subject to attack by outside forces and must be reinforced against possible failure. End protection is needed if the rock is terminated at a point that is not known to be stable. If the rock is terminated at a stable point such as a controlling structure, natural rock outcropping, etc., Method A in Figure 9 may be used. In most cases, some questions will exist as to the stability of the end section. Method B should then be used as shown in Figure 9.

FILTER MATERIALS:

A filter is a layer or combination of layers of materials which will restrict the movement of underlying materials yet still provide for drainage of water through all layers without loss of material from any layer. A filter may be a graded granular material or a geotextile or a combination of these.

- The filter material shall be designed in accordance with the NRCS Soil Mechanic's Note No. 1. The filter layer thickness shall be the greater of (1) 1.33 times the calculated maximum grain size, (2) 6 inches, or (3) 1/3 the thickness of the riprap, but shall not be more than 12 inches.
- Commercially made geotextile is acceptable in place of a mineral filter, or may be used in conjunction with one. The physical durability of the material shall meet the requirements of NRCS Wisconsin Construction Specification (WCS) 13, Geotextiles, as directed by pages 17-WI-69 through 17-WI-78, Guide For the Use of WCS 13, Geotextiles. The ends of the geotextile shall be buried at least 12 inches on the top and ends of construction. The Corps of Engineers recommends the use of a Dutch Toe (wrapping the end of the geotextile into the riprap) as illustrated in Figure 6. A 4 to 6 inch layer of sand may be desirable between the geotextile and riprap to prevent tearing of the cloth during installation of the rock.

OTHER PROTECTIVE MEASURES:

1. <u>Gabions</u>

   Gabions can also provide acceptable shoreline protection. The designer is encouraged to follow steps 1 through 13 of the riprap design procedure for determining the extent of the gabion protection. Design of the gabions themselves should follow manufacturer's recommendations and NRCS Wisconsin Construction Specification (WCS) 17, Wire Mesh Gabions and Mattresses. The wave runup should be increased by a factor of 1.2 as noted in step 12 of the design procedure for riprap. The filter requirements are the same as stated for riprap. Banks shall be sloped at a 1 1/2 horizontal to 1 vertical or flatter.

2. Beaching Slope

Shore protection with beaching slopes utilize the movement of semi-fluid sands up the beach with breaking waves, and off the beach with the receding waves to dissipate energy. For any given wave size, a beach will stabilize with a particular relationship between beach slope and the median grain size of the beach material. This method of protection shall only be used for slopes in the range of 10 to 4 horizontal to 1 vertical.

Requirements for the design of beaching slopes are:

Slope	*D_{50} size of protective layer	Filter layer needed	Minimum layer thickness (in) Filter	Protective
10:1	0.5 mm to 1.0 mm	No	None	12
8:1	1.0 mm to 5.0 mm	No	None	12
6:1	5.0 mm to 1.0 in.	Yes	6	12
4:1	1 in. to 3 in.	Yes	6	12

*D_{50} size is percent of material passing by weight.

A. Only material larger than 0.17 mm is to be used for obtaining the D_{50} size of the material for the protective layer. The minimum D_{50} size allowed shall be 0.5 mm.

B. Extend the slope protection below the normal low lake elevation for the year a distance of 2 design wave heights, 2 x H_o.

C. Extend slope protection above the Ordinary High Water elevation a distance equal to the computed wave runup plus 1 ft.

D. Wave height and runup can be calculated using the method for designing rock riprap.

E. Gradation for the protective layer shall be based on the D_{50} size and limits described in the rock riprap section in Table 5.

F. Material for the protective layer that is outside the design particle size range ($> 2.5 \times d_{50}$) may be used if the layer thickness is increased by the percentage of the material outside the range.

G. The filter layer shall be designed using NRCS Soil Mechanics Note No. 1.

3. Concrete Revetments

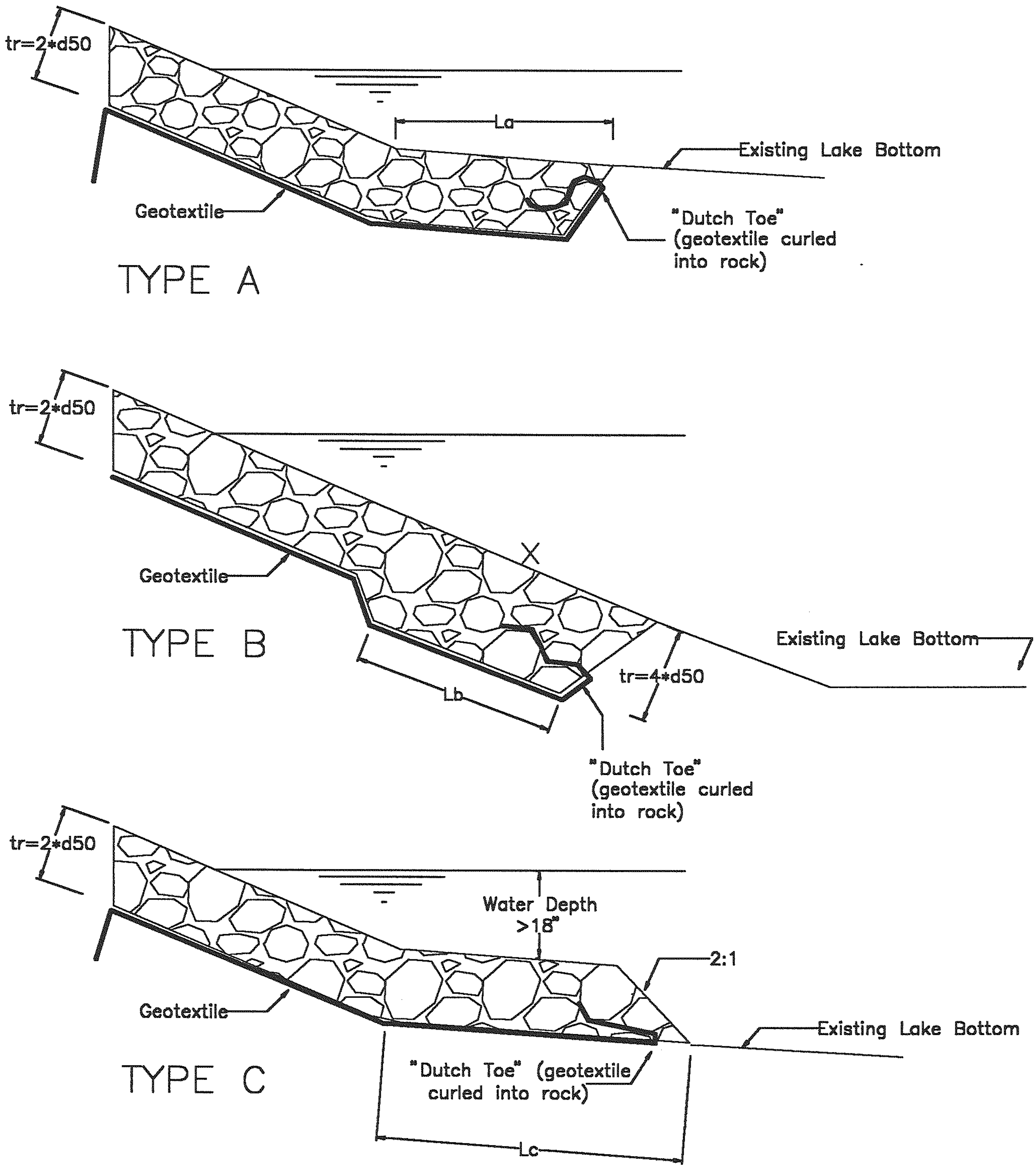
Concrete revetments for shore protection may be either (1) a sloping concrete or concrete block apron which provides a nonerosive surface for waves to break against and run up on, or (2) a bulkhead type revetment used where steep banks prohibit the use of sloping forms of protection. The designer should consider the fact that the resultant surface will be smooth, and therefore less effective at dissipating wave energy than a rougher surface. When designing lakeshore protection using concrete revetments, follow steps 1 through 12 given in the design procedure. The wave runup must be increased by a factor of 1.2 to account for a smooth surface as noted in step 12. Footings for these structures should extend a minimum depth of three design wave heights below the normal low lake level. The top of the structures should extend a minimum of the wave runup plus 1 ft. above Ordinary High Water elevation. Criteria for the filter design should be same as for riprap. When using precast concrete paving blocks, the blocks will be laid in a single layer and only provide one layer of protection. When this layer is disturbed, little protects the bank underneath. The weight of the blocks alone cannot provide the same resistance to movement as riprap, so interlocking, cabled, or rod-tied blocks are preferred over those that merely lay side-by-side.

4. Piling

Piling is another type of revetment used where natural shorelines are too steep for sloping protection. Piling may be installed either vertically or with a slight batter. Minimum thickness for piling are:

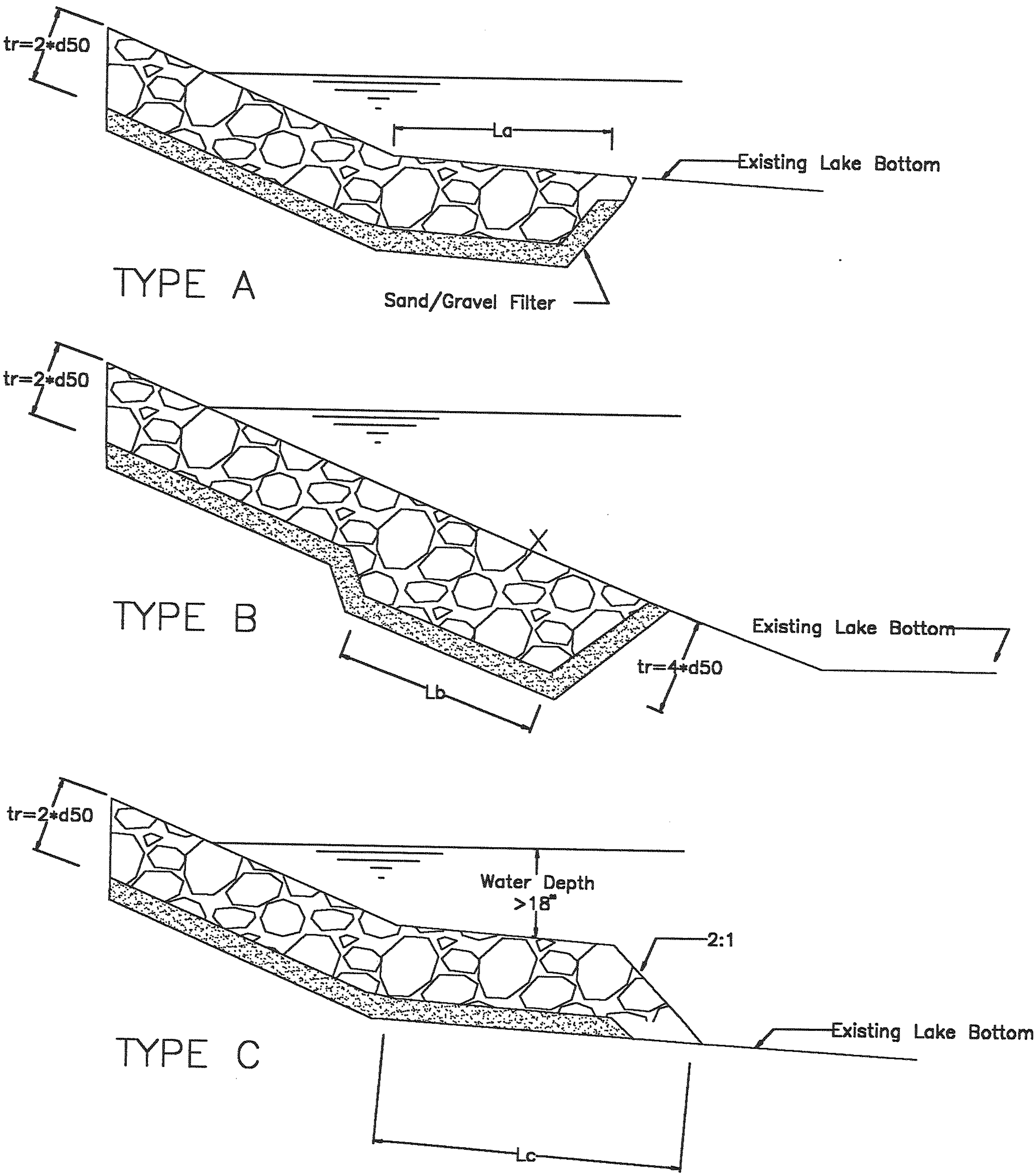
Material	Minimum Thickness(in)
Metal sheet	.109
Wood plank	2.0
Wood pole	4.0

Wood planks and poles shall be pressure treated for in-ground use. The land side of piling should be backfilled to absorb wave energy. For design of piling, the lake bottom may be considered stable at a depth of three design wave heights below the normal yearly low lake level. The top of the piling should be the wave runup plus 1.0 ft. above the Ordinary High Water elevation. Calculate the wave runup using a 1 1/2 horizontal to 1 vertical slope and a factor of 1.2 for a smooth surface in step 12.



Lb = 8 * d50
La = Lc = (Elevation of existing lake bottom minus elevation of lower limit) times 6 feet but not less than three feet or 4 * tr, whichever is greater.
In the TYPE B drawing, the "X" indicates the elevation calculated as the lower limit for the riprap protection. It falls in the center of the thicker section.

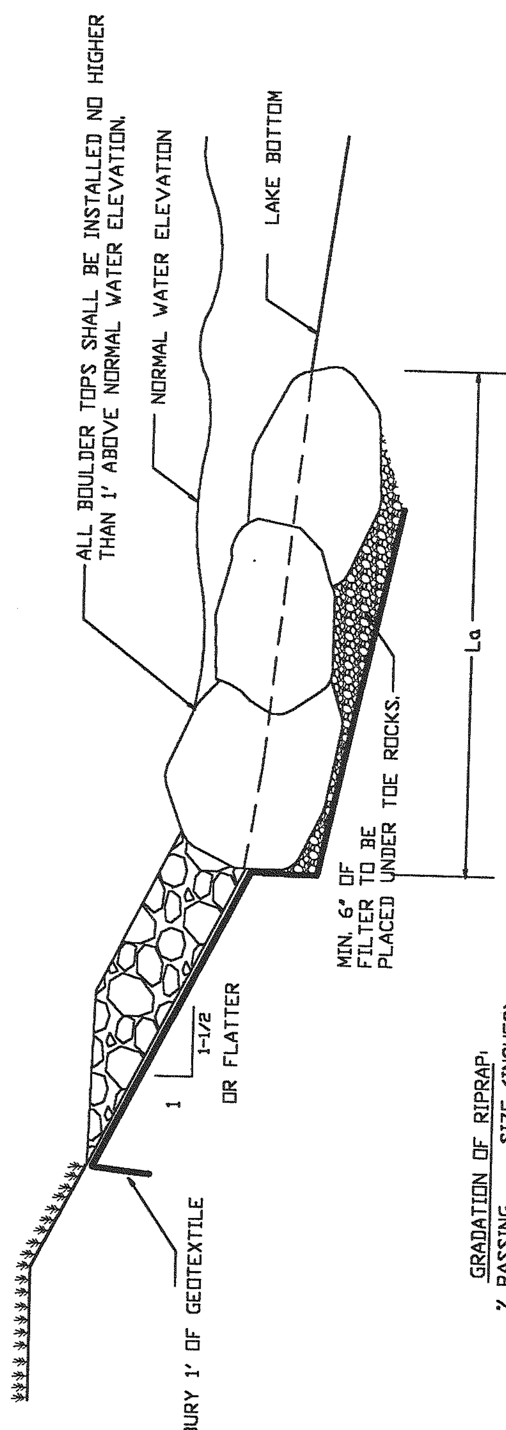
Figure 6.
Alternate methods for Toe Protection with Geotextile



Lb = 8 * d50
La = Lc = (Elevation of existing lake bottom minus elevation of lower limit) times 6 feet but not less than three feet or 4 * tr, whichever is greater.
In the TYPE B drawing, the "X" indicates the elevation calculated as the lower limit for the riprap protection. It falls in the center of the thicker section.

Figure 7.

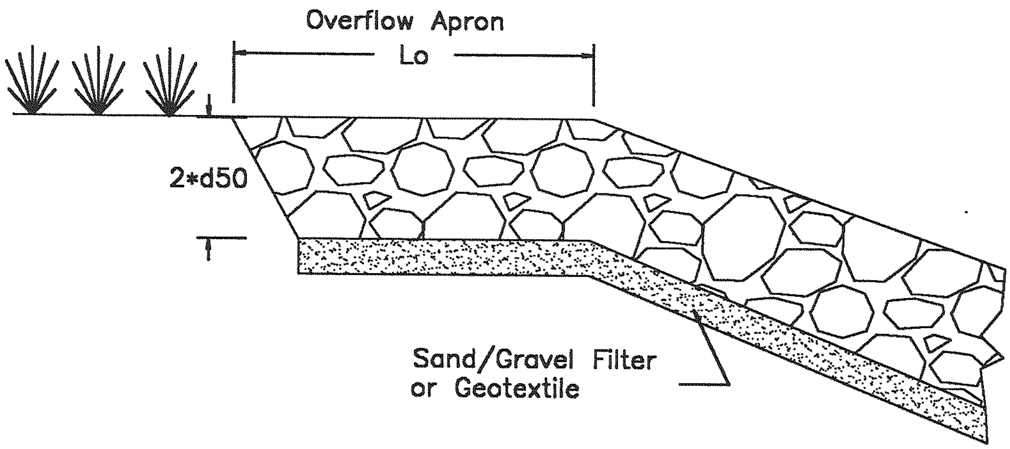
Alternate methods for Toe Protection with Sand/Gravel Filter



GRADATION OF RIPRAP

% PASSING	SIZE (INCHES)
100	2.0 TO 2.5 x d50
85	1.6 TO 2.1 x d50
50	1.0 TO 1.5 x d50
15	0.3 TO 0.5 x d50

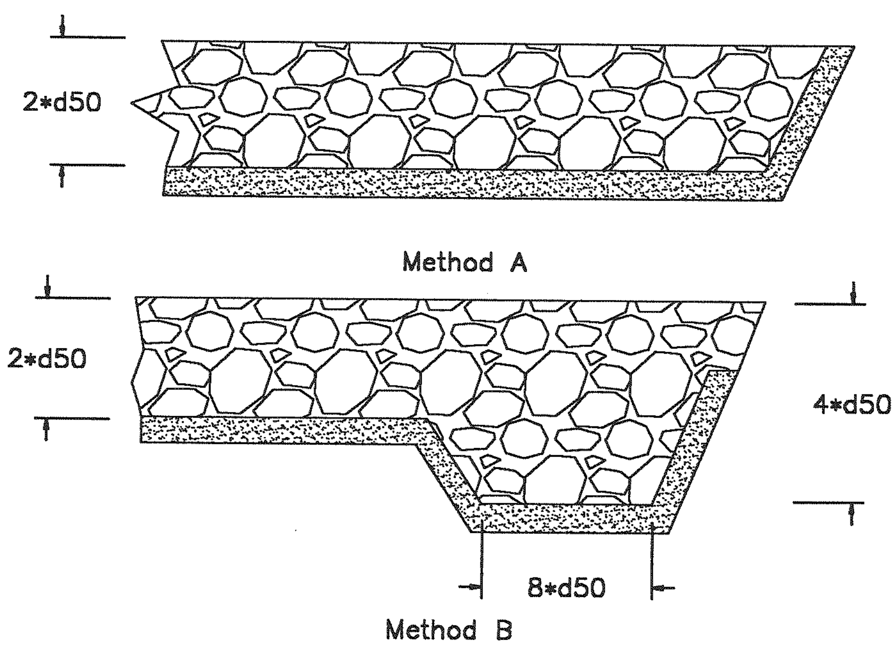
Figure 8.
Toe Protection with Boulders



Lo = 6 x (Wave Protection Height — Top of Bank) ,
but not less than 3 feet.

Top Protection

(for overtopping waves)



End Protection

Figure 9.
Top and End Protection Methods

Lakeshore Protection Design Worksheet

Project

Name ______________________ County ______________ Lake ____________

By ______________ Date ________ Ckd By ______________ Date ________

First Order Weather Station ______________

EFFECTIVE FETCH COMPUTATIONS		
Radial No.	Angle	Length(ft.)
1	12	______
2	9	______
3	6	______
4	3	______
5 (Central)	0	______
6	3	______
7	6	______
8	9	______
9	12	______
	Total Length =	______

Effective Fetch (F_e) = Total / 9 = ______ / 9

Effective Fetch = ______ ft = ______ mi

Wind direction along central radial ____

Wind Stress Factor (U_a) ____ miles/hr (Table 1)

Wave Period (T) (Figure 3) ______ sec.

Wave Length (L) = 5.12 T^2 = ______ feet

Average depth of lake along central radial (d) ______ feet

d/L = ______ / ______ = ______

Wave Type:

____ Deep Water

____ Transitional

____ Shallow Water

See Table 2 for wave types. If shallow water wave condition exists, refer to Shore Protection Manual; otherwise proceed below.

Significant Wave Height (H_s) (Figure 3) ______ feet

Hazard: High Moderate Low Design Frequency (Table 3) ______

Safety Design Factor (DF_{wph}) (Table 4) ______

Design Wave Height (H_o) = H_s x DF_{wph} = ______ x ______ = ______ feet

Slope Ratio of constructed revetment (z) ______ : 1

H_o / L = ____ / ____ = ______

R / H_o (Figure 5) ______

If material is not rock riprap, multiply: R / H_o x 1.2 = ______ (new R / H_o)

Runup (R) = H_o x R/H_o = ______ x ______ = ______ feet

Set-up (S) = 0.1 x H_o = 0.1 x ______ = ______ feet (but not more than 0.5 feet)

Lakeshore Protection Design Worksheet

Page 2

Project Name ______________________

Ordinary High Water elevation (OHW) ________________

Normal Yearly low lake elevation (if different from OHW) ________________

Lower limit (LL) = 1.5 x H_o = 1.5 x ________ = ________feet   Elevation = OHW - LL =_______

Upper limit (UL) = R + S = _______ + ______ = _______feet   Elevation = OHW + UL =____________

Elevation of top of bank as determined in field ____________

If the upper limit is higher than the top of the bank, an overtopping apron is required.

Length of apron shoreward (L_o) = (Upper limit - Top of bank) x 6

L_o = (________ - ________) x 6 = __________ feet (but not less than 3 feet)

RIPRAP DESIGN

Design Frequency (rock size) (Table 3) ___________

Safety Design Factor (DF_{riprap}) (Table 4) _______

$H_{rock} = H_s \times DF_{riprap}$ = ______________ x __________ = __________ feet

(H_s is same as determined earlier)

G_s = ______________

W_{50} = ______________ x $(H_{rock})^3$ = _________ x (__________$)^3$ = _________ lbs. (Eqn. ____)

d_{50} = ______________ inches (Table 6)

Gradation calculated for this location:

D_{100}	2.0 x d_{50} = __________ "	2.5 x d_{50} = __________ "
D_{85}	1.6 x d_{50} = __________ "	2.1 x d_{50} = __________ "
D_{50}	1.0 x d_{50} = __________ "	1.5 x d_{50} = __________ "
D_{15}	0.3 x d_{50} = __________ "	0.5 x d_{50} = __________ "

Thickness of riprap = 2.0 x d_{50} = 2.0 x ________ = __________ inches

End Protection:	Method A______	Method B______	(Figure 8)	
Toe Protection:	Type A______	Type B______	Type C______	(Figure 6 or 7)
Filter Requirements:	Granular Filter______	Geotextile______		

Lakeshore Protection Design Worksheet

Project
Name EXAMPLE County JEFFERSON Lake RIPLEY

By ______ Date ______ Ckd By ______ Date ______

First Order Weather Station MADISON

EFFECTIVE FETCH COMPUTATIONS		
Radial No.	Angle	Length(ft.)
1	12	7600
2	9	7300
3	6	7400
4	3	7800
5 (Central)	0	7700
6	3	7500
7	6	6500
8	9	6300
9	12	6500
	Total Length =	64,600

Effective Fetch (F_e) = Total / 9 = 64,600 / 9

Effective Fetch = 7178 ft = 1.36 mi

Wind direction along central radial SE

Wind Stress Factor (U_a) 31 miles/hr (Table 1)

Wave Period (T) (Figure 3) 1.94 sec.

Wave Length (L) = 5.12 T^2 = 19.33 feet

Average depth of lake along central radial (d) 15 feet

d/L = 15 / 19.33 = 0.78

Wave Type:

✓ Deep Water

___ Transitional

___ Shallow Water

See Table 2 for wave types. If shallow water wave condition exists, refer to Shore Protection Manual; otherwise proceed below.

Significant Wave Height (H_s) (Figure 3) 1.1 feet

Hazard: High Moderate (Low) Design Frequency (Table 3) H_{10}

Safety Design Factor (DF_{wph}) (Table 4) 1.27

Design Wave Height (H_o) = H_s x DF_{wph} = 1.1 x 1.27 = 1.4 feet

Slope Ratio of constructed revetment (z) 3 : 1

H_o / L = 1.4 / 19.33 = 0.07

R / H_o (Figure 5) 1.25

If material is not rock riprap, multiply: R / H_o x 1.2 = — (new R / H_o)

Runup (R) = H_o x R/H_o = 1.4 x 1.25 = 1.8 feet

Set-up (S) = 0.1 x H_o = 0.1 x 1.4 = 0.2 feet (but not more than 0.5 feet)

Lakeshore Protection Design Worksheet

Page 2

Project Name EXAMPLE

Ordinary High Water elevation (OHW) 100.0

Normal Yearly low lake elevation (if different from OHW) 99.3

Lower limit (LL) = 1.5 x H_o = 1.5 x 1.4 = 2.1 feet Elevation = OHW - LL = 97.2

Upper limit (UL) = R + S = 1.8 + 0.2 = 2.0 feet Elevation = OHW + UL = 102.0

Elevation of top of bank as determined in field 103.5

If the upper limit is higher than the top of the bank, an overtopping apron is required.

Length of apron shoreward (L_o) = (Upper limit - Top of bank) x 6

L_o = (________ - ________) x 6 = __________ feet (but not less than 3 feet)

RIPRAP DESIGN

Design Frequency (rock size) (Table 3) Hs

Safety Design Factor (DF_{riprap}) (Table 4) 1.0

$H_{rock} = H_s \times DF_{riprap}$ = 1.1 x 1.0 = 1.1 feet

(H_s is same as determined earlier)

G_s = 2.50

W_{50} = 4.156 x $(H_{rock})^3$ = 4.156 x (1.1)^3 = 5.5 lbs. (Eqn. 3)

d_{50} = 4.5 inches (Table 6)

Gradation calculated for this location:

D_{100}	2.0 x d_{50} = 9 "	2.5 x d_{50} = 11 "
D_{85}	1.6 x d_{50} = 7 "	2.1 x d_{50} = 10 "
D_{50}	1.0 x d_{50} = 4.5 "	1.5 x d_{50} = 7 "
D_{15}	0.3 x d_{50} = 1.4 "	0.5 x d_{50} = 2.3 "

Thickness of riprap = 2.0 x d_{50} = 2.0 x 4.5 = 9 inches

End Protection: Method A ✓ Method B______ (Figure 8)

Toe Protection: Type A ✓ Type B______ Type C______ (Figure 6 or 7)

Filter Requirements: Granular Filter______ Geotextile ✓

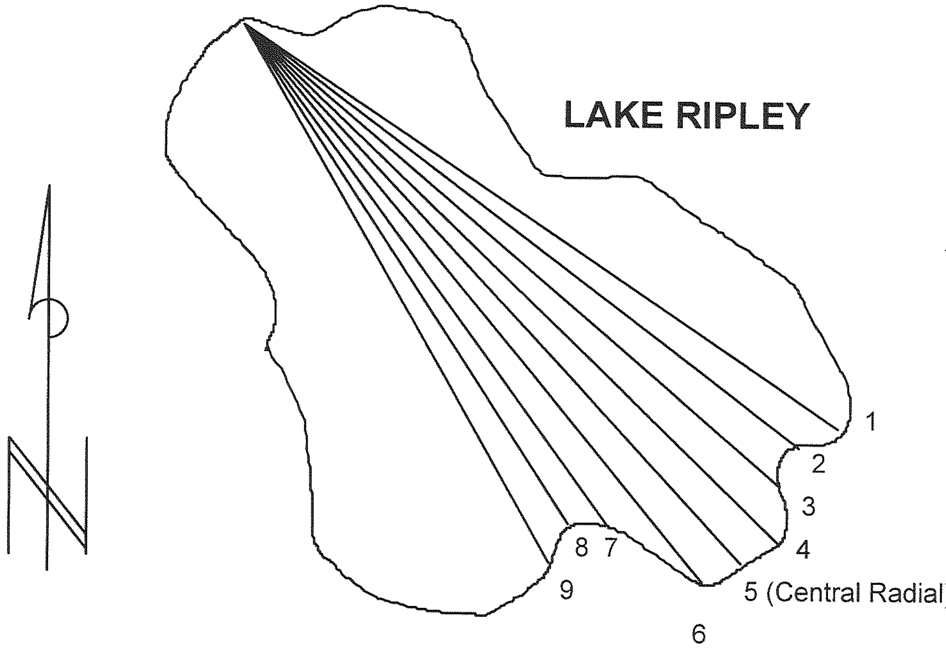


Figure 9. Example

Fetch No.	Fetch Length, Feet
1	7600
2	7300
3	7400
4	7800
5	7700
6	7500
7	6500
8	6300
9	6500
Total	64600

Effective Fetch Length = F_e =

64600 / 9 = 7178 feet

LAKESHORE RIPRAP DESIGN COMPUTATIONS SPREADSHEET

CLIENT: Example   COUNTY: Jefferson   DATE: 03/07/97
DSN BY: CHK BY: ______________   DATE: ________
COMMENTS:

****

Effective Fetch Computation

Radial #	Angle	Length(ft)
1	12	7600
2	9	7300
3	6	7400
4	3	7800
5	0	7700
6	3	7500
7	6	6500
8	9	6300
9	12	6500
Total Length =		64600
Effective Fetch(Fe) =		7178 Feet
=		1.36 Miles

Weather Station Location: 5 Madison
ENTER NUMBERS ONLY (Press ALT A for List)
Wind direction along central axis 7 SE
ENTER NUMBERS ONLY (Press ALT B for List)
Wind Stress Factor (Ua) = 31 mph
Wave Period (T) = 1.94 Seconds
Wave Length (L) = 19.33 Feet
Average depth of lake along central axis (d) = 15 Feet
d/L = 0.78
Wave type is Deepwater Wave

Hazard Class of Site: 1
(1=Low, 2=Med, 3=High)

Wave Height Design

Significant Wave Height (Hs) = 1.1 Feet
Design Wave Height (Ho) = 1.4 Feet
Input Slope Ratio of Revetment (i.e. 2:1): 3 (USE ONLY 1.5,2,3,4,5,6,10)
Ho/L = 0.07
Runup (R) = 1.8 Feet   Setup (S) = 0.2 Feet

Elevation Design

Ordinary High Water Elevation = 100.0
Normal Yearly Low Lake Elevation(if different) 99.3
Average Top Elevation of Existing Bank = 103.5
Lake Bottom Elevation at Shoreline = 99.0
Lower Limit For Protection = 97.2 Calc
Upper Limit For Protection = 102.0 Calc   102.0 Used
No Overtopping Pad Needed

Rock Design

Specific Gravity of Rock (Gs): 2.5
Shape of Rock: 1=Cubical 2=Sperical 1
d50 Rock Size = 4.5 Inches (Calc)   6 Inches (Used)
Rock Thickness = 12.0 Inches
Toe Type (A,B,C, or boulDer) a   La = 11 Feet
Length of Shoreline= 60 Feet

Riprap Gradation

% Passing	Size of Stone (Inches)		
100	12	to	15
85	9.6	to	12
50	6	to	9
15	1.8	to	3

Quantities

Riprap: 48 Cu. Yds.
Geotextile: 169 Sq. Yds.
Filter: 26 Cu. Yds.

BIOENGINEERING TECHNIQUES FOR SMALL LAKE LAKESHORE PROTECTION

Control of shoreline erosion can be achieved with soil bioengineering techniques provided the energy of the waves does not exceed the resistance of the plant roots or combination of plant roots and manufactured systems. Wave height is an indication of the energy. To assess the acceptability of treatments, the wave height must be calculated by the procedure in this Chapter.

The following table can be used to assist in selecting materials or combination of materials for treatment. (Note: this information has been provided by Bestmann Green Systems and is in no way an endorsement for their products).

From the top portion of the table shown on the next page, locate the type and level of stress factors present on the site for proposed bioengineering work. The stress levels shown represent maximum values, not average values. The highest stress level indicated is used to determine the materials needed. In general, materials listed in the lower portion of the table under the same stress level column will provide the necessary protection for the site. If the highest stress level column for the proposed site has two factors in it, move into the next higher stress level column to determine the materials needed. The stress tolerance of the materials shown below assumes that each material is used alone. When materials are used in combination with each other, or with additional protective structural measures, the range of application is increased.

Placement of the fiber or rock roll has been found to be most cost effective when the normal water depth along the shoreline is about one roll diameter. The rolls are effective for controlling bank undercutting and the roll is tucked under the overhang. Do not use the fiber rolls when fluctuating lake levels exceed the diameter of the roll. They must be kept wet for the plant species to survive.

Anchoring the rolls is critical to the installation. A "duckbill" anchor or equivalent product is effective. Unless specified differently, for 20" diameter logs 8 anchors are needed for each log. For 16" and 12" diameter logs 10 anchors are needed for each log. Space them equally along the length of the log.

Use only healthy and disease free plants. Knowledge of plant species and their site adaptability is critical for planning the system.

NOTE: Involve agency personnel in the site planning that have any kind of responsibility for any aspect of the job.

STRESS TYPE	STRESS LEVELS I	II	III	IV	V
Wave Height	<0.5 ft	<1.0 ft	<1.7 ft	<2.5 ft	<4 ft
Slope	<10:1	<5:1	<3:1	<2:1	variable
Sun Exposure	full sun	mostly sun	part sun	part shade	shade

MATERIALS

MATERIALS	I	II	III	IV	V
Med. Plant Plugs	x				
Fiber Webbing	x				
Lrg. Plant Plugs	x	x			
Plant Carpets	x	x			
Plant Pallets		x	x		
Fiber Mat		x	x		
Fiber Roll		x	x		
Plant Roll		x	x	x	
Brush Mattress		x	x	x	
Fiber Roll (PE)			x	x	x
Rock Roll				x	x
Plant Revetment				x	x

Tabular data was provided by permission of Bestmann Green Systems

Typical Cross Sections for Stress Levels

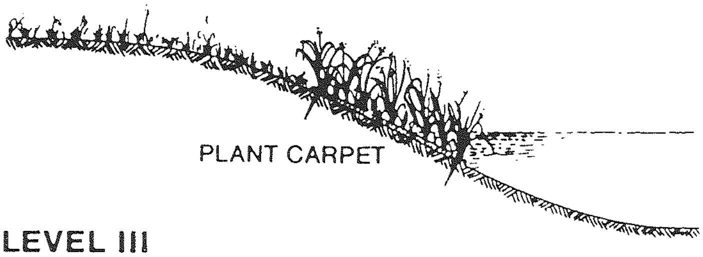
The following typical cross sections illustrate possible treatments as noted in the table above.

TYPICAL CROSS SECTIONS - LAKESHORE BIOENGINEERING

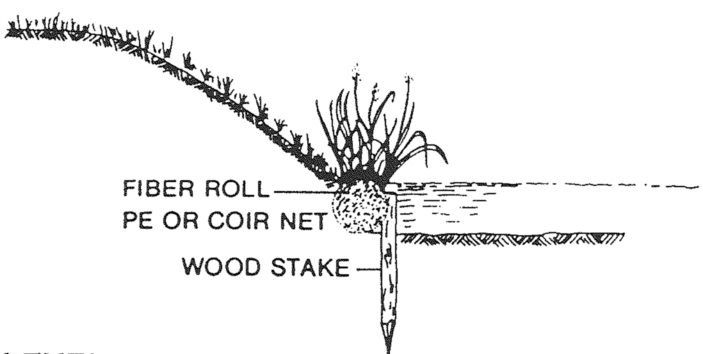
These typical cross sections are shown to illustrate ideas that are compatible with Stress Levels I - V given in the table.

LEVEL I

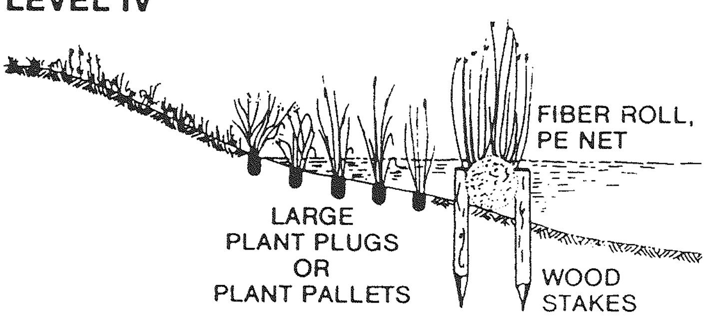
LEVEL II



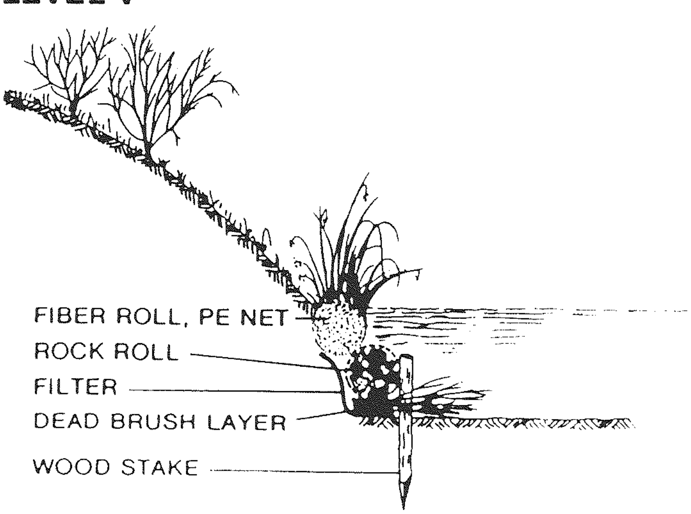
LEVEL III

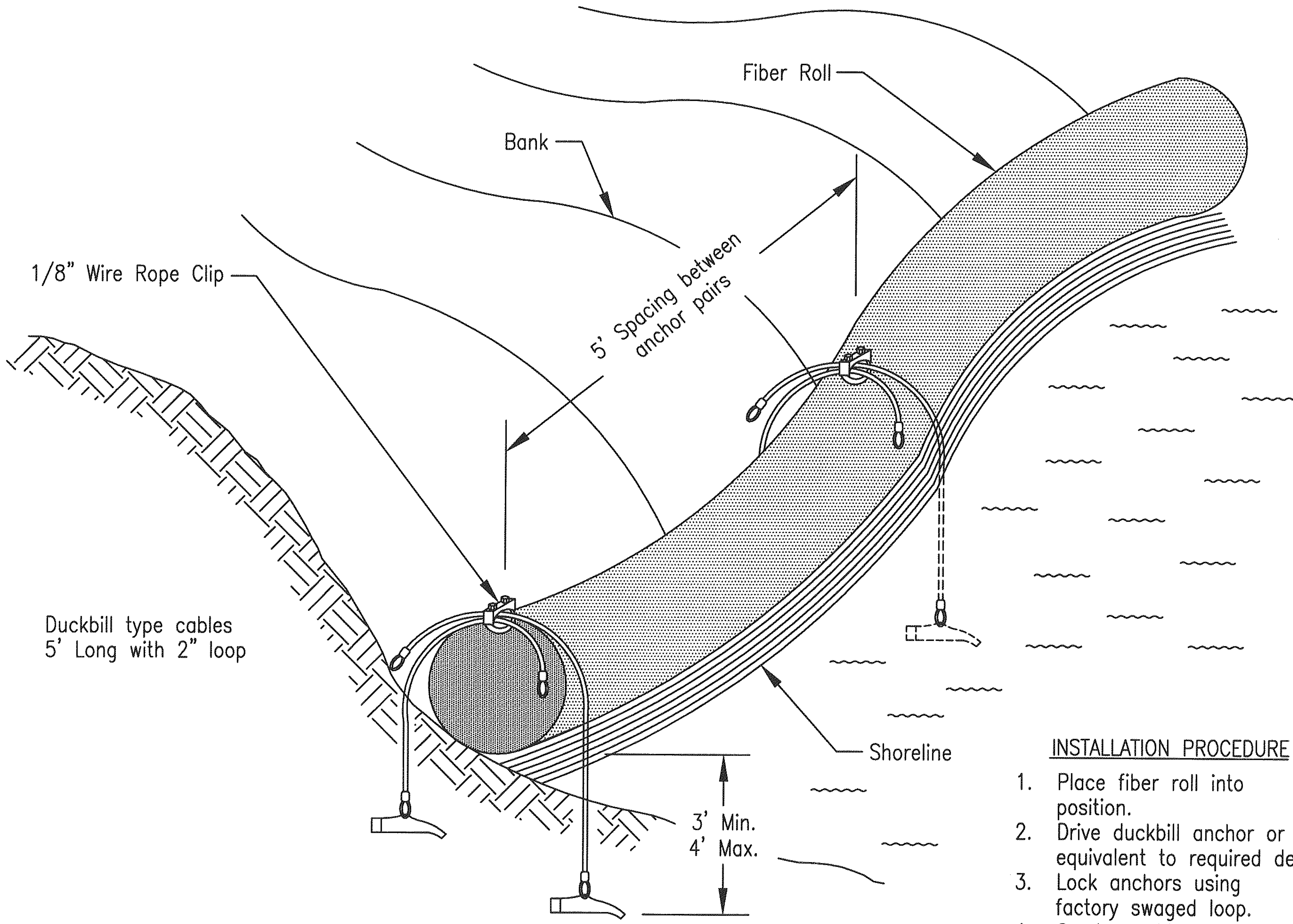


LEVEL IV



LEVEL V



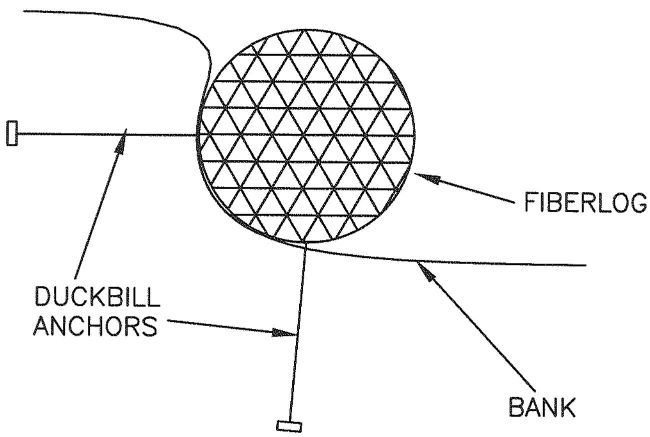


SHORELINE STABLIZATION
DUCKBILL FIBER ROLL

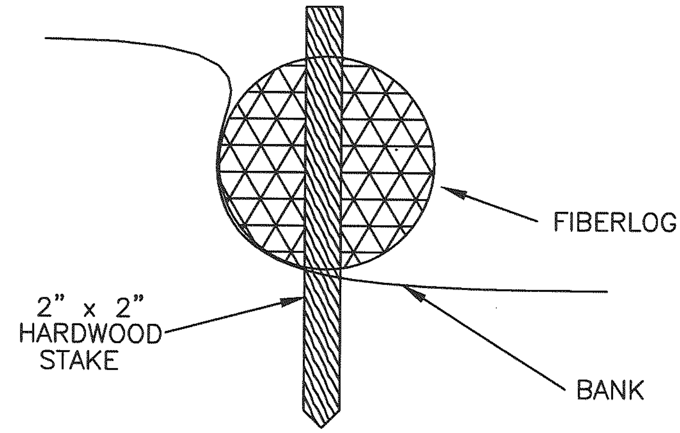
INSTALLATION PROCEDURE

1. Place fiber roll into position.
2. Drive duckbill anchor or equivalent to required depth.
3. Lock anchors using factory swaged loop.
4. Overlap cables and secure with wire rope clip.

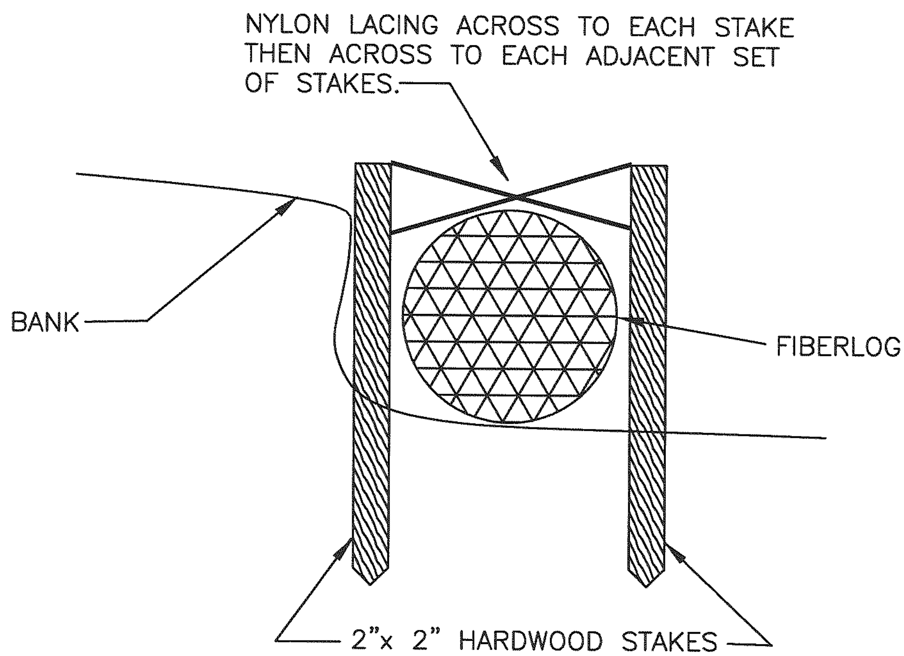
COCONUT FIBER LOG
INSTALLATION OPTIONS FOR SHORELINE PROTECTION



DUCKBILL ANCHOR SYSTEM



2"x 2" HARDWOOD STAKE

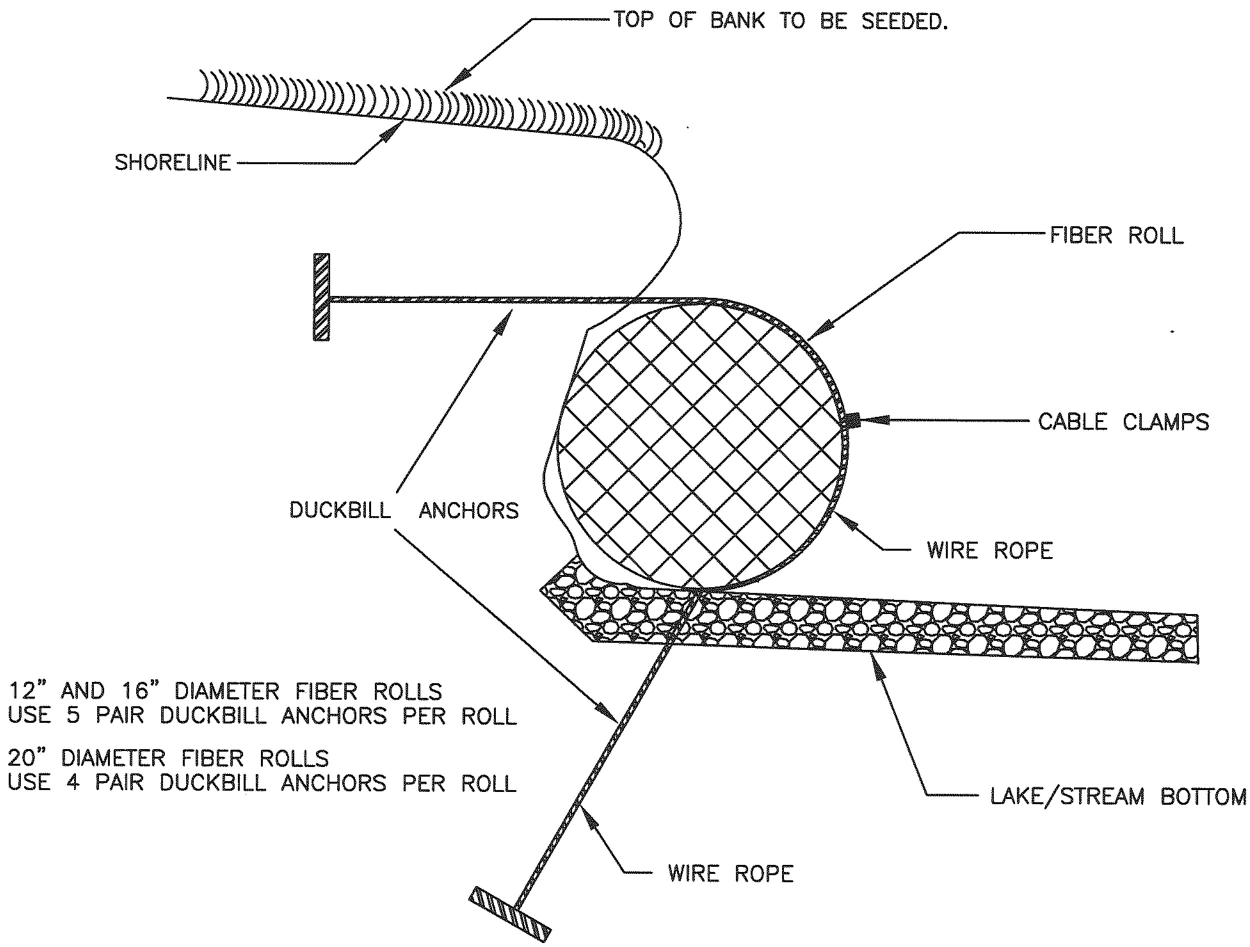


DOUBLE HARDWOOD STAKES

DESIGN CRITERIA TABLE*

WAVE HEIGHT:	<1 FT.	<20 IN.	<2.5 FT.	<4 FT.
FIBER ROLL COIR NET	X	X		
FIBER ROLL PE NET		X	X	X

*ASSUMES VEGETATION IS PLANTED INTO FIBER LOG.



FIBER ROLL SHORELINE PROTECTION WITH DUCKBILL ANCHORING SYSTEM

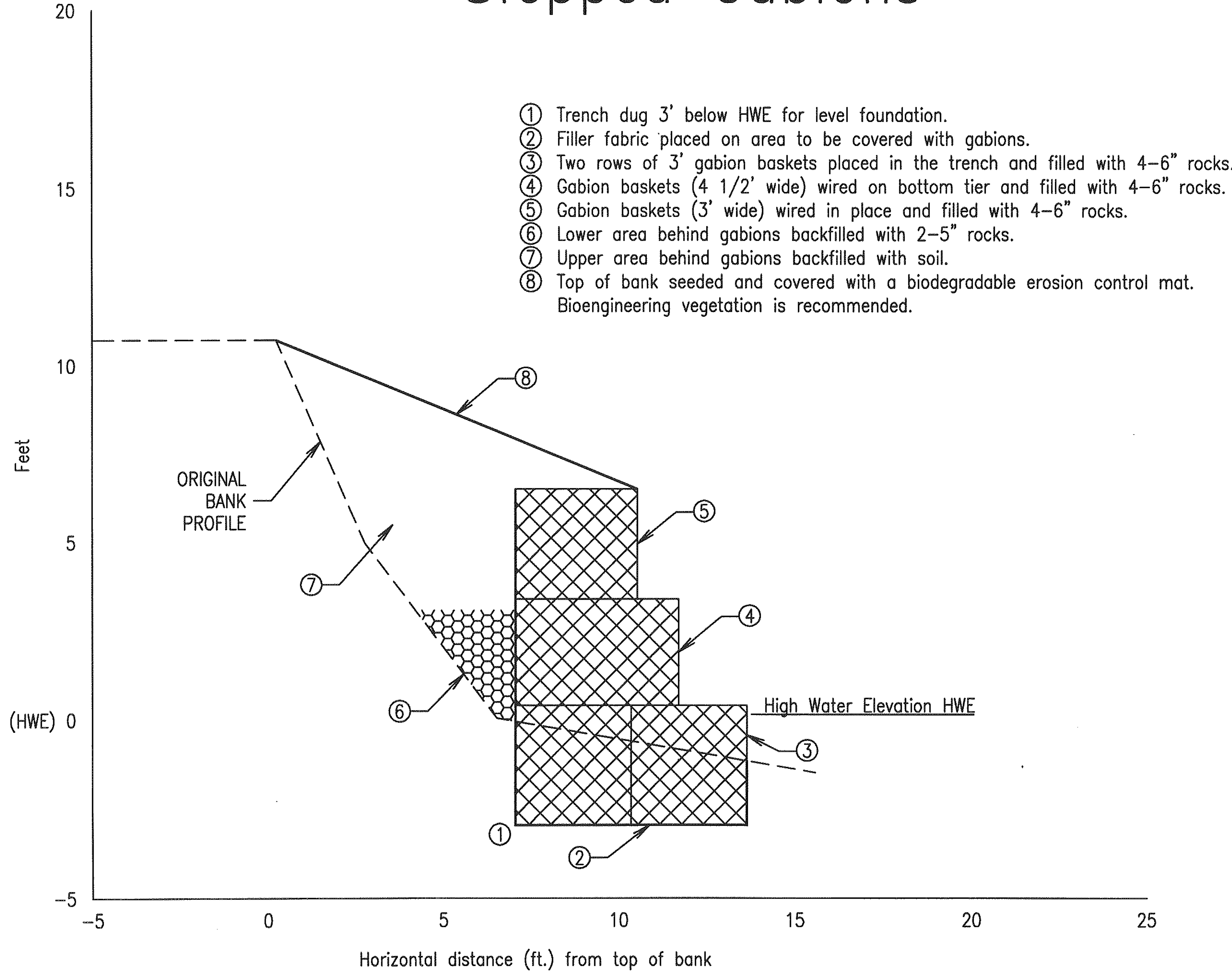
ESTIMATED QUANTITIES

20" Fiber Logs (10' sections) each:______
16" Fiber Logs (20' sections) each:______
12" Fiber Logs (20' sections) each:______
Duckbill Anchors _____ ft. long, each:_____
Connecting Clamps (4 per anchor) each:_____
Nylon Cord as necessary.

CONSTRUCTION NOTES:

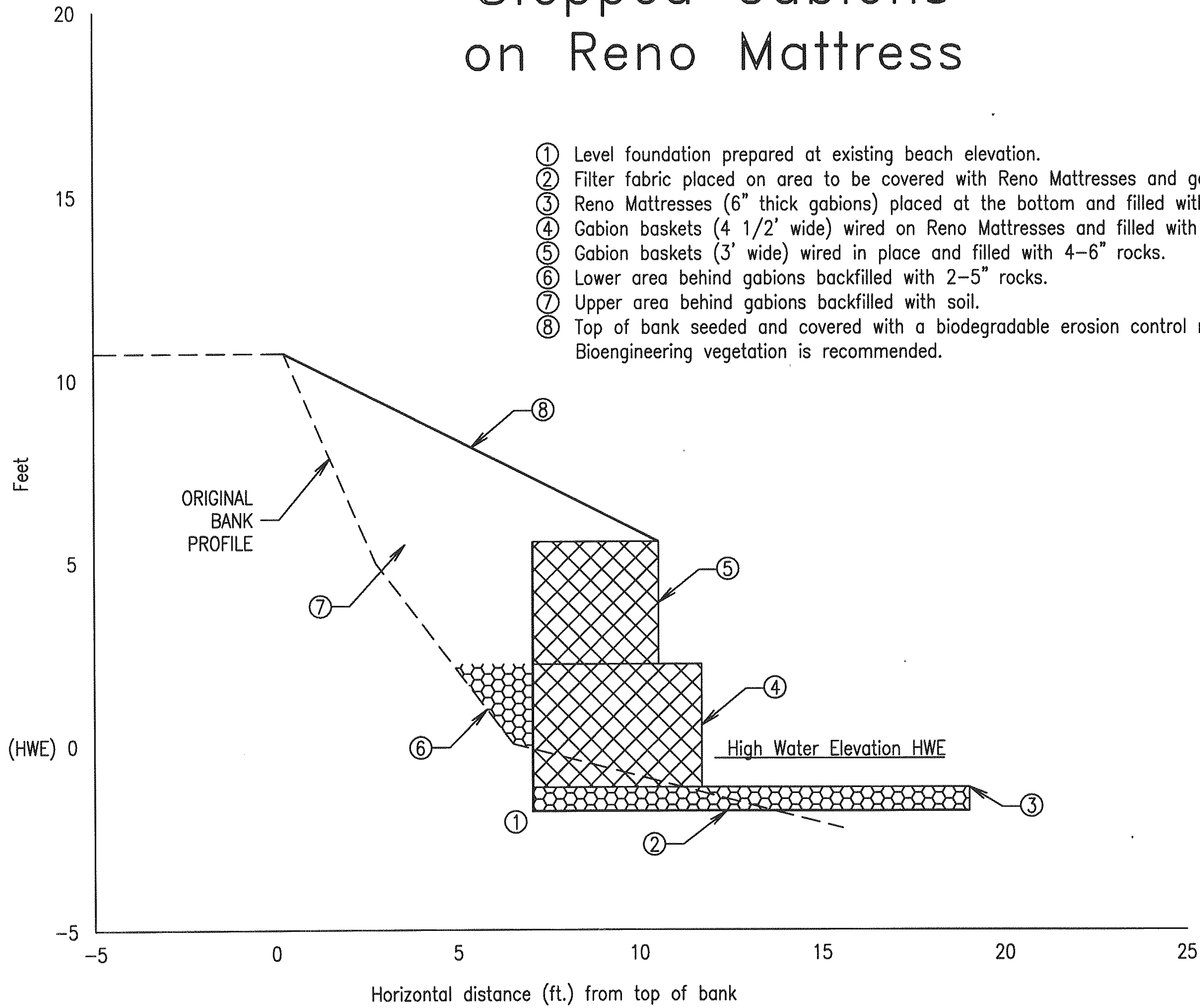
Fiber logs will be placed at the toe of the shoreline and anchored in place with Duckbill anchors. 20" logs need 8 anchors each and 16" and 12" logs need 10 anchors each. These anchors will be wrapped around the log and attached with galvanized cable clamps. Embed anchors into shoreline as deep as possible with driver. Tighten clamps as necessary. Firmly backfill fiber log and fold top of shoreline over the top of the log. A snug fit into shoreline is best. Lace ends of fiber log together with nylon cord. Vegetation may be sprigged into fiber log as desired.

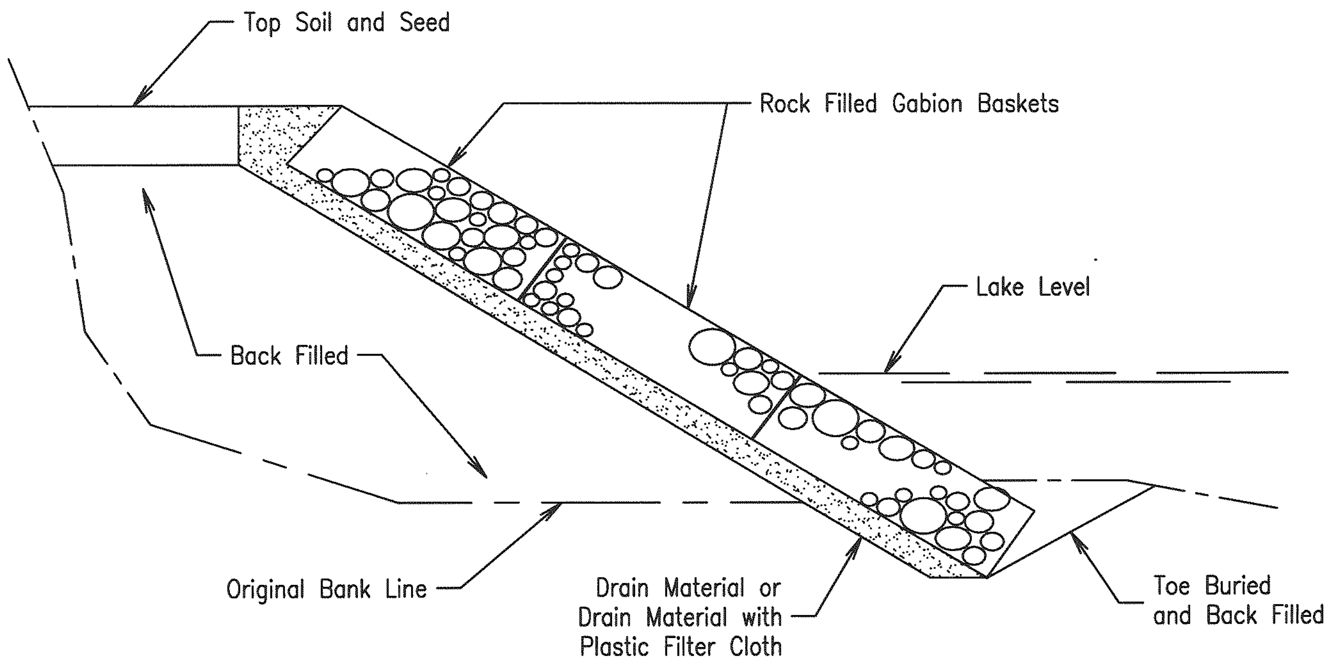
Stepped Gabions



Stepped Gabions on Reno Mattress

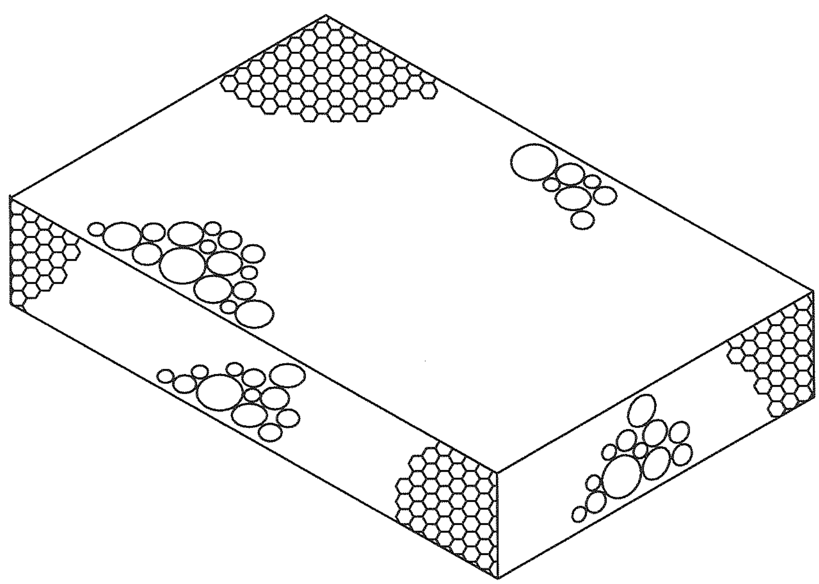
1. Level foundation prepared at existing beach elevation.
2. Filter fabric placed on area to be covered with Reno Mattresses and gabions.
3. Reno Mattresses (6" thick gabions) placed at the bottom and filled with 3–5" rocks.
4. Gabion baskets (4 1/2' wide) wired on Reno Mattresses and filled with 4–6" rocks.
5. Gabion baskets (3' wide) wired in place and filled with 4–6" rocks.
6. Lower area behind gabions backfilled with 2–5" rocks.
7. Upper area behind gabions backfilled with soil.
8. Top of bank seeded and covered with a biodegradable erosion control mat. Bioengineering vegetation is recommended.



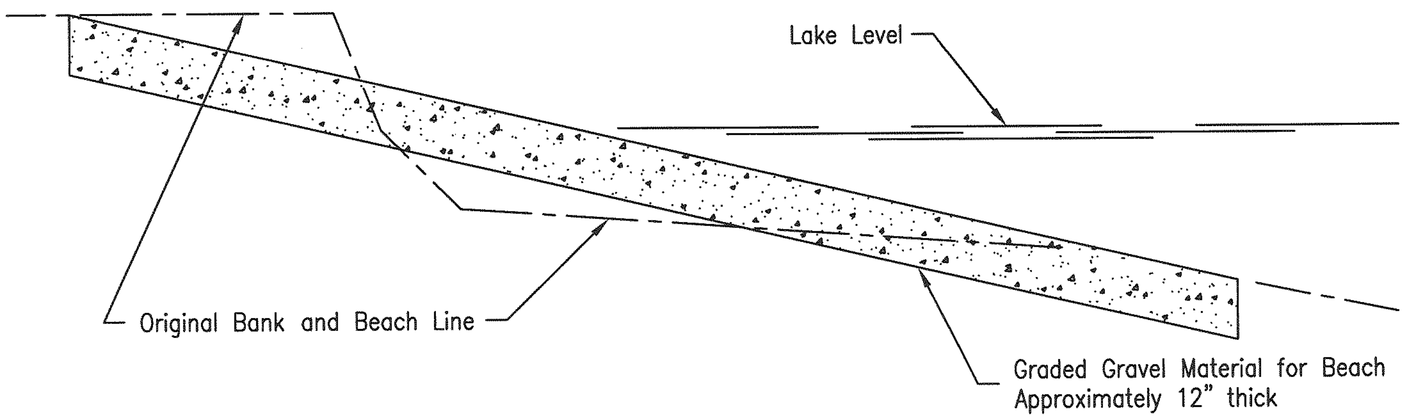


GABIONS FOR LAKESHORE PROTECTION
TYPICAL CROSS SECTION

Drain material—well graded gravel, maximum size 1" with less than 5% passing 100 sieve (similar or equal to)



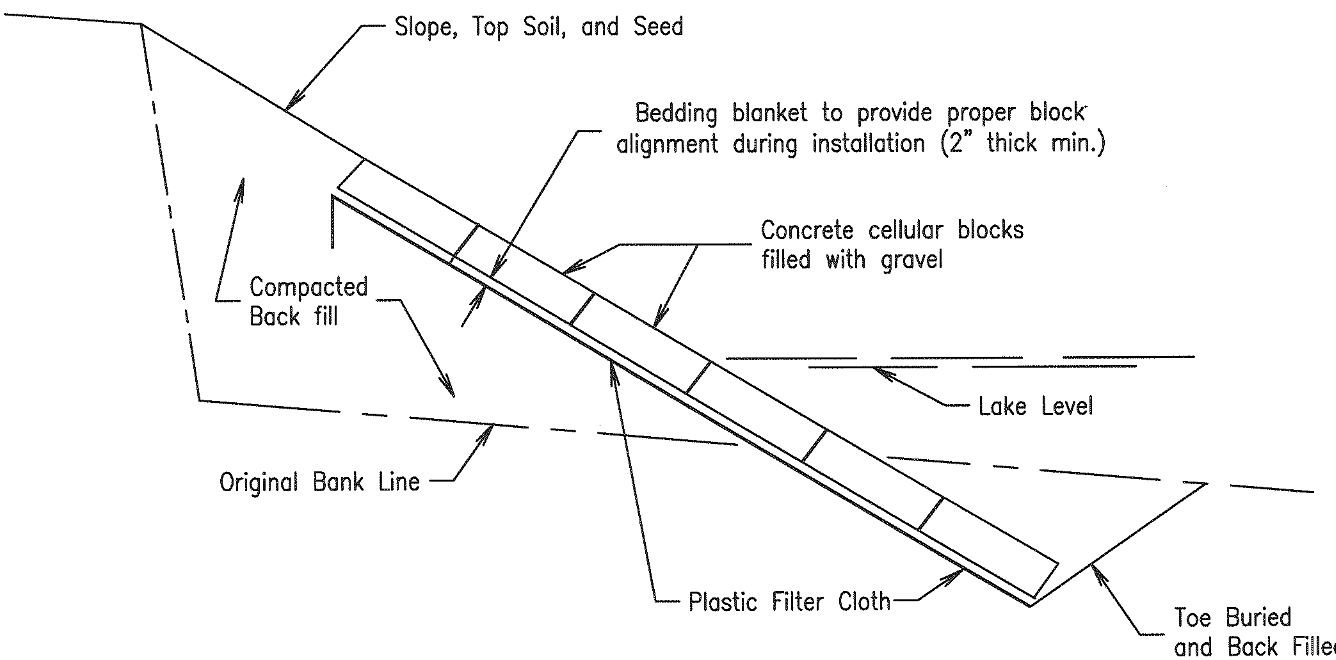
GABIONS FOR LAKESHORE PROTECTION
ISOMETRIC VIEW



TYPICAL CROSS SECTION

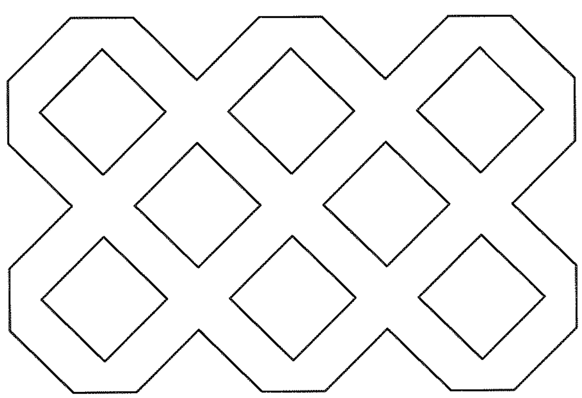
NOTE: The beaching shall range from 10 to 1 TO 4 to 1 based on the size of the graded material used.

Seeding blanket to be well graded gravel, maximum size 1" with less than 5% passing 100 sieve (similar or equal to).

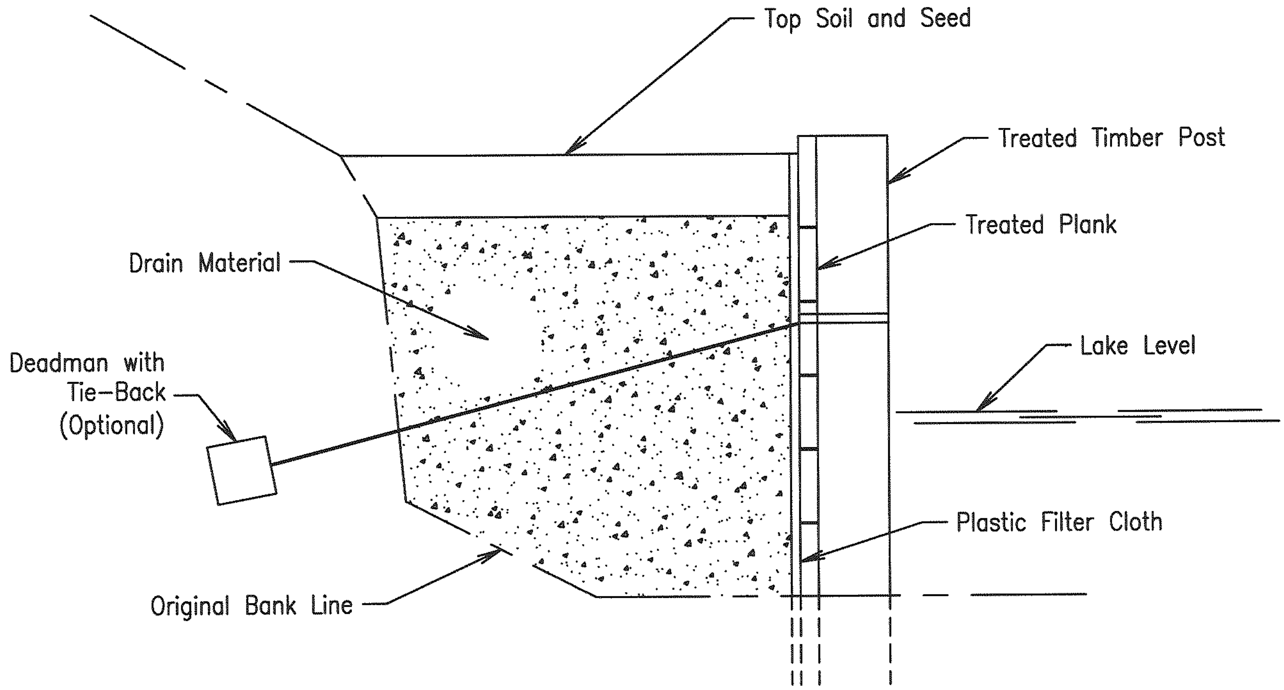


CONCRETE CELLULAR BLOCKS FOR LAKESHORE PROTECTION
TYPICAL CROSS SECTION

Approximate size of concrete cellular blocks – 16" x 24" x 3-1/4" thick

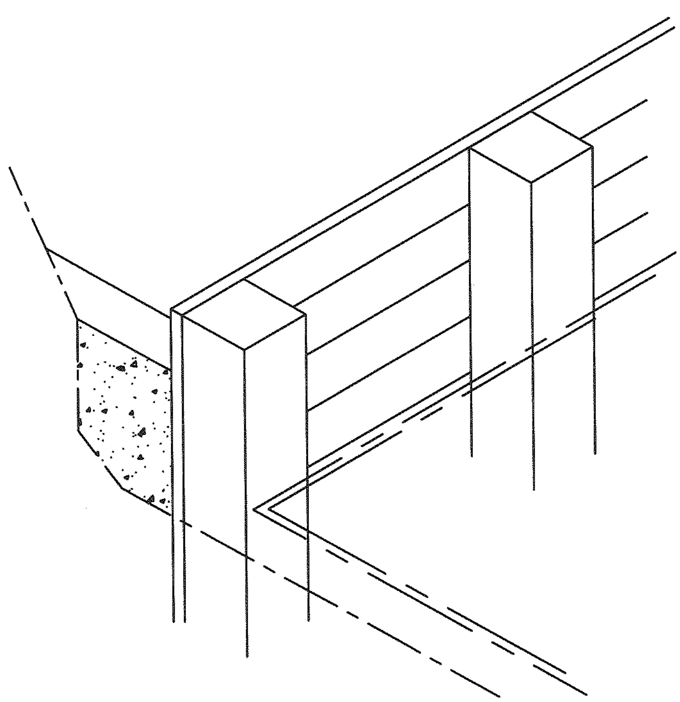


CONCRETE CELLULAR BLOCKS FOR LAKESHORE PROTECTION
PLAN VIEW OF CONCRETE BLOCK

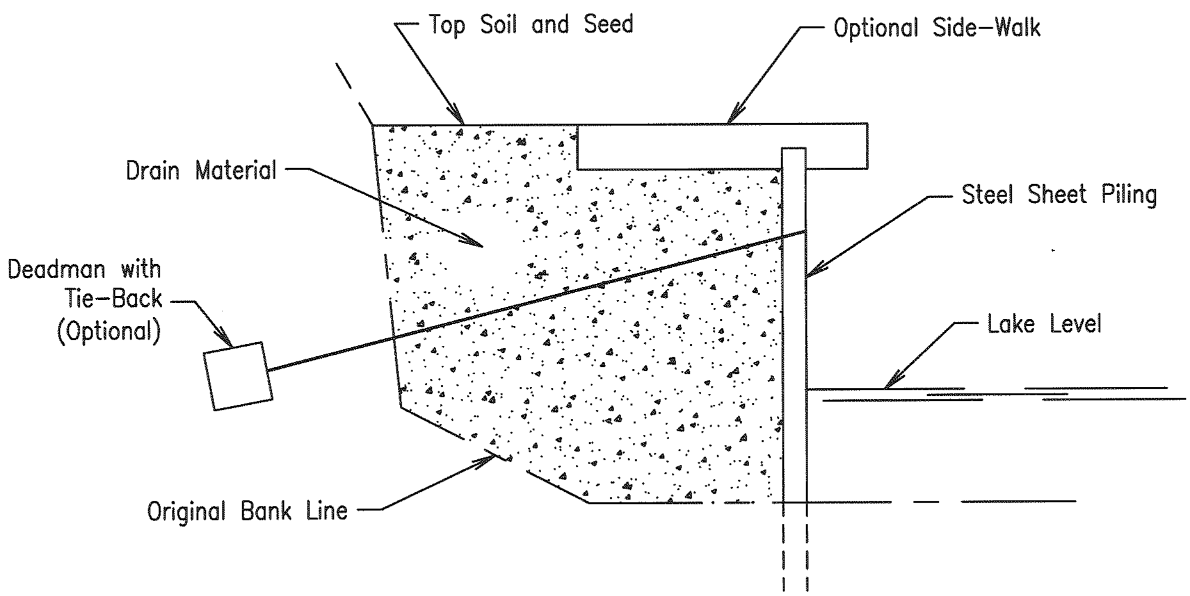


TREATED PLANK AND POST WALL FOR SHORELINE PROTECTION
TYPICAL CROSS SECTION

Drain material–well graded gravel, maximum size 1" with less than 5% passing 100 size sieve (similar or equal to)



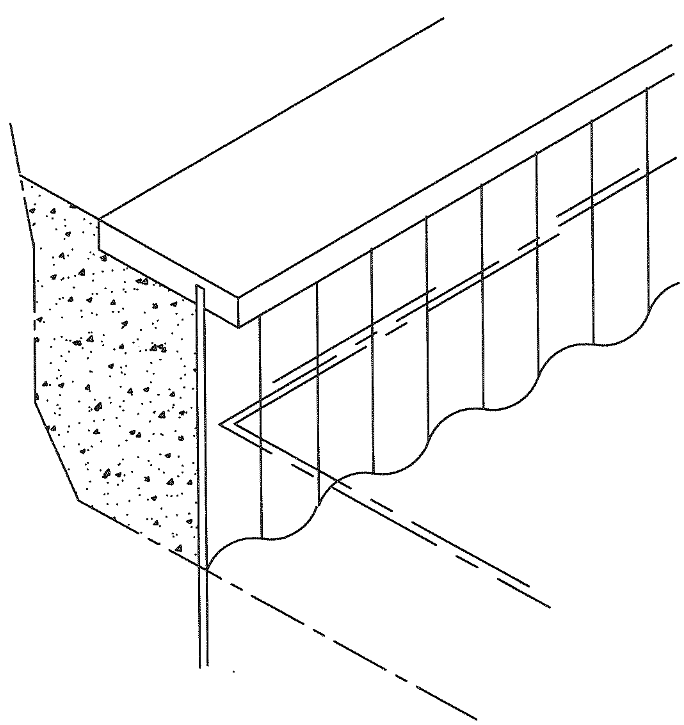
TREATED PLANK AND POST WALL FOR SHORELINE PROTECTION
ISOMETRIC VIEW



STEEL SHEET PILING WALL FOR SHORELINE PROTECTION

TYPICAL CROSS SECTION

Drain material-well graded gravel, maximum size 1" with less than 5% passing 100 size sieve (similar or equal to)



ISOMETRIC VIEW

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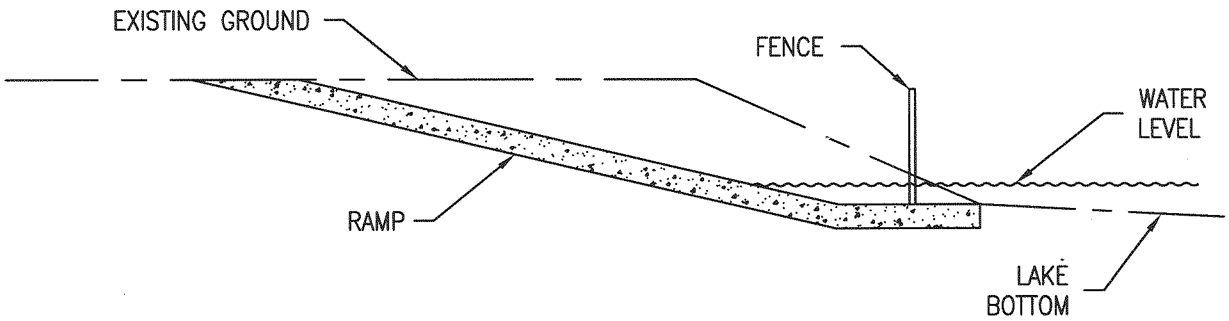
LIVESTOCK LAKE SHORELINE WATERING RAMP

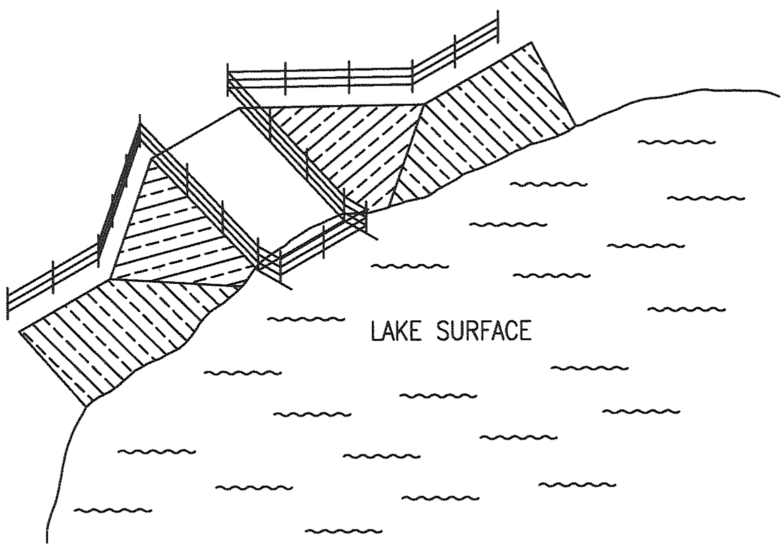
Livestock lakeshore cattle watering ramps need a ramp slope safe for the cattle to walk on in most seasons of the year. A slope of 4:1 or flatter has proven to work well. The ramp side slopes should be 2:1 or flatter. The lowest elevation of the ramp should provide about one foot of water but not extend more than 5 feet into the water.

Ramp surfacing shall be as specified for livestock stream crossings in the Practice Standard 560, Access Road, Section IV, Filed Office Technical Guide, NRCS. Refer to the Wisconsin Standard Detail Drawings For Conservation Practices on file at NRCS Field Offices for a standard drawing.

Fence the sides of the ramp surfacing and across the bottom end of the ramp. This will restrict cattle access into the stream bottom. See Practice Standard 382, Fencing, Section IV, Field Office Technical Guide, NRCS.



TYPICAL CROSS SECTION



ISOMETRIC VIEW

LAKESHORE WATERING RAMP

MAINTENANCE PLAN

Standard 580 requires a Maintenance plan. This is to be written specifically for the site or project. Typically there are not any OPERATION functions for shoreline protection systems.

An example MAINTENANCE PLAN and some example statements for a plan are shown below. These are not all inclusive, nor are any or all of these required.

NRCS Standard Drawing WI-901 can be used.

MAINTENANCE PLAN (sample)

Lakeshore Protection

I agree to the following for the next ten years:

1. Inspect the rock and lakeshore annually and after heavy wind events for erosion or displacement of rocks. Give immediate attention to repair needs.
   a. Replace dislodged rocks.
   b. Remove debris.
   c. Fill and/or reseed as needed.

2. Undesirable brush and trees shall be controlled by cutting and/or application of approved chemicals. Small species are acceptable as bioengineering inter-planted vegetation.

3. Refill eroded or settled areas that may occur. Reseed.

4. Eliminate all burrowing rodents and repair damage caused by them.

5. Replace plants that failed to grow in the biolog (fiber roll, fiber log).

6. Boats and docks or piers are not to be stored on the treated bank.

______________________________ ______________

Owner's Signature Date

WISCONSIN SUPPLEMENT
ENGINEERING FIELD HANDBOOK
CHAPTER 16
STREAMBANK AND SHORELINE PROTECTION

STANDARD 580
COMPANION DOCUMENTS

SELECTING CONSERVATION PRACTICES AND LANDSCAPE CONTEXT FOR PROTECTION OR RESTORATION

It is important to recognize the site-level landscape settings or zones on a streambank or lakeshore that influences the selection of potential practices.

This Companion Document displays a conceptual cross-section schematic of applicable landscape zones, descriptions of each zone, and a short list of appropriate practices. Because of the strong physical and ecological interaction of banks with their adjacent corridors of land and vegetation, project planning should consider the entire bank and adjacent land which includes the bed, banks, and riparian areas. These landscape components strongly interact and are best planned as a whole to optimize desired effects and meet client and ecological objectives.

The planner must match site impairments, landscape zones, and client objectives with conservation practices.

Wisconsin NRCS Technical Standards

- 322 - Channel Bank Vegetation (National NRCS)
- 342 - Critical Area Planting
- 391 - Riparian Forest Buffer
- 393 - Filter Strip
- 395 - Stream Habitat Improvement and Management
- 396 - Fish Passage
- 580 - Streambank and Shoreline Protection
- 584 - Channel Stabilization
- 643A - Shoreland Habitat

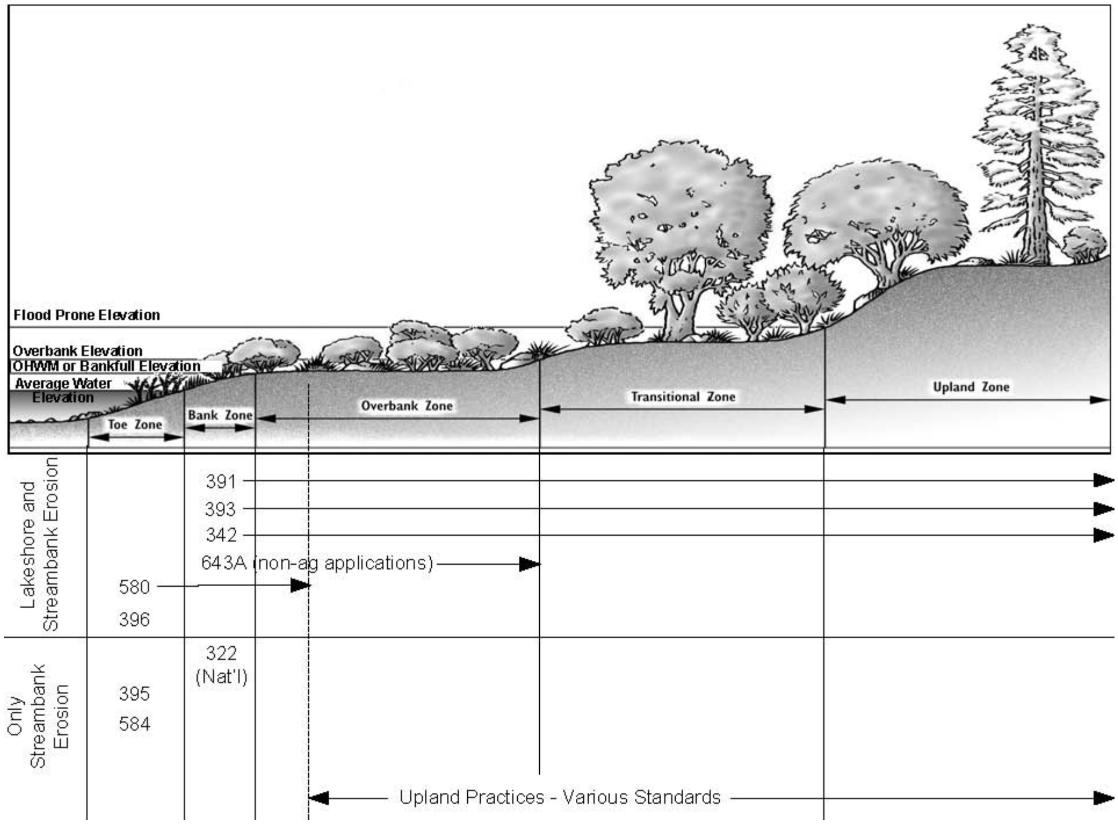
The National Engineering Handbook (NEH), 210-VI, Part 654, NRCS Stream Restoration Design, has additional resources. It is available at the eDirectives Website, http://policy.nrcs.usda.gov/index.aspx, see Title 210-Engineering/National Engineering Handbook listing. Individual chapters, technical supplements, and case studies can be downloaded from this site.

NEH-654 provides tools for designing stream restoration projects. Over 200 practitioners from government, private, and academic fields have participated in its production.

NEH-653, “Stream Corridor Restoration: Principles, Processes, and Practices,” was released in 1998 and provides basic principles about stream restoration and how to plan stream restoration projects.

NEH-654 complements NEH 653 by providing assessment and design tools that are applicable to any stream restoration work, whether it primarily follows a natural stream restoration or is strictly a structural project.

Location of Hydrologic Zones Along a Streambank or Shoreline and Applicable NRCS Technical Standards



<u>Definitions and Descriptions of Hydrologic Zones</u>

Bank Zone - The area above the Toe Zone located between the average water level or the bankfull elevation or OHWM. Vegetation may be herbaceous or woody, and is characterized by flexible stems and rhizomatous root systems.

Flood Prone Elevation (streams only) - Twice the maximum bankfull depth.

Overbank Zone - The area located above the top of the bank, or the bankfull elevation continuing upslope to an elevation equal to two thirds of the flood prone depth. Vegetation is generally small to medium shrub species.

Toe Zone - The portion of the bank that is between the average water level and the bottom of the lakebed or channel, at the toe of the bank. Vegetation is generally herbaceous emergent aquatic species, tolerant of long periods of inundation.

Transitional Zone - The area located between the overbank zone, and the flood prone width elevation. Vegetation is usually larger shrub and tree species.

Upland Zone - The area above the Transitional Zone; this area is seldom if ever saturated.

OHWM (both streams and lakes) or Bankfull Elevation (streams only) - The point on the bank or shore up to which the presence and action of the water is so continuous as to leave a distinct mark either by erosion, destruction of terrestrial vegetation, or other easily recognized characteristics (the elevation of the water during the flow that occurs on average, every 1.2 years. In many channels this is the point where water begins to flow out on to the floodplain. Since floodplains may be small, indistinct or newly developing, it is important to verity correct identification of the bankfull surface by checking against the 1.2-year discharge using one of the methods for determining discharge listed in Companion Document 580-8, Detailed Instructions for Reference Reaches.

Note: Some locations have fewer than four hydrologic zones because of differences in soils, topography, entrenchment and/or moisture regime, erosion or human influence.

MANAGEMENT ASSESSMENT - STREAMBANKS AND SHORELINES
Streambank and Shoreline Protection Code 580

1. Land use adjacent to the project area?

☐Cropland Description______________________________
☐Pasture ______________________________
☐Wetland ______________________________
☐Idle (CRP) ______________________________
☐Residential Level of management ______________________________
☐Recreation ______________________________
____

2. Describe wildlife and stream or shoreline habitat in the project area (e.g., spawning beds, obvious corridors, endangered species).

____
____
____

3a. Describe the existing vegetation and vegetation management in each zone.

Toe Zone: ______________________________
____
Bank Zone: ______________________________
____
Buffers: ______________________________
____
Overbank Zone: ______________________________
____
Transitional Zone: ______________________________
____
Upland Zone: ______________________________
____

3b. Describe the planned or desired vegetation and vegetation management in each zone.

Toe Zone: ______________________________
____
Bank Zone: ______________________________
____
Buffers: ______________________________
____
Overbank Zone: ______________________________
____
Transitional Zone: ______________________________
____
Upland Zone: ______________________________
____

4. Describe the existing and planned access points to the water.

	Existing	Planned
Number:	______	______
Public or private use:	______	______
Frequency of use (light, medium, heavy):	______	______
People, vehicle use, or animal/livestock access:	______	______

5. What is the allowed (or existing) use of watercrafts on the waterbody?

Motorized boat traffic: ☐Large ☐Medium ☐Small ☐Non motorized

Describe posted restrictions: ______

______

Describe impact of watercraft: ______

______

6. Is the landowner willing to carry out specific maintenance needs?

☐Maintain a buffer without mowing.
☐Maintain a nonstructural measure.
☐Watering and weeding frequently.
☐Storing docks and boat lifts off the buffer.
☐Maintain a legal access corridor.

Describe: ______

______

7. What is the stormwater/watershed management at the project site?

Describe how runoff is currently managed (e.g., roof gutters, rain gardens, diversions, berms, terraces, etc.): ______

______

8. What is the landowner's vision of their property (desired condition and future plans)?

☐Natural buffer with native vegetation.
☐Neat, manicured lawn.
☐Small impervious area.
☐Landscaped area.
☐Continue with existing use.

Describe: ______

______

______

______

______

______

STREAMBANK SITE ASSESSMENT CHECKLIST
Streambank and Shoreland Protection Code 580

General Data			
Field Staff:	Date:	Legal Description:	GPS Coordinates:
Property Owner Information			
Name(s):	Address:	Telephone:	Trust: ☐Yes ☐No Tax ID#:
Water Body Information			
Name:	Type:	Watershed Code:	Size of Parcel:

Floodplain / Riparian Habitat / Physical and Biological Features / Stream Designation

Simon and Hupp Stage of Evolution *(See Companion Document 7)*: ______________________________

Rosgen Classification *(See Companion Document 5, Stream Classification Using the Rosgen System, and Job Sheet 811, Stream Channel Classification)*: ______________________________

BEPI Score: ______________ *(http://dnr.wi.gov/org/water/fhp/waterway/permits/BankErosionPotentialIndexWorksheet.pdf)*

Area of special natural resource interest: ☐Yes ☐No

Section 303d listed water body: ☐Yes ☐No *(http://dnr.wi.gov/org/water/wm/wqs/303d/303d.html)*

ORW or ERW: ☐Yes ☐No *(http://dnr.wi.gov/org/water/wm/wqs/orwerw/list1006.pdf)*

Trout Stream Class: ☐I ☐II ☐III ☐Unclassified ☐Cold water ☐Warm water
(http://www.dnr.wi.gov/fish/species/trout/streammaps.html)

Stream order: ______________________________

Evidence of fish spawning? ☐Yes ☐No

Invertebrate use? ☐Yes ☐No

Describe other habitat features: ______________________________

____

Fish habitat within the stream: ______________________________

____

Emergent plants (plants rooted in bottom sediments and emerging from surface):

Density: ☐Low ☐Medium ☐High

Diversity: ☐Low (1-5 species) ☐Medium (5-15 species) ☐High (>15 species)

Floating-leaved plants (rooted plants with floating leaves):

Density: ☐Low ☐Medium ☐High

Diversity: ☐Low (1-5 species) ☐Medium (5-15 species) ☐High (>15 species)

Submergent plants (rooted plants that remain below the water surface):

Density: ☐Low ☐Medium ☐High

Diversity: ☐Low (1-5 species) ☐Medium (5-15 species) ☐High (>15 species)

Does landowner remove aquatic plants? ☐Yes ☐No

Any other management activity? ☐Yes ☐No Describe: ______________________________

____

Type of pier: ☐Solid ☐Cantilevered ☐Permanent ☐Removable
☐Wharf (parallel or perpendicular to shoreline) ☐Other

Describe riparian area in further detail: ____

Stream Features

Water surface profile at time of site visit: ☐Upstream ☐Downstream ☐Site location

OHWM / Bankfull elevation: __________ feet.

Any evidence of water level fluctuations with runoff (flashy streams; water control structures; etc.)? __________

Calculate the capacity and velocity of the stream: __________________ cfs ___________________ fps.

Adjacent tributaries or flowing water: ☐Yes ☐No

Coarse wood habitat/downed trees/large branches (>6" diameter): ☐Absent ☐Rare ☐Common ☐Abundant

Choose one: ☐Pools and riffles **OR** ☐Pools and Steps or cascades

Describe spacing and frequency: ____

Abrupt grade changes: ☐Yes ☐No Describe: ____________________________________

Stream Access

Width: ___________ linear feet.

Path design: ☐Straight ☐Meandering ☐Flat ☐Steep

Path substrate: ☐Lawn turf ☐Wood chips ☐Gravel ☐Pavement ☐Stairway
☐Other-describe: ____

Access function: ☐Stream View ☐Wildlife Viewing ☐Boat/Dock Access ☐Swimming ☐Fishing

Extent of use: ☐Low ☐Medium ☐High Access view corridor: ☐Present ☐Absent

Erosion Evidence

Evidence: ☐None ☐Bare earth ☐Furrows/slumping/gullies ☐Deposits of silt/sand
☐Sedimentation in stream ☐Upland rills ☐Headcutting

Rate severity: ☐Low ☐Medium ☐High

Describe the bank recession rate: ____

Probable cause(s) of instability: ☐Water level fluctuation ☐Ice action/ice dams
☐Groundwater seeps ☐Overland flow ☐Other _____________

Presence of existing erosion control practices: ☐Present ☐Absent

Describe types (i.e., retaining walls; landscape timbers; etc.): ____________________________

Riparian Buffer Area Vegetation

Sun exposure: ☐N ☐NE ☐E ☐SE ☐S ☐SW ☐W ☐NW

Buffer dimensions: __________ width feet. __________ length feet.

Buffer slope: ☐Flat (< 10 %) ☐Moderate (10-20%) ☐Steep (> 20%)

Vegetation layers: ☐Trees ☐Shrubs ☐Ground cover

Plant diversity:

Aquatics/littoral zone: ☐Low (1-5 species ☐Medium (5-15 species) ☐High (>15 species)

Wet-edge plants: ☐Low (1-5 species) ☐Medium (5-15 species) ☐High (>15 species)

Upland Plants: ☐Low (1-5 species) ☐Medium (5-15 species) ☐High (>15 species)

Maximum distance wet feet plants extend from shore: __________ linear feet.

Uniform: ☐Yes ☐No

Can the buffer zone be increased? ☐Yes ☐No Why? ________________________________

____

Enhance or change existing vegetation by: ☐Plant native vegetation ☐Leave as no-mow area ☐Other

List common species present: ____

____

Aquatic habitat: ☐poor ☐fair ☐good ☐excellent

Upland habitat: ☐poor ☐fair ☐good ☐excellent

Invasive species present: ☐Yes ☐No Describe: ______________________________

Describe accessibility for construction equipment: ______________________________

____

Streambed and Bank Composition

Soil series: ____

Complete a Unified Soil Classification System (USCS) profile log using Job Sheet 814 or 817 found on the Wisconsin Natural Resource Conservation Service (NRCS) web page.

Visually determine if the stream bed is: ☐Aggrading ☐Degrading ☐Stable

(See Investigations, WI Supplement to EFH Chapter 16,)

Bed substrate type(~percentage): ____% Boulders ____% Cobble ____% Gravel ____% Bedrock

(See Job Sheet 810) ____% Sand ____% Silt ____% Organic matter

Presence of stream sediment matter: ☐Yes ☐No Describe: ☐Fine sand ☐Silt ☐Organic matter

Existing Structures

☐Dam ☐Bridge ☐Culvert ☐Other Describe size and proximity to project site for each: ________

____

Structures present (swimraft; boathouse; boat hoist; PWC lift; seawall; riprap; bioengineering; benches; etc.):

____

☐Year-round house ☐Seasonal house ☐Shed ☐Garage ☐Old foundations ☐Other

Access to stream: ☐Paved drive ☐Gravel drive ☐Unimproved two-track ☐None

Foot path access: ☐Yes ☐No Describe: ______________________________

____

Closest distance from buildings to waters edge: __________ linear feet

What percentage of the upland portion of the site is covered by impervious surfaces?

a. Total impervious surface area.......... = __________ square feet

b. Total upland area .... = __________ square feet

c. Impervious surface area fraction...... = __________ (= a / b)

d. Percent impervious surface area ..... = __________ % (= c X 100)

Consider the following items and describe:

Roads/lanes: ____________________

Property lines/setbacks: ____________________

Well location: ____________________

Wetlands on site: ____________________

Easements: ____________________

Utilities/overhead lines: ____________________

Surface channels/drainage paths/flow patterns: ____________________

Runoff & stormwater controls/gutters: ____________________

Other: ____________________

Septic System

Septic System: ☐Yes ☐No

Type of system: ☐Septic tank (with: ☐drain field ☐mound ☐dry well) ☐Holding tank ☐Other

Distance measured from septic drain field to water body: ____________ linear feet.

Evidence of failing sewage system: ☐Yes ☐No

(i.e., water ponding on surface; sewage odors in the home or yard; dense aquatics by shore; etc.)

Cultural Resources

Consult either the NRCS or Tribal databases for information on the site.

Other Considerations

Aesthetics: ____________________

____

Neighbors: ____________________

____

Sources of contamination (milkhouse waste, street & parking lot runoff, etc.): ____________________

____

Site Sketch

Attach pictures, maps, drawings, and other illustrations that depict essential site features.

STREAMBANK EROSION FACTORS, MECHANISMS, AND CAUSES

Streambank Erosion Factors

The Wisconsin Department of Natural Resources (WDNR), for permitting purposes, adapted Dave Rosgen's Bank Erosion Hazard Index (BEHI) procedure to rate the potential severity of streambank erosion. The following seven factors are used in the BEPI (Bank Erosion Potential Index), adapted from Rosgen, David L. "A Practical Method of Computing Streambank Erosion Rate."

1. Bank Materials
2. Hydraulic Influence of Structures
3. Maximum bank height divided by the OHWM (bankfull) height
4. Bank Slope
5. Stratification/Bank Layering
6. Bank Vegetation
7. Thalweg Location

The worksheet can be found in WDNR Administrative Code NR-328, Subchapter III, "Shore Erosion Control Structures on Rivers and Streams" (http://dnr.wi.gov/org/water/fhp/waterway/permits/BankErosionPotentialIndexWorksheet.pdf). The WDNR metrics and a description of each of the streambank erosion factors are defined in the worksheet. The higher the BEPI score, the higher potential for streambank erosion.

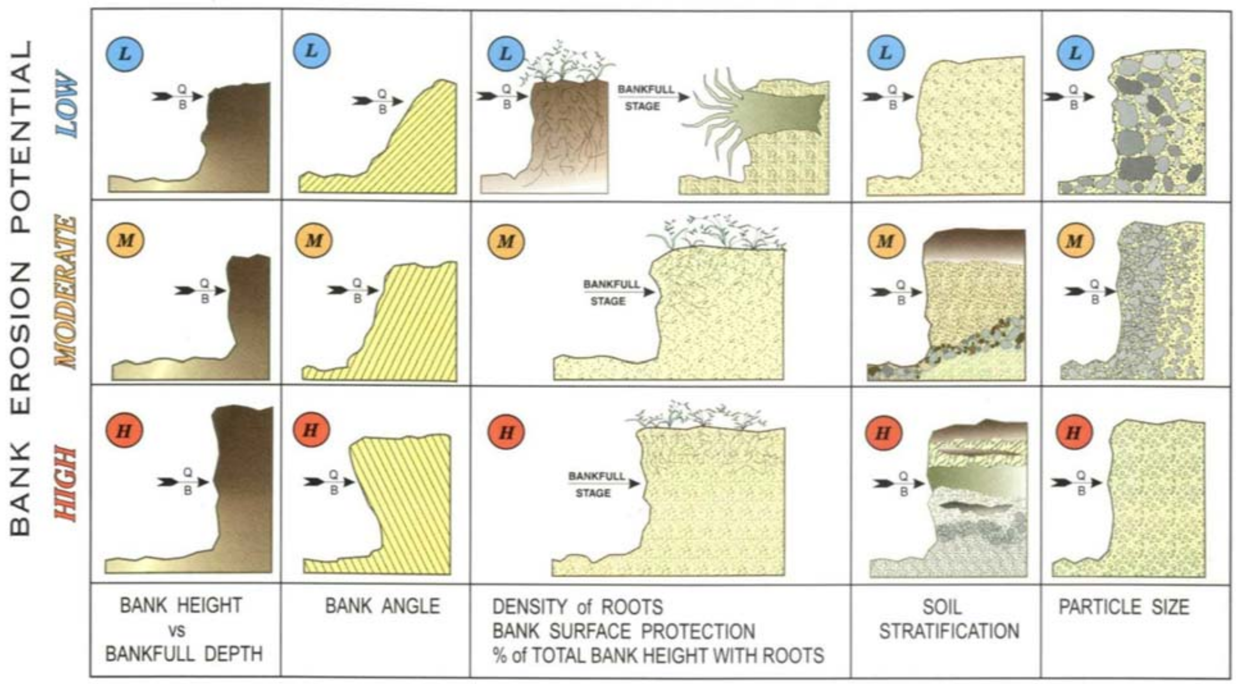


Figure 1: Streambank erodibility factors.

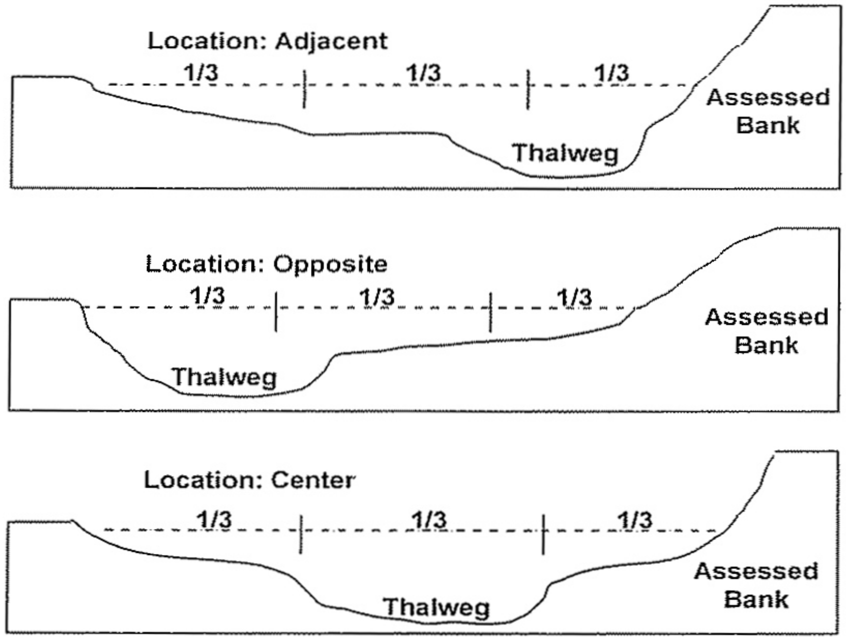


Figure 2: Thalweg location in relation to assessed bank

Following is more detailed information on bank materials.

Streambank Materials and Erosion

Streambank failure is closely related to the composition of the streambank material. Although these materials can be highly variable, they can be broadly divided into four categories.

***Bedrock*.** Outcrops of bedrock are generally quite stable; however, they can cause erosion in the opposite bank if it is softer material.

***Cohesionless Banks*.** Cohesionless soils are heterogeneous mixtures of silts, sands, and gravels. These soils have no electrical or chemical bonding between particles and are eroded particle by particle. Erosion of cohesionless soils is determined by gravitational forces, bank moisture, and particle characteristics. Factors influencing erosion also include seepage forces, piping, and fluctuations in shear stress.

***Cohesive Banks*.** These banks generally contain large quantities of clay particles which create a higher level of bonding between the particles. Consequently, cohesive soils are more resistant to surface erosion because they are less permeable. This reduces the effects of seepage, piping, and frost heaving. However, because of low permeability, these soils are more susceptible to failure during rapid drawdown of water levels due to the increase in soil pore water pressures.

***Stratified or Interbedded Banks*.** These banks are generally the most common bank type in fluvial systems because of the natural layering process. These soils consist of layers of materials of various textures, permeability, and cohesion. When cohesionless layers are interbedded with cohesive soils, the erosion potential is determined by the characteristics of the cohesionless soil. When the cohesionless soil is at the toe of the bank, it will generally control the erosion rate of the overlaying cohesive layer (Figure 3). When a cohesive soil is at the toe of the slope, it will generally protect any cohesionless layers above (although these layers will still be subject to surface erosion).

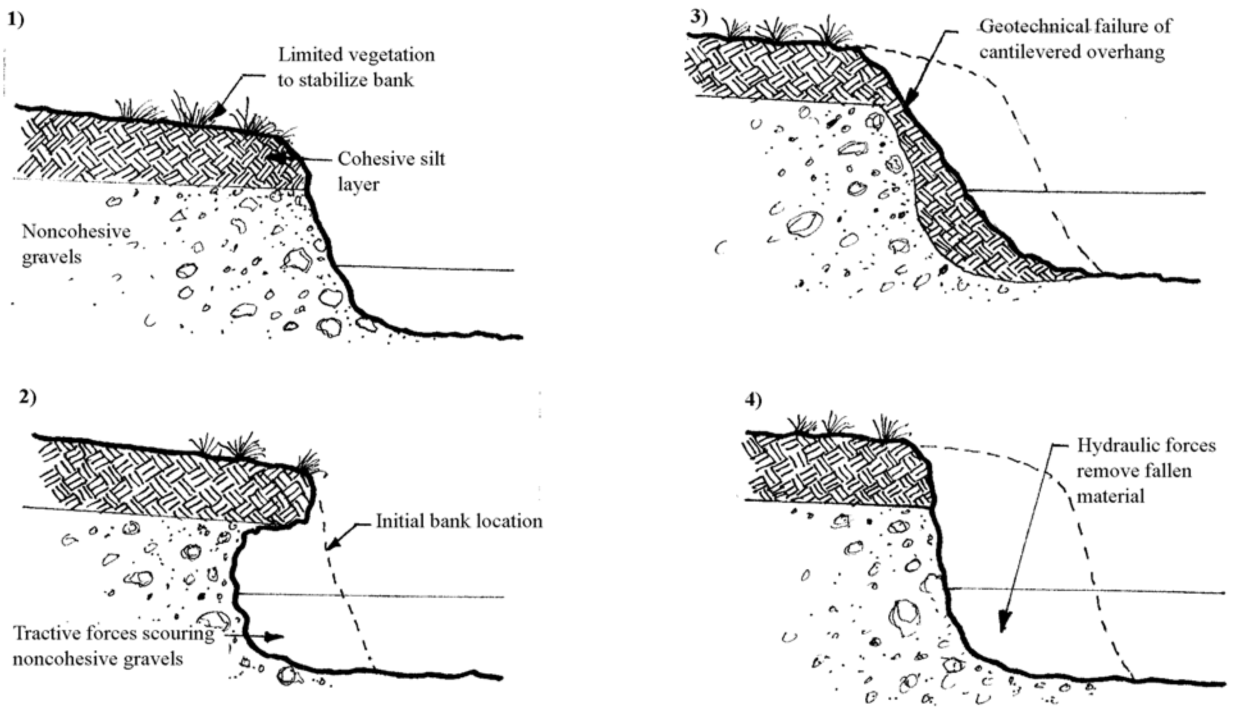


Figure 3: Stratified Streambanks and Combination Failures (*Adapted from Johnson and Stypula 1993*)

<u>Streambank Failure Mechanisms</u>

Bank failures in fluvial systems generally occur in one of three ways (Fischenich 1989): hydraulic forces remove erodible bed or bank material, geotechnical instabilities result in bank failures, or a combination of hydraulic and geotechnical forces cause failure. Fischenich (1989: pp 103) describes each failure mechanism and its characteristics as follows.

Hydraulic Failures**.** Bank erosion occurs when flowing water exerts a tractive force that exceeds the critical shear stress for that particular streambank material. Hydraulic failure is generally characterized by a lack of vegetation, high boundary velocities, and no mass soil wasting at the toe of the slope.

Geotechnical Failures**.** Geotechnical failures that are unrelated to hydraulic failures are usually a result of bank moisture problems. Moisture can affect the ability of the bank material to withstand stresses. Failures are often the result of the shear strength of the bank material being exceeded. Characteristics of geotechnical failures can vary, although mass wasting of soil at the toe of the bank is often one indicator.

Combination**.** The most common failure is due to a combination of hydraulic and geotechnical forces (refer to Figure 1). For example, bed degradation due to hydraulic forces can lead to an oversteepening of the banks which can result in a geotechnical failure of mass wasting.

Cause of Failures**.** Although bank failures result from three different mechanisms, the actual causes of erosion are complex and varied (Fischenich 1989). Successful protection projects need to address the causes of failure.

Erosion from hydraulic forces is usually connected to flow velocities and/or its direction (Fischenich 1989). Human actions are often responsible. Channelization and constrictions caused by bridges are examples that will change velocities. Changes in flow direction often result from an obstruction along or in the channel. Any unnatural destruction of bank vegetation promotes erosion by hydraulic forces. Geotechnical failures are usually the result of moisture conditions in the streambank which create forces that exceed bank resistance. Common examples of the causes include (Hagerty 1991; USACE 1981):

- Banks are destabilized by the piping of cohesionless soil from lenses (Figure 2).
- Capillary action temporarily decreases the angle of repose of the bank material to less than the existing bank slope.
- Liquefaction of fine-grained material causes fluid-like failures of the bank from pore pressure increase during rapid drawdown.
- Shrinking and swelling of clay soils during wetting and drying cycles causes tension cracks.
- Freezing and thawing of soil which weakens the shear strength.
- Subsurface moisture changes weaken the internal shear strength of the soil mass at the interface of different soil types.

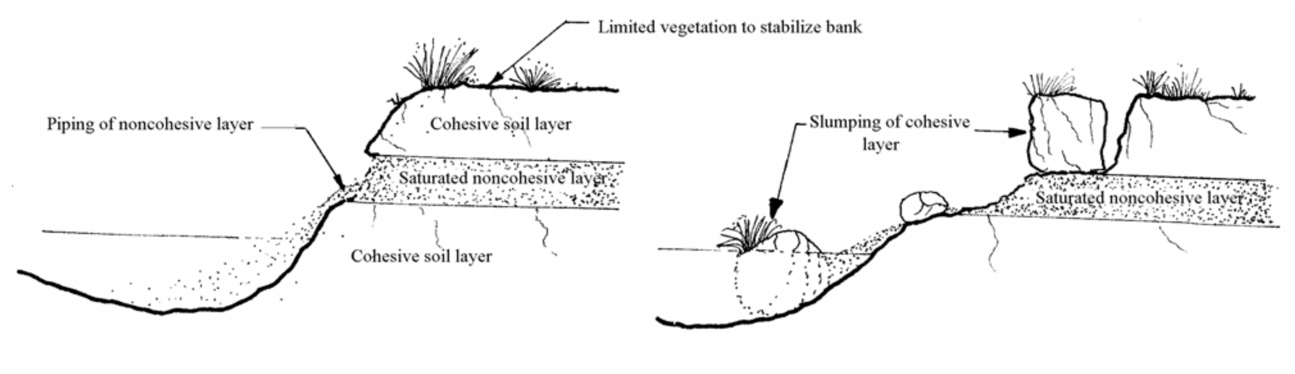


Figure 4: Bank Erosion Due to Piping (Adapted from Hagerty 1991).

<u>Streambank Erosion Mechanisms (Leopold, 1994)</u>

Streambank erosion mechanisms include the following:

- Shear caused by high velocity flow against banks
- Seepage forces
- Frost

The most widely known and generally accepted cause of bank erosion is shear stress on streambanks caused by fast moving water during peak flows. However, in many rivers, the shear stress is not important as an erosion mechanism because bank material is softened, granulated, crumbled, or slumped due to either seepage or frost.

The loose material becomes a pile of debris ready to be moved downstream during the next high flow. After a flood peak has passed, water drains through soil in the floodplain to the streambank, causing slumping or other erosion.

If it is during the winter, flow from the floodplain to the streambank is slow and provides a source of water to any ice crystals growing on the bank surface. As an ice crystal grows, a granule of bank sediment can be held at the tip of the crystal. When the crystal melts, the sediment falls to the base of the bank. As this process is repeated, sediment is accumulated at the base of the bank to be washed away in the next high flow.

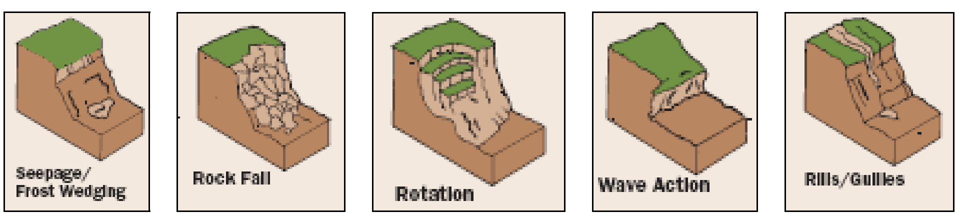
Investigations

For information on investigating a site to determine stability, see the Wisconsin supplement to EFH Chapter 16, “Stream Stability Problem Identification” and “Investigations””

Since bank failures are geotechnical or related to hydraulics, or both, an interdisciplinary team is crucial in identifying the causes of failure. Investigations should cover the list of items in the Wisconsin supplement to EFH Chapter 16, “Streambank Protection Design” and “Stream Channel Restoration Design.” Some of the steps to assist in determining streambank failure mechanisms and causes include the following.

1. Identify the streambank erosion factors on page 1 at the site including streambank composition and stratification (bank materials and layering).
2. Assess possible streambank failure mechanisms by observing the site over a period of time.
3. Several cross sections should be taken to graphically show the channel in relation to the floodplain. This information will help reveal the type of degradation (i.e., lateral erosion or downcutting) and will provide baseline data for future monitoring. If a channel is actively downcutting, these sites are significantly more difficult to stabilize and should generally be avoided unless instream structural measures are planned. If the streambank is cutting laterally, appropriate bioengineering methods may be more successful.
4. A longitudinal profile survey should be completed to highlight convergence or divergence of the water surface and low bank profile, which would indicate instability. See Longitudinal Profile Instruction in Companion Document 8, Detailed Instructions for Reference Reaches.
5. Type of bed material and distribution should be determined. This will provide clues to the resistance of the material to erosive flows. Particle size distributions can be calculated by collecting and screening samples, or for the surface layer only, a pebble count of exposed particles can be sampled (Leopold, 1994).

Other Erosion Mechanisms



Frost Wedging is a process of physical weathering in which water freezes in a crack and exerts a force on the soil or rock causing further rupture. Frost action generally occurs on poorly drained soils, such as clay, and often results in the development of heaves or depressions.

Rockfall is a type of mass movement that involves the detachment and movement of a small block of rock from a bank face to its base. Normally occurs when the rock has well defined bedding planes that are exaggerated by freeze-thaw action or thermal expansion and contraction.

Rotational Slip is a downward mass movement of unconsolidated soil material that moves suddenly along a curvilinear plane. Groundwater exerts outward pressure on soil particles and causing a seep which creates a landslide. Additional causes include increased weight, toe erosion and saturated conditions. This process is also called a **slump** or a **slide**.

Wave action is the impact of waves hitting directly on exposed soil. Waves vary with wind speeds and duration, water depth, and the continuous length of water over which winds blow in one direction. Wave heights can be calculated when these properties are known. Choosing and designing a shoreline stabilization method requires knowing the maximum height of waves affecting the property. Waves can also be created by heavy boat traffic near shorelines.

Rill erosion is the removal of soil through the cutting of many small, but conspicuous, channels where runoff concentrates. Rill erosion is intermediate between sheet and gully erosion. The channels are shallow enough that they are easily obliterated by tillage; thus, after an eroded field has been cultivated, determining whether the soil losses resulted from sheet or rill erosion is generally impossible. Rilling is the most common process of rainfall erosion losses.

Gully erosion is the consequence of water that cuts down into the soil along the line of flow. Gullies form in exposed natural drainage-ways, in plow furrows, in animal trails, in vehicle ruts, between rows of crop plants, and below broken man-made terraces. In contrast to rills, they cannot be obliterated by ordinary tillage. Deep gullies cannot be crossed with common types of farm equipment. The total amount of soil eroded due to gullies is not necessarily as great as that removed from rilling.

STREAM CLASSIFICATION USING THE ROSGEN SYSTEM

1. Identify bankfull elevations and mark cross-sections.

   Identify the bankfull elevation by walking along a reach that is 20-30 times the bankfull width long, marking bankfull indicators with flags. This usually includes at least three meander bends. Choose three locations to measure cross-sections, placing them at crossovers, where the thalweg switches from one bank to the other. The flags help identify bankfull elevation even when indicators are not present at selected cross-sections.

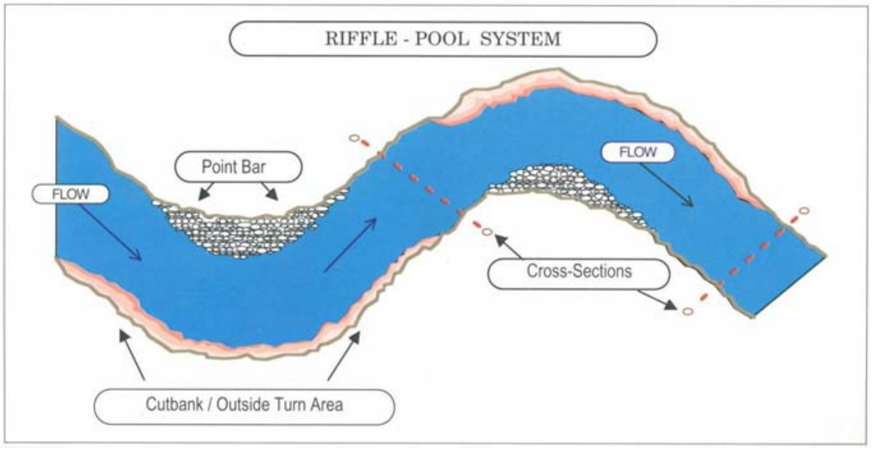


Figure 1: Recommended cross-section locations for bankfull stage measurements in "riffle/pool" system

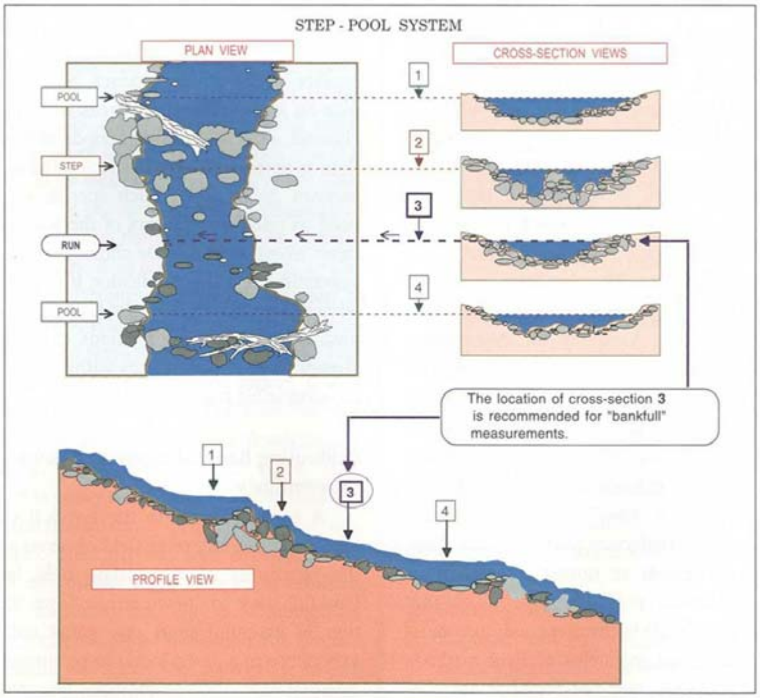


Figure 2: Recommended location for measurement of bankfull stage in "step/pool" system

2. Survey cross-sections.

Measure a stream channel cross section. This means surveying the cross section from bankfull elevation on one bank to the other bank. You will need to survey up into the flooplain as well (see step 3). Wisconsin Job Sheet 811, Stream Channel Classification*,* may be used to aid in classification.

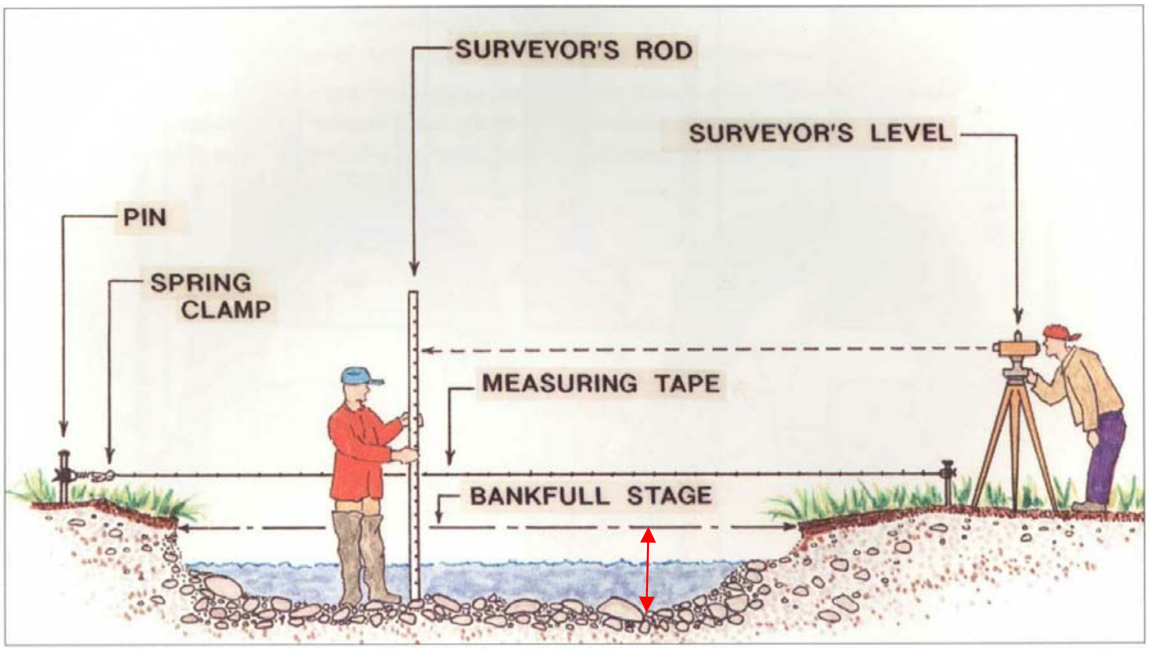


Figure 3: Measuring a stream channel cross-section

In the above diagram:
bankfull width is the distance between the banks at bankfull stage (dashed arrow)
maximum bankfull depth is the difference in elevation between the bankfull stage and the deepest part of the cross section (red arrow)
bankfull depth or *mean depth* is the cross sectional area at bankfull divided by the bankfull width. See step 7 for detailed instructions on calculating mean depth.

In Wisconsin, the bankfull elevation is roughly the water elevation during the 1.2 year discharge. The bankfull elevation is the same as the ordinary high water mark (OHWM). In many channels this is the point where water begins to flow out onto its floodplain. Since floodplains may be small or inconspicuous in some stream types where the floodplains are naturally indistinct, it is important to verify correct identification of the bankfull surface by checking it against the 1.2 year discharge. Your geologist or engineer can provide assistance in determining the bankfull elevation and bankfull discharge and return interval. Several methods of determining bankfull discharge are provided in NEH 654, Stream Restoration Design, Chapter 6, Stream Hydraulics, Wisconsin Supplement, **Hydraulics for Design.**

Discharge can also be found indirectly by using Manning's equation to find the velocity and then multiplying that by the cross sectional area. Several methods of determining Manning's n are provided in NEH 654, Stream Restoration Design, Chapter 6, Stream Hydraulics, Wisconsin Supplement, **Hydraulics for Design.**

3. Determine the entrenchment ratio.

Determine the floodprone elevation and measure the width. To find the floodprone elevation, take the maximum depth from the bankfull elevation to the stream bed and multiply by 2. Measure the width at the floodprone elevation. Divide the width at the floodprone elevation by the width at bankfull elevation to determine the Entrenchment Ratio. The floodprone elevation roughly represents the water elevation during the 50 year discharge.

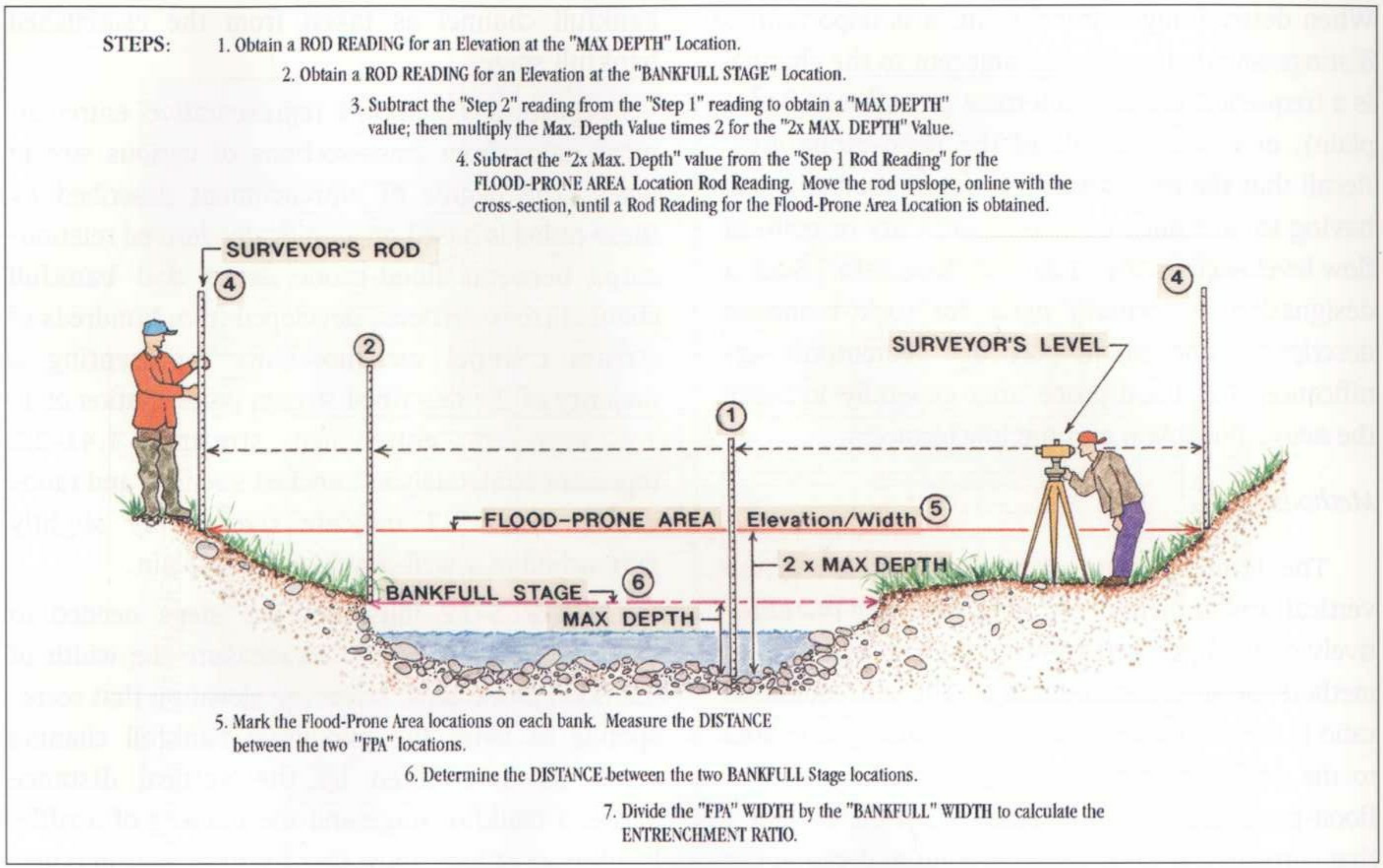


Figure 4: Floodprone width and Entrenchment Ratio

4. Measure the water surface slope (gradient).

Slope is measured between two bed features of the same type (top of riffle to top of riffle or center of pool to center of pool). Measurements should be accurate to the hundredths level because stream gradients are often low. Wisconsin has many "C" and "E" stream types which tend to have flat gradients in the range of 0.001 to 0.0001 feet/feet. Be sure to measure a reach that is long enough - at least 20 times the width at bankfull.

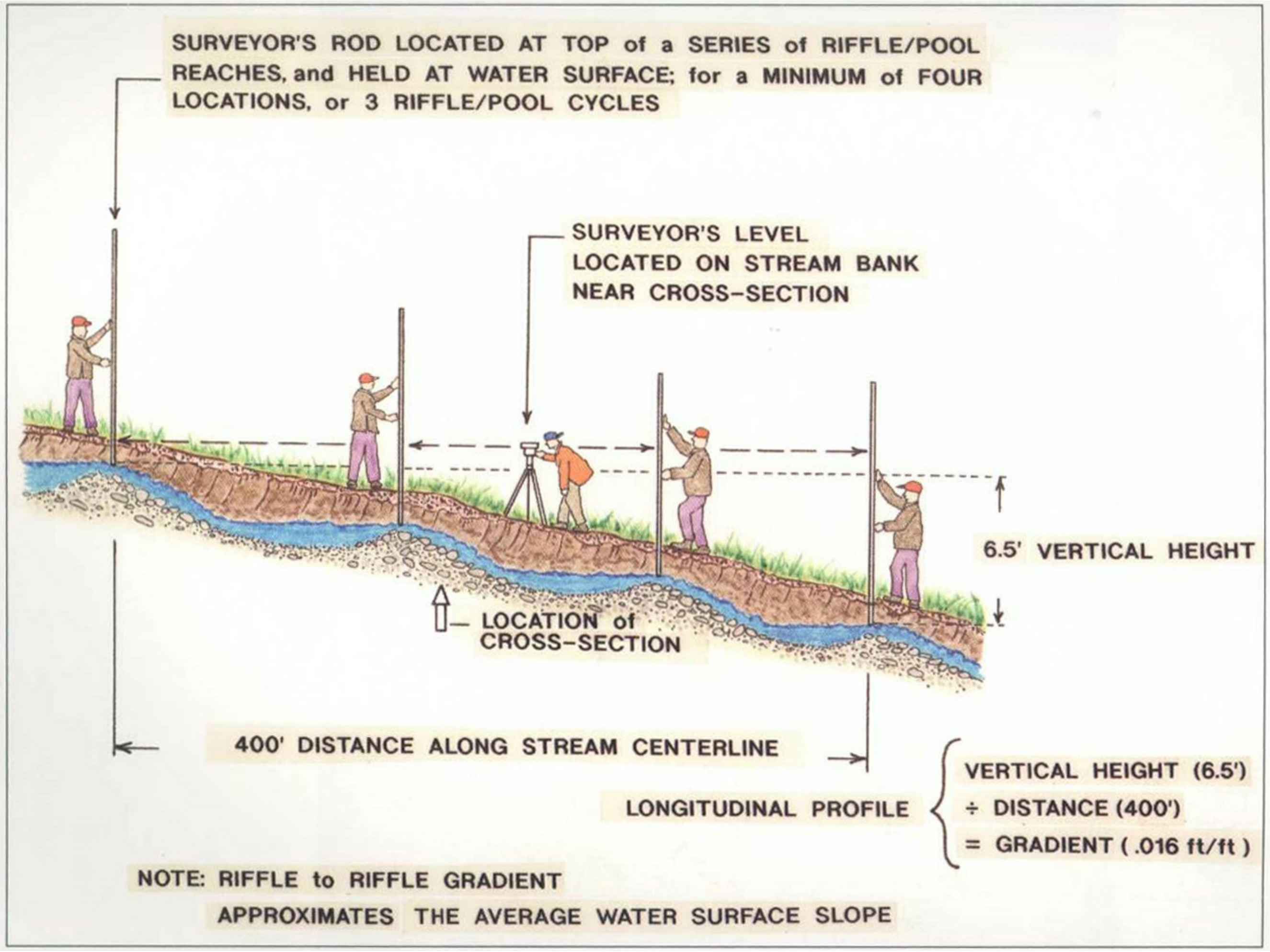


Figure 5: Measuring stream gradient through a typical riffle/pool sequence

5. <u>Measure the sinuosity of the stream.</u>

For small streams, this can be done with a tape measure. Measure the length along the stream and measure the length of the valley for the same reach of stream. In other cases, these measurements can be made using an aerial photo.

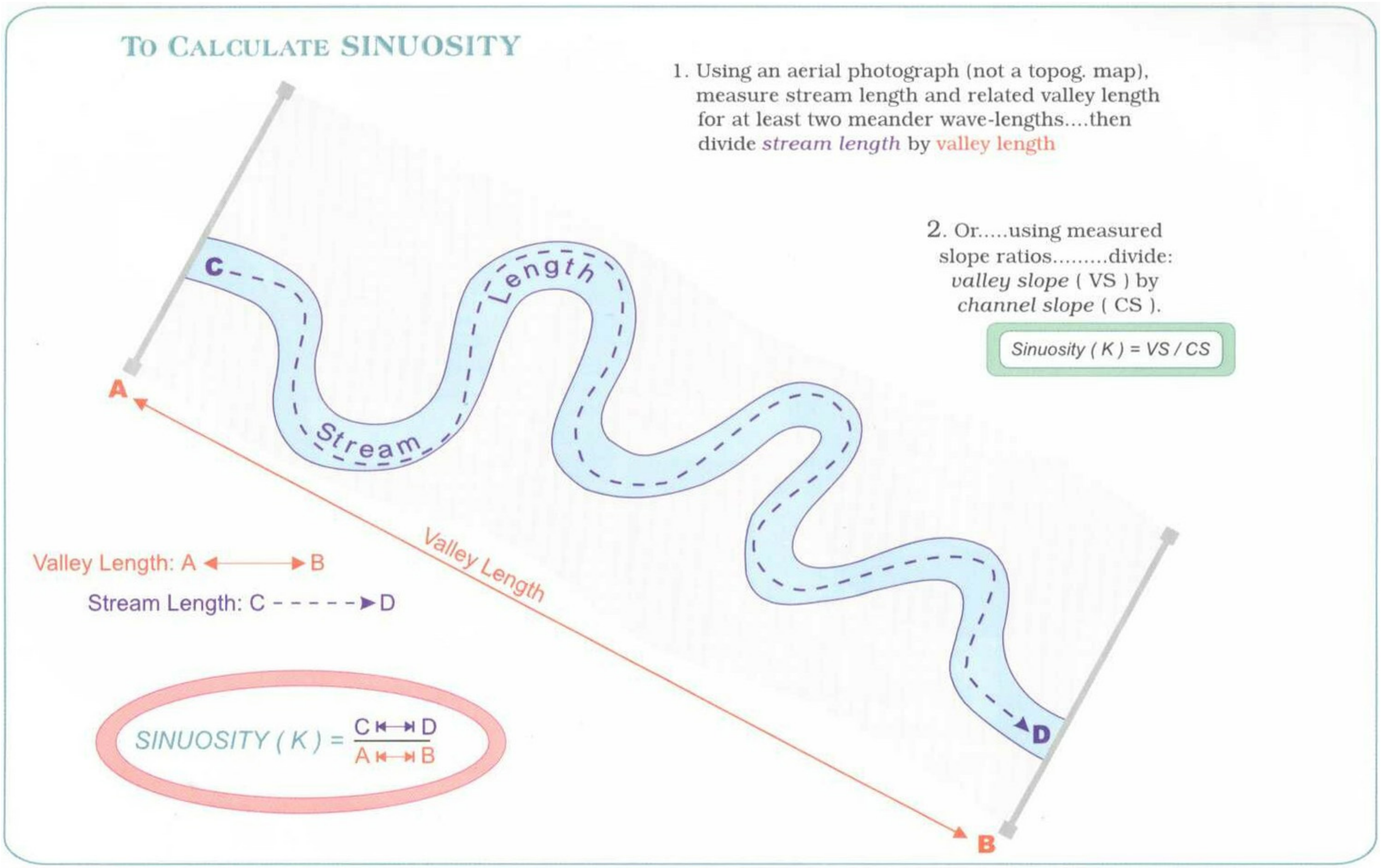


Figure 6: Channel Sinuosity Calculations

6. Pebble Count.

Take a pebble count of the material in the active channel. First, determine the percentage of the reach in pools and the percentage that is riffles. Take ten measurements at ten different locations as shown below. Calculate the D50 particle size.

Pebble count data can be taken on Wisconsin Job Sheet 810, Pebble Count ftp://ftp-fc.sc.egov.usda.gov/WI/jobsheets/js-810.pdf. If desired, pebble count data can be entered into the free Ohio DNR STREAM Modules developed by Mecklenburg and others Stream Morphology - Modules. The spreadsheet will plot the pebble count and determine D50 for you.

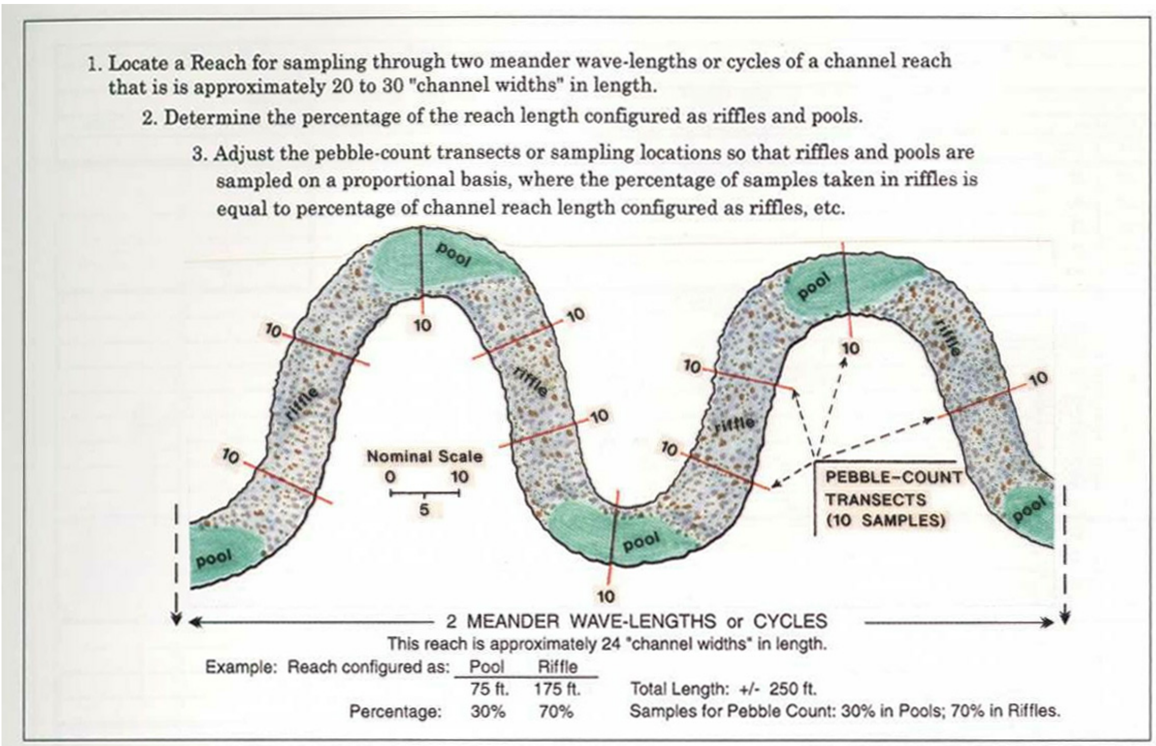


Figure 7: Pebble count procedure

Figure 8: sand gage

7. Mean Depth (Bankfull Depth)

Find the mean depth at bankfull. Determine the area of the cross section. It may be easiest to divide the cross section into cells and compute the area of the cells and then add the areas of the cells together. Area can also be found by plotting on grid paper and counting squares or calculating on a CAD system or using the Wisconsin spreadsheet Area By Coordinate Method . ftp://ftp-fc.sc.egov.usda.gov/WI/engcad/Spreadsheets/Area-By-Coordinate-Method.xls. Divide the area by the width to get mean bankfull depth (d_{bkf}).

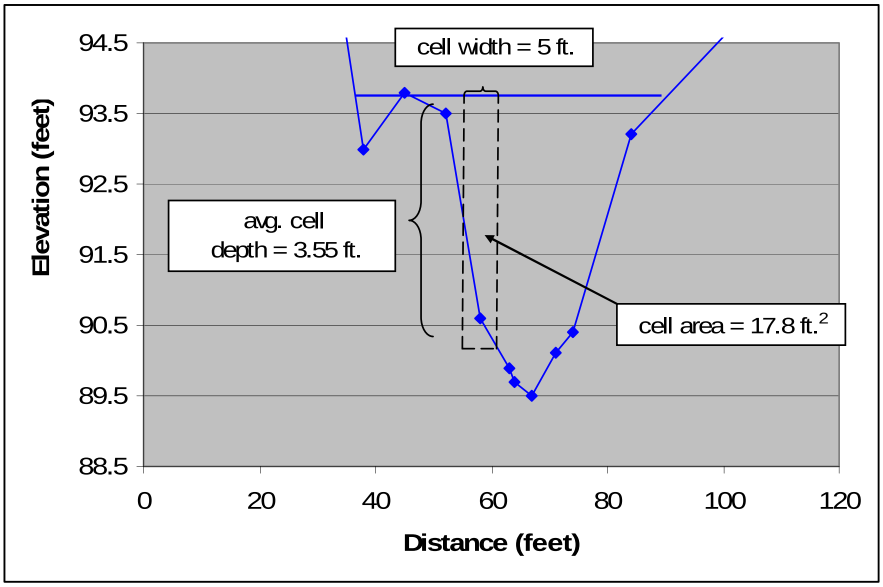


Figure 9: Area calculation of an individual cell

8. <u>Use the key to classify the stream.</u>

Wisconsin Job Sheet 811 Stream Channel Classification can be used to enter reach data for classification js-811.pdf on ftp-fc.sc.egov.usda.gov.

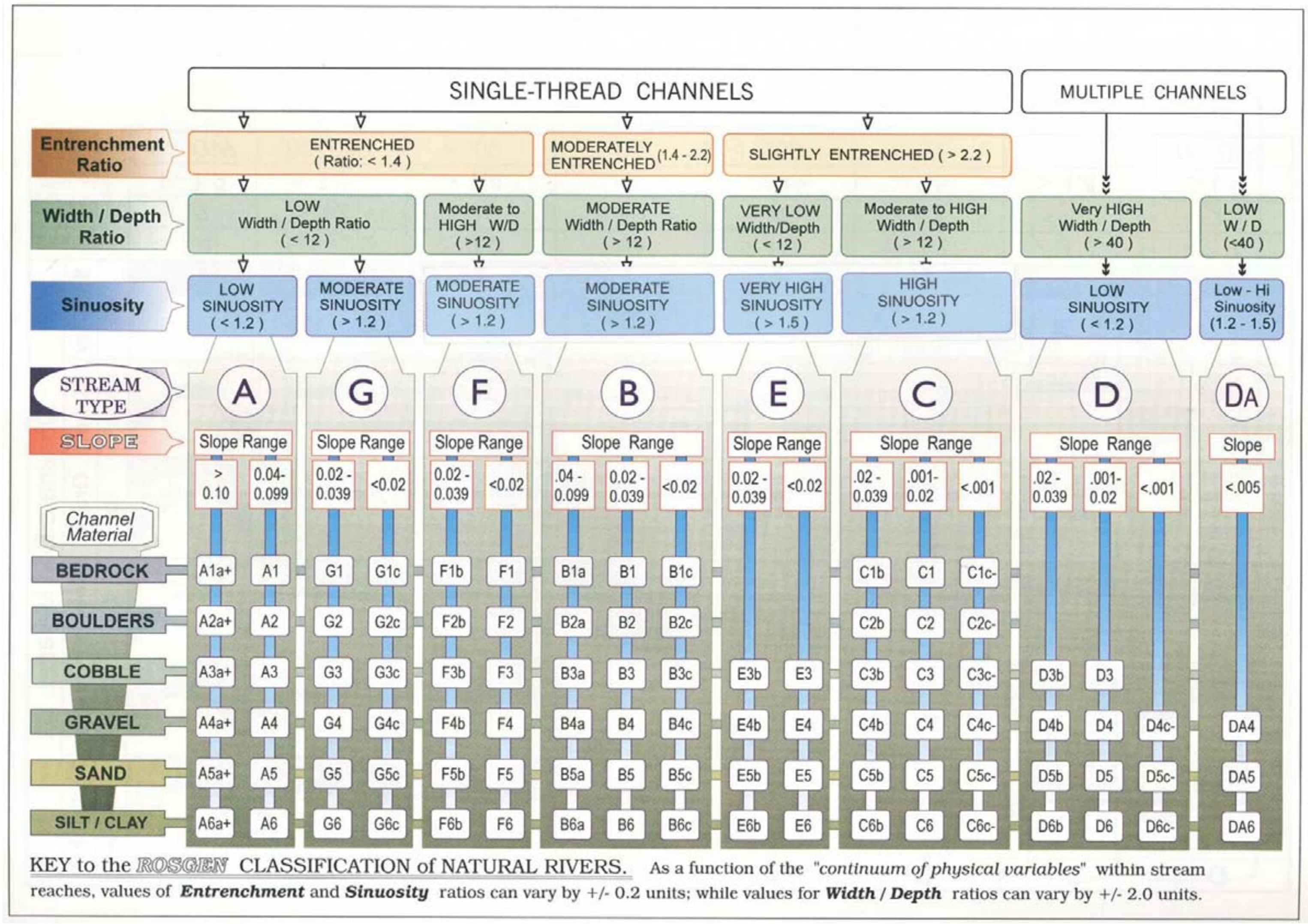


Figure 10: Stream Classification Key

TREATMENT STRATEGIES BASED ON CLASSIFICATION

Stream classification can be used not only to assess general trends in stream behavior but also to provide a guide to the selection of treatment strategies. The two tables provided below have been developed as such a guide*. Since every stream system is unique, these are only general trends and there are certainly exceptions.

Treatment Strategies Based on Stream Classification for Low Banks (< 8 ft.)

Simon CEM Stage	Rosgen Classifi-cation	Treatment Strategies	Typical Practices[1]
I Stable[2]	C, E	Maintain existing watershed runoff volumes and patterns and sediment loads. Maintain or improve existing riparian corridor vegetation. May need to implement soil bioengineering in isolated spots.	Spot treatments with fascines, live stakes, seedlings, rooted stock, or grasses.
III Down-cutting	Gc	Reduce watershed runoff and sediment loads. May need to raise channel bottom to reconnect stream to floodplain and reestablish sinuosity, or may need to establish grade control structurally. May need to reestablish or improve riparian corridor vegetation, DO NOT IMPLEMENT SOIL BIOENGINEERING ALONE.	May need to either fill channel and realign or install grade control; then whatever soil bioengineering is required.
Early IV Widening and down-cutting	F	May need to reduce watershed runoff and sediment loads. May need to create more floodplain (excavation) and shape banks enough to place toe protection. May need to reestablish or improve riparian corridor vegetation. DO NOT IMPLEMENT SOIL BIOENGINEERING ALONE.	May require minor grading with permanent toe protection; then whatever soil bioengineering is required.
IV[3] Widening w/o down- cutting	C, E[3]	Maintain existing watershed runoff volumes and patterns and sediment loads. Reestablish or improve existing riparian corridor vegetation. Consider physically modifying channel width. May need to shape banks enough to place temporary toe protection. Implement soil bioengineering where needed.	May require minor grading with temporary toe protection; then whatever soil bioengineering is required.
Late IV Widening	F, Bc	Maintain existing watershed runoff and sediment loads. May need to create more floodplain (excavation) and shape banks enough to place toe protection. May need to reestablish or improve riparian corridor vegetation. DO NOT IMPLEMENT SOIL BIOENGINEERING ALONE.	Minor grading with permanent toe protection; then whatever soil bioengineering is required.
Early V Deposition	F, Bc	Maintain existing watershed runoff and sediment loads. May need to create more floodplain (excavation) and shape banks enough to place toe protection. Improve riparian corridor vegetation. Implement soil bioengineering where needed.	Minor grading with permanent toe protection; then whatever soil bioengineering is required.
Late V Deposition	Bc, C, E	Maintain existing watershed runoff and sediment loads. May need to shape some banks enough to place toe protection. Improve riparian corridor vegetation. Implement soil bioengineering where needed,	Minor grading with permanent toe protection; then whatever soil bioengineering is required.
VI Stable[2]	C, E	Maintain existing watershed runoff volumes and patterns and sediment loads. Maintain or improve existing riparian corridor vegetation. May need to implement soil bioengineering in isolated spots.	Spot treatments with fascines, live stakes, seedlings, rooted stock, or grasses.

Treatment Strategies Based on Stream Classification* for High Banks (≥ 8 ft.)

Simon CEM Stage	Rosgen Classifi-cation	Treatment Strategies	Typical Practices[1]
I Stable[2]	C, E	Maintain existing watershed runoff volumes, patterns and sediment loads. Maintain or improve existing riparian corridor vegetation. May need to implement soil bioengineering an isolated spots.	Spot treatments with fascines, live stakes, seedlings, rooted stock, or grasses.
III Down- cutting	Gc	Reduce watershed runoff and sediment loads. Raise channel bottom to reconnect stream to floodplain and reestablish sinuosity, or establish grade control structurally. May need to reestablish or improve riparian corridor vegetation. DO NOT IMPLEMENT SOIL BIOENGINEERING ALONE.	Either fill channel and realign or install grade control; then whatever soil bioengineering is required.
Early IV Widening and down-cutting	F	Reduce watershed runoff and sediment loads. Create more floodplain (excavation) and shape banks to reduce slope failure hazard and place toe protection. May need to reestablish or improve riparian corridor vegetation. DO NOT IMPLEMENT SOIL BIOENGINEERING ALONE.	Major grading with permanent toe protection; then whatever soil bioengineering is required.
IV[3] Widening w/o down- cutting[3]	C, E[3]	Maintain existing watershed runoff volumes, patterns and sediment loads. Reestablish or improve existing riparian corridor vegetation. Consider physically modifying channel width. May need to shape banks enough to reduce slope failure hazard and to place temporary toe protection. Implement soil bioengineering where needed.	May require grading with temporary toe protection; then whatever soil bioengineering is required.
Late IV Widening	F, Bc	Maintain existing watershed runoff and sediment loads. Create more floodplain (excavation) and shape banks to reduce slope failure hazard and place toe protection. May need to reestablish or improve riparian corridor vegetation. DO NOT IMPLEMENT SOIL BIOENGINEERING ALONE.	Major grading with permanent toe protection; then whatever soil bioengineering is required.
Early V Deposition	F, Bc	Maintain existing watershed runoff and sediment loads. May need to create more floodplain (excavation) and shape some banks to reduce slope failure hazard and to place toe protection. Improve riparian corridor vegetation. Implement soil bioengineering where needed.	Minor grading with permanent toe protection then whatever soil bioengineering is required.
Late V Deposition	Bc, C, E	Maintain existing watershed runoff and sediment loads. May need to shape some banks to reduce slope failure hazard and to place toe protection. Improve riparian corridor vegetation. Implement soil bioengineering where needed.	Minor grading with permanent toe protection then whatever soil bioengineering is required.
VI Stable[2]	C, E	Maintain existing watershed runoff volumes, patterns and sediment loads. Maintain or improve existing riparian corridor vegetation. May need to implement soil bioengineering in isolated spots.	Spot treatments with fascines, live stakes, seedlings, rooted stock, or grasses.

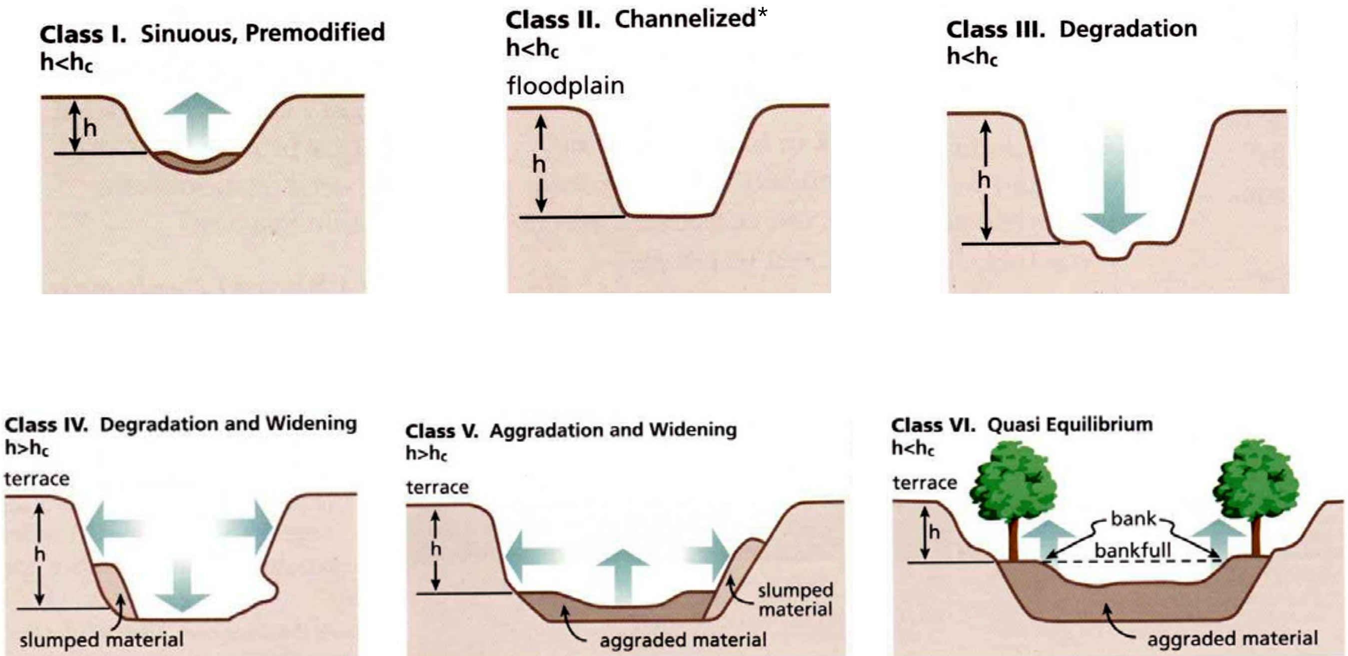
[1] Most soil bioengineering practices will be placed on the active floodplain above the top of the low streambanks. Some practices may be placed on the upper part of the bank.

[2] Stable from a geomorphic perspective.

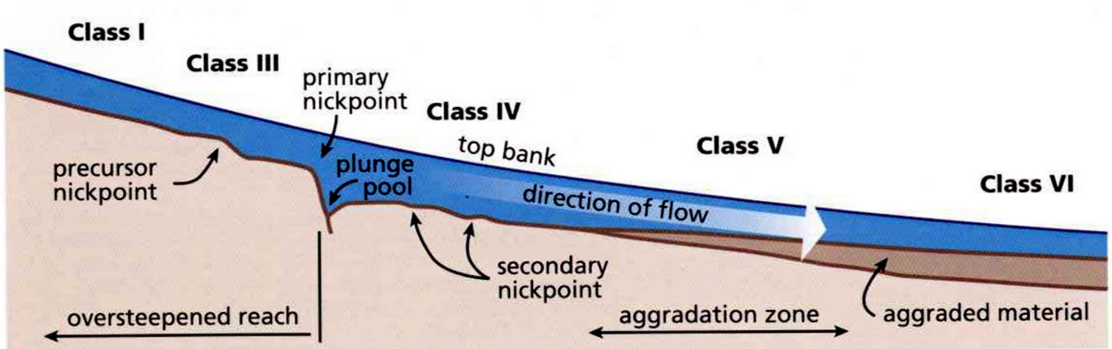
[3] "C" or "E" stream types with higher width/depth ratios than the norm, and with accelerated streambank erosion rates, may be in Stage III due to loss or deterioration of riparian corridor vegetation.

*Based on information provided by Lyle J. Steffen, retired Geologist, USDA-NRCS, Lincoln, NE.

CHANNEL EVOLUTION MODEL (SIX STAGES)
Simon and Hupp, 1986



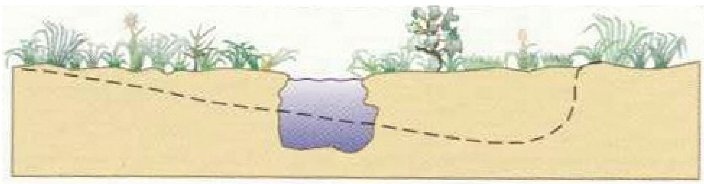
**Anthropogenic*



The channel evolution model (CEM) above illustrates the importance of establishing or assuring a stable grade before initiating any bank protection project. A channel that is actively degrading (Stage III above) may potentially undermine any project that is placed on the banks. Note that a stage II is not necessarily found in all channels and that it does not necessarily initiate a stage III. Also, keep in mind that it is possible to skip steps and that physical constraints may limit the ability of the channel to evolve in any one direction.

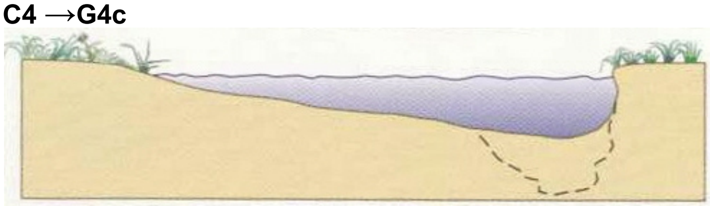
Sequence of Stream Type Occurrence Based on Morphological Change
Rosgen, 1996

E4 → C4



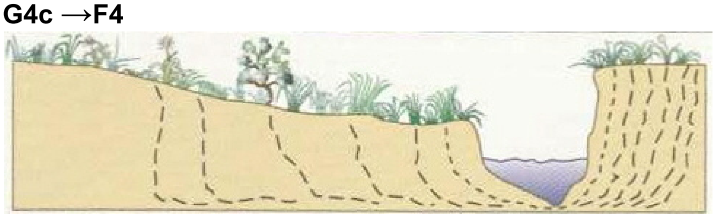
Morphological Variables

C4 →G4c



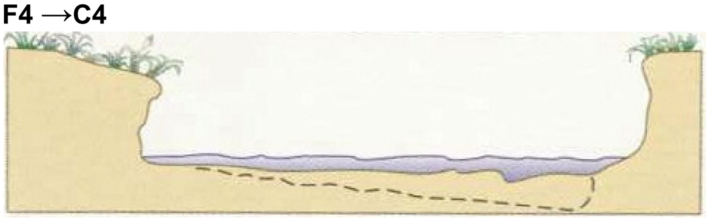
Stream Type C4
Entrenchment Ratio: 20
Width/depth ratio: 18
Sinuosity: 1.8
Slope: .005
Meander width ratio: 8
Valley slope: .009

G4c →F4



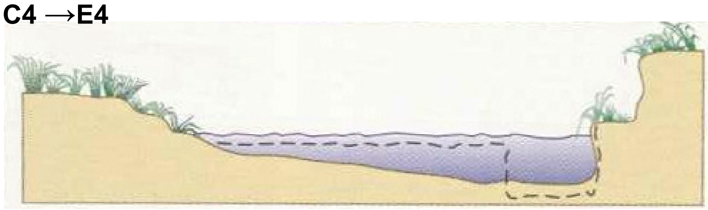
Stream Type G4
Entrenchment Ratio: 1.1
Width/depth ratio: 5
Sinuosity: 1.3
Slope: .007
Meander width ratio: 4

F4 →C4



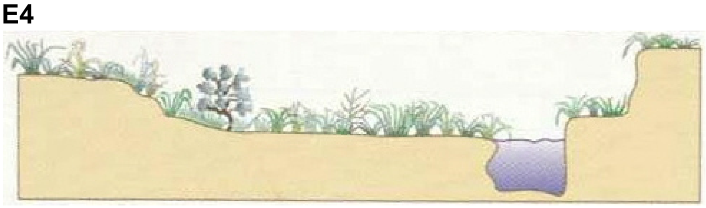
Stream Type: F4
Entrenchment Ratio: 1.0
Width/depth ratio: 150
Sinuosity: 1.2
Slope: .008
Meander width ratio: 1.5

C4 →E4



Stream Type: C4
Entrenchment Ratio: 12
Width/depth ratio: 20
Sinuosity: 1.6
Slope: .006
Meander width ratio: 6

E4



DETAILED INSTRUCTIONS FOR REFERENCE REACHES

A reference reach must be stable. A stable channel has the ability (in the present climate but over a period of time) to transport the flows and sediment of its watershed in such a manner that the dimensions, pattern, and profile of the river are maintained without either aggrading (building up) or degrading (downcutting).

When to use a reference reach:

- streambank protection.
- fish habitat enhancement.
- stream stability assessment.
- stream restoration.

Streambank Protection

A reference reach can provide information on the dimensions of a stable stream which can be used to speed recovery of a stream when installing a streambank protection project. (The dimensions of a stable stream can also be determined by looking at a regional curve. See Wisconsin Supplement to NEH 654, Regional Curves for Wisconsin.) For example, has the stream widened? If so, it will likely take years for the stream to fill in part of the widened channel with sediment on its own and create a new, narrow channel. To reduce the recovery time, construct a narrow channel as part of the streambank protection project. How narrow should the channel be? The stable reference reach can be used as a template to determine the width, depth, and other parameters. The reference reach can exist on the same stream system or in a nearby watershed where the stream is of the same type and the geology is similar.

Fish Habitat Enhancement

Oftentimes the goal of work on a stream is to provide fish habitat. The dimensions of pools and riffles, the existence of undercut banks, the grain size of bed material, the slope and velocity of the stream, the length, slope and depth of runs and glides, etc., are all important aspects of fish habitat. The stable reference reach can be used as a template to construct habitat most advantageous to fish. The reference reach can exist on the same stream system or in a nearby watershed where the stream is of the same type and the geology is similar.

Stream Stability Assessment (Departure Analysis)

A number of factors come into play when considering the stability of a stream. Comparing the dimensions of a particular stream reach to another reach of the same stream type that is known to be stable can help determine whether or not a stream reach is stable. The difference or departure from the stable reach can aid in assessment of stability of the stream reach in question.

Stream Restoration

The stable reference reach can be used as a template to determine the width, depth, slope, sinuosity, and other parameters. The reference reach can exist on the same stream system or in a nearby watershed where the stream is of the same type and the geology is similar.

Refer to NRCS National Engineering Handbook (NEH) 654, Chapter 11, Stream Restoration Design Handbook, for more detailed information on using the reference reach for stream restoration.

Bankfull Overview

The role of the bankfull discharge in shaping the morphology of all alluvial channels is the fundamental principle behind stream classification. The dimension, pattern, and profile of rivers at the bankfull discharge provide a consistent reference point that can be used to compare the morphology of rivers from around the world.

Correctly identifying the elevation of the bankfull discharge is the most important task when classifying a stream. All of the morphological variables used in stream classification are expressed as bankfull values. For example, Width/Depth Ratio is the width of the bankfull channel divided by the mean bankfull depth. Because it is unlikely that we will make a site visit during a bankfull event, we must rely on physical indicators (floodplains, depositional features, breaks in slope) that represent the water surface of the stream at the bankfull discharge. There are many bankfull indicators, but each indicator is not always reliable for all stream types in all climates. Locating bankfull is a skill that is developed over time by walking the banks of many different stream types in a variety of climates. However, one can improve their ability to recognize features associated with bankfull flows in a given region by visiting stream gaging stations where bankfull elevations can be calibrated to a known discharge. You may want to work with your geologist or engineer to calibrate bankfull.

The appropriate use of any or all of the bankfull stage indicators requires adherence to four basic principles (selection from Rosgen 1996 Applied River Morphology page 5-8):

1. Seek indicators in the locations appropriate for specific stream types.
2. Know the recent flood and/or drought history of the area to avoid being mislead by spurious indicators (e.g., colonization of riparian species within the bankfull channel during drought, or flood debris accumulations caught in willows that have rebounded after flood flows have receded).
3. Use multiple indicators wherever possible for reinforcement of a common stage of elevation.
4. Where possible, calibrate field determined bankfull stage elevation and corresponding bankfull channel dimensions to known recurrence interval discharges at gaged stations. This procedure can verify the difference between the floodplain of the river and the low terrace.

Below is a list of common bankfull stage indicators.

1. Floodplains. The term bankfull elevation is often associated with the point at which the stream begins to spread out onto the floodplain.. This definition can be applied to stream types C, D, DA, and E, which often have well-developed floodplains; however, this approach does not apply to entrenched stream types (A, B, F, G), which generally do not have floodplains. Do not confuse low the terrace with the floodplain. Terraces are abandoned floodplains that often have perennial vegetation and definite soil structure.
2. Highest active depositional feature. The elevation on top of the highest depositional feature (point bar or central bar) within the active channel is often associated with bankfull stage. These depositional features are especially good bankfull stage indicators for confined channels.
3. Slope breaks and/or change in particle size distribution. Breaks in slope of the banks and/or a change in the particle size distribution from coarse to fine. Coarser material is associated with the active channel.
4. Evidence of an inundation feature such as small benches.
5. Staining of rocks.
6. Exposed root hairs below an intact soil layer indicating exposure to erosive flow.
7. Lichens and (for some stream types and locales) certain riparian vegetation species. In northern Wisconsin, alders are fairly good bankfull indicators. Be careful to note the alders haven’t moved farther into the channel due to slumping of soil. Also take care not to call bankfull if alders are growing adjacent to springs.

Although not all bankfull indicators work for all stream types in all climates, bankfull indicators should be consistent on an individual stream reach basis. For example, an observed break in slope or depositional feature must be present through the entire reach and fairly consistent elevation above the existing water surface, which can be verified by plotting a longitudinal profile (notice the consistent stage of the bankfull line above the water surface in Figure 1).

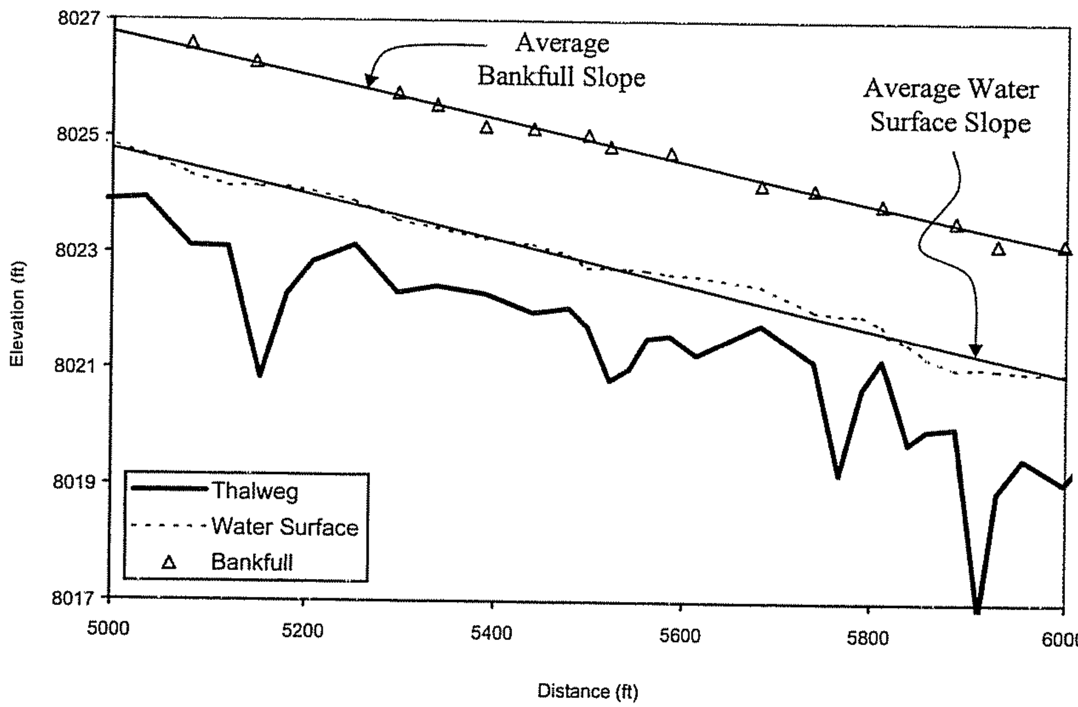


Figure 1. Example Longitudinal Profile Showing Consistent Bankfull Indicators

Bankfull Indicators and Site Selection Instructions

1. Walk the stream reach and look for consistent bankfull indicators as well as three representative riffles for the stream classification cross sections.

2. Select the bankfull elevation at each cross section. The stream must be free to adjust its boundaries at the riffle cross sections (Figure 2).

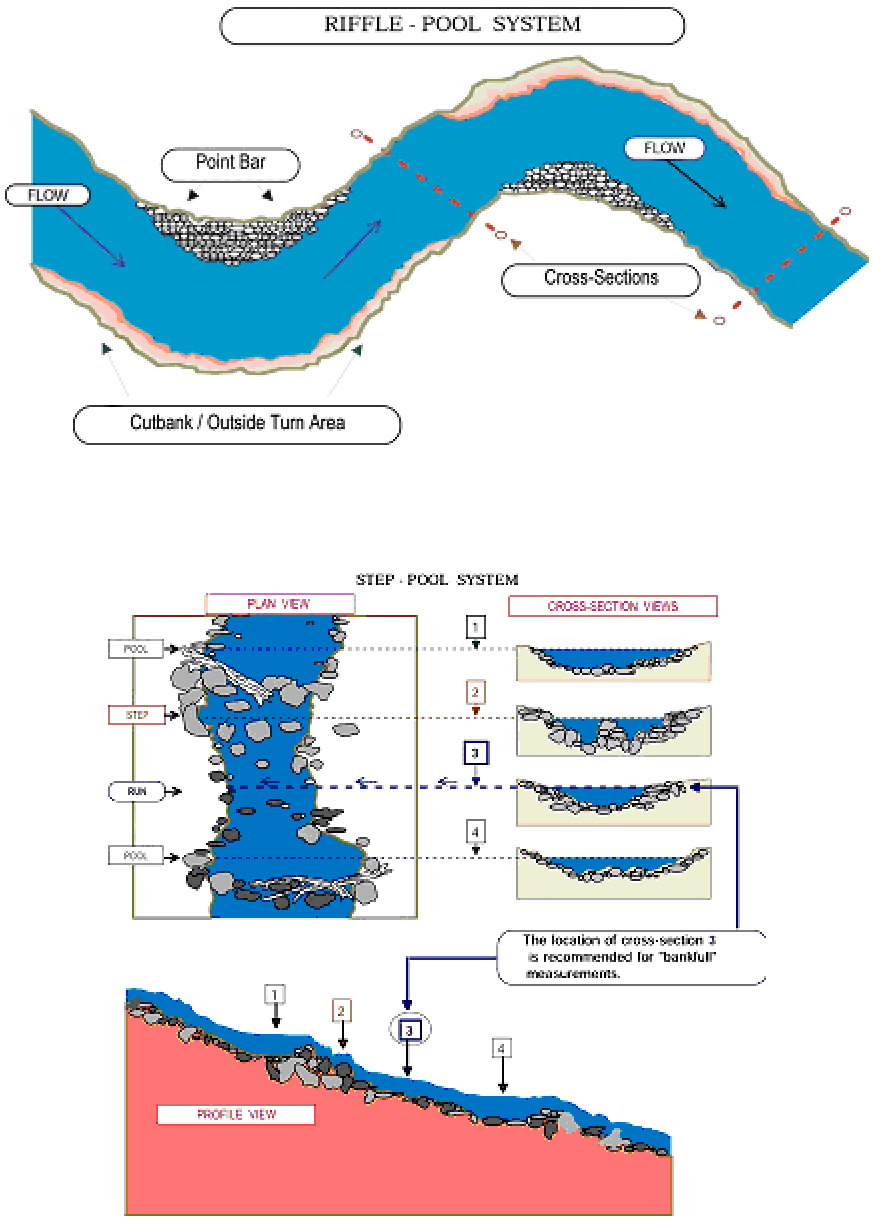


Figure 2. Recommended Cross Section Locations for Bankfull Cross Sectional Area

Cross Sections

The cross section data provides key morphological parameters required for stream classification. Bankfull cross sectional area, bankfull width, mean bankfull depth, maximum bankfull depth, width/depth ratio, and entrenchment ratio are determined and recorded on the Stream Channel Classification form (Wisconsin Job Sheet 811) and are illustrated in Figure 3. Calculation of entrenchment ratio is illustrated in Figure 4. Basic surveying skills are required for the cross sectional survey and are well described in Harrleson, et al, (1994). A summary of instructions and calculations are provided in the following section.

Cross Sectional Area

The cross section is divided into multiple trapezoids and the area of each individual trapezoid is computed. The total cross sectional area is determined by adding the area of all the individual trapezoids.

Mean Bankfull Depth

Mean bankfull depth is computed by dividing the bankfull cross sectional area by the bankfull surface width.

Maximum Bankfull Depth

Maximum bankfull depth is the measurement of the depth of the thalweg to the bankfull stage.

Width/Depth Ratio

Width/depth ratio is the bankfull surface width divided by the bankfull mean depth. The width/depth ratio describes the channel shape (wide and shallow = large number, narrow and deep = small number).

Entrenchment Ratio

Entrenchment is the vertical containment of a river and is quantitatively defined as the width of the flood-prone area divided by the bankfull surface width. Flood-prone area is the width of the channel at an elevation that is twice the maximum bankfull riffle depth (Figure 4). The measurement of flood-prone area width must be measured perpendicular to the fall line of the valley, regardless of cross-section position.

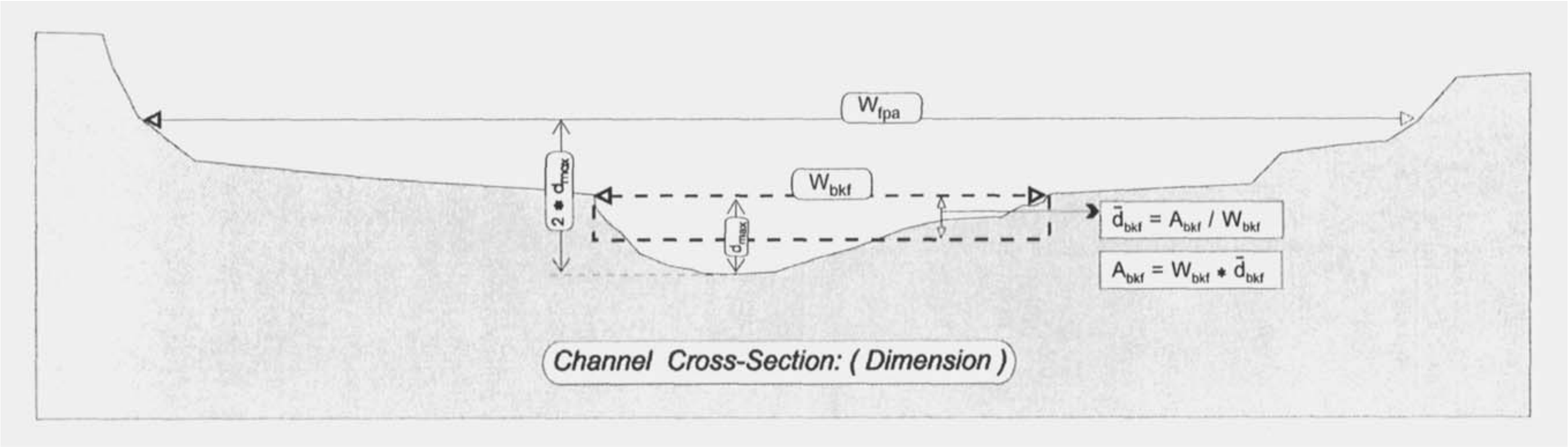


Figure 3. Morphological Parameters Obtained from the Cross Section

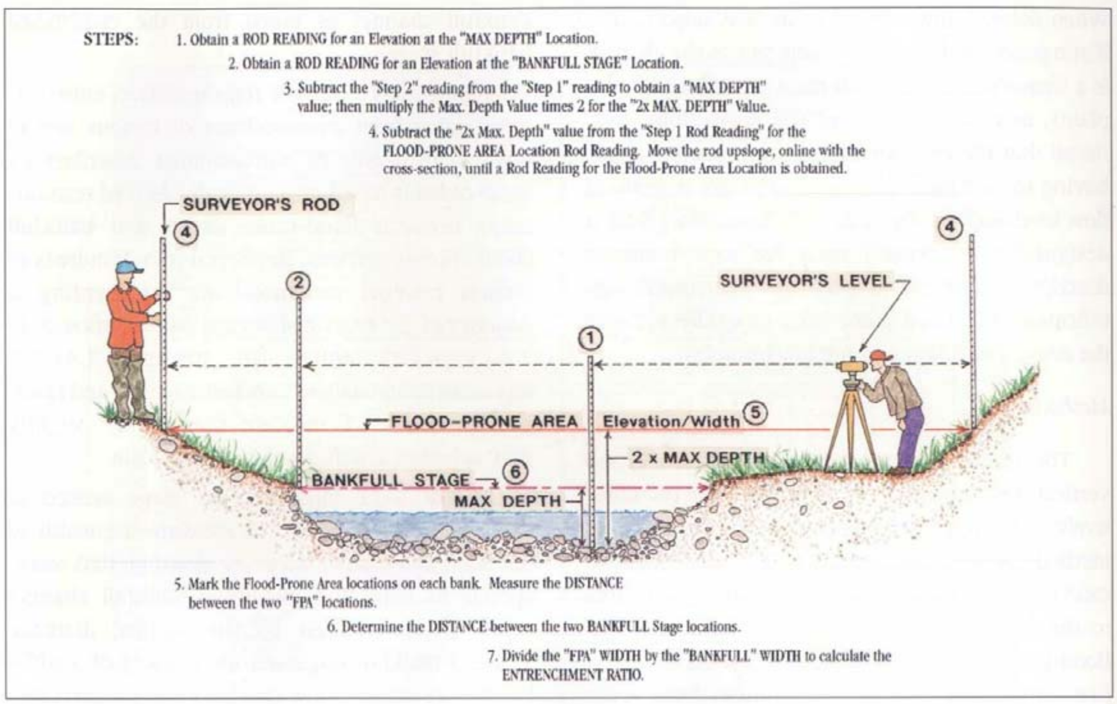


Figure 4. Determining Entrenchment Ratio

Cross Section Instructions

1. Set up the surveying instrument in a location where the entire cross section can be viewed. The instrument should be placed at an elevation higher than the highest feature required for the survey. Ideally, only one instrument setup will be required to survey the entire cross section; however, determining the width of the flood-prone area may require multiple instrument setups due to dense foliage.
2. Stretch the tape across the channel (zero on left bank) making sure the tape is perpendicular to the direction of flow.
3. Backsight a benchmark or permanent feature used for relocation and/or resurvey of cross-section.
4. Obtain rod readings at major breaks in bed elevation and key features such as left bankfull (LBF), left edge water (LEW), thalweg (THL), right edge water (REW), and right bankfull (RBF).
5. Record the distance on the tape (station), the corresponding rod height and notes in forms provided (see Table 1 for example).
6. Measure the flood-prone area width (width of the channel at an elevation that is 2 times the maximum bankfull depth) (Figure 4).
7. Calculate the bankfull cross sectional area and plot the cross section (Table 2, Figure 5).
8. Calculate mean depth, width/depth ratio, and entrenchment ratio and record on the Stream Channel Classification Form (Wisconsin Job Sheet 811).
9. Estimate the bankfull discharge. The following describes one method. Using the regression equations in Flood Frequency Characteristics of Wisconsin Streams, plot the recurrence interval versus discharge on log probability paper. Extrapolate to determine the discharge at the 1.2 year recurrence interval.

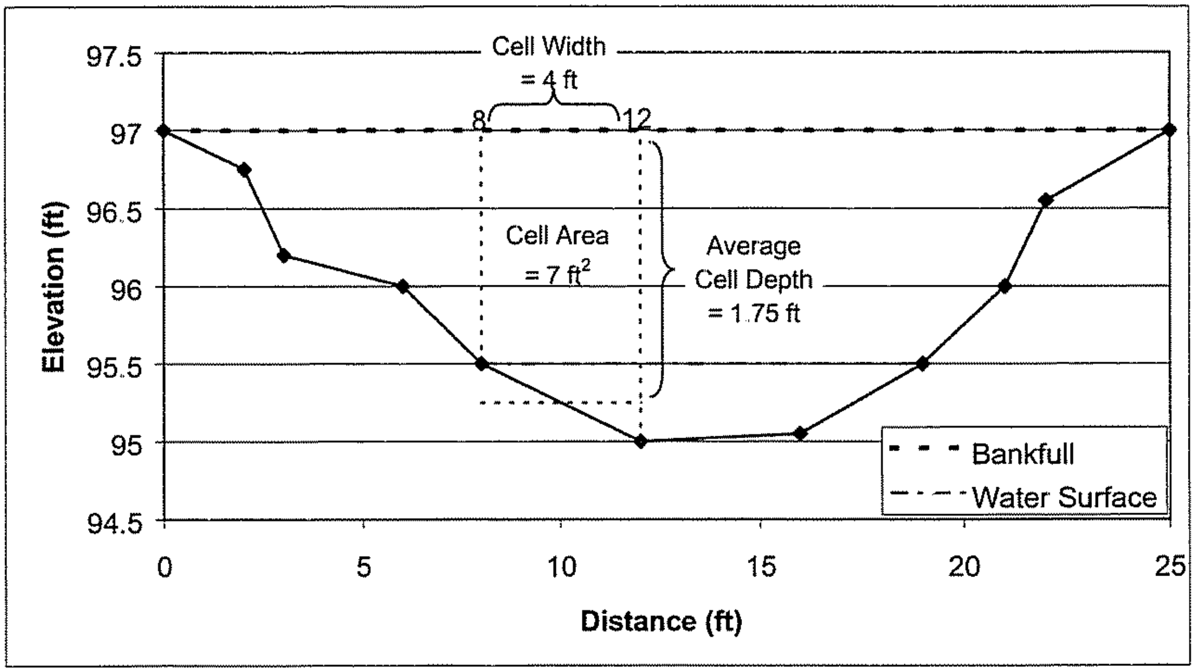
   Use this estimate of bankfull discharge to determine the bankfull velocity. Make sure the bankfull velocity is reasonable. (Velocity = Bankfull Discharge/Bankfull Area)
10. Record all data on Wisconsin Job Sheets 811, Stream Channel Classification, and 820, Reference Reach Summary Data.

Table 1. Example Cross Section Notes

Stream		Drainage Area		Date	Team #
Station (ft)	**US (ft)**	**HI (ft)**	**FS (ft)**	**Elevation (ft)**	**Notes**
BM	5.0	105		100	Benchmark
0			8	97	LBF
2			8.25	96.75	
3			8.8	96.2	
6			9	96	
8			9.5	95.5	LEW
12			10	95	
16			9.95	95.05	THL
19			9.5	95.5	REW
21			9	96	
22			8.45	96.55	
25			8	97	REF

Table 2. Example Cross Sectional Area Calculation

Station (ft)	Elevation (if)	Depth (if)	Cell Width (if)	Average Cell Depth (if)	Incremental Area (&)
0	97	0			
2	96.75	0.25	*2—0=2*	(0 + *0.25)12* = 0.125	2 * *0.125* = 0.25
3	96.2	0.8	3 —2 = 1	(0.25 + 0.8)/2 = 0.525	1 * 0.525 = *0.525*
6	96	1	6—3=3	(0.8+1)12=0.9	3*0.9=2.7
8	*95.5*	1.5	8—6=2	*(1+1.5)/2=L25*	2*1.25=2.5
12	95	2	4	1.75	7.0
16	95.05	1.95	4	1.975	7.9
19	95.5	*1.5*	3	1.725	5.175
21	96	1	2	1.25	*2.5*
22	96.55	0.45	1	0.725	0.725
25	97	0	3	0.225	0.675
Total Area (ft.^{2})					30.0



Fig

Figure 5. Example Cross Section

Table 3. Example Calculations of Key Morphological Parameters

Bankfull Area (ft^2)	Bankfull Width (ft)	Mean Bankfull Depth (ft)	Width Depth Ratio	Width of Flood-Prone Area (ft)	Entrenchment Ratio
30.0	25	1.2	25/1.2 = 20.8	150 (measured)	150/25 = 6

Longitudinal Profile

The longitudinal profile characterizes average stream slopes and depths of riffles, pools, runs, glides, rapids, and step/pools. The average water surface slope is required for delineating stream types and is used for a normalization parameter for dimensionless ratios (see Wisconsin Job Sheet 820, Reference Reach Summary Data). The water surface slopes of individual bed features (facet slopes) can be compared using longitudinal profile data (e.g., riffle facet slope vs. pool facet slope). In addition, the longitudinal profile can be used to obtain maximum depth of individual bed features as well as bed feature spacing.

The average water surface slope is measured between two bed features of the same type (e.g., top of riffle to top of riffle) over a distance of 20 to 30 bankfull channel widths. To calculate average slope, divide the change in water surface elevation by the stream length between the two features.

Longitudinal profiles require basic surveying skills and equipment. Because longitudinal profiles cover a large distance (20-30 bankfull channel widths) multiple instrument setups are often required.

Longitudinal profiles are measured in the downstream direction. Typically, a 300-foot tape is laid parallel to the river along one bank following the river curvature from an upstream starting point. An elevation measurement and the associated distance along the tape (station) are taken at major breaks in the bed topography. Four types of features are measured at each station: thalweg (deepest part of channel), water surface, bankfull, and top of the lowest bank. The thalweg and water surface measurements should reflect bed elevation and water surface slope changes as the stream progresses through a bed feature sequence (e.g., riffle, run, pool, glide). When bankfull indicators differ on the left and right side of the stream, always survey the low indicator. Also, note that the low bank is often the same as the bankfull elevation. Note position (stationing) of cross-section locations along profile. A summary of an example profile survey with survey notes and plan and profile views are shown in the following procedure.

Longitudinal Profile and Bed Stability

Does the low bank profile depart from the bankfull surface and water surface profiles? If the low bank height slope is flatter than the bankfull surface slope, the stream is incising (downcutting). If the low bank height slop is steeper than the bankfull surface slope, the stream is aggrading (building up).

In the example in figure 6, the low bank is diverging from the bankfull slope and the water surface slope. This shows the stream is incising and is an indicator of instability.

Longitudinal Profile Instructions

1. Setup the instrument with a clear line of sight to a benchmark. The first setup should reference (backsight) a benchmark (BM) of known elevation. Approximate the number and location of each setup needed based on potential line-of-sight limitations. The instrument should be placed at an elevation higher than the highest feature required for the survey.

2. Backsight (BS) the benchmark (place the rod on the benchmark and obtain a rod reading). Determine the height of the instrument (HI). HI = BM elevation **+** BS rod reading.

3. Starting at the upstream end of the reach, position a 300-foot tape parallel to the stream along one bank.

4. Place the rod at the thalweg at station 0 on the tape. Obtain the rod reading and record the value in the FS column and write THL in the notes column as shown in Table 4. Record water surface (WS), bankfull (BKF), and low bank height (LBH, which is the same as bankfull stage in this example) measurements perpendicular to the tape at station 0 as shown in Figure 6.

5. Continue the same sequence downstream to the next break in the channel bed and repeat the same four measurements at the new station.

6. At cross section intersection locations, note the distance (station) on the longitudinal profile tape. When using multiple instrument setups, take a measurement on top of both cross section end points to obtain common elevations of the cross section and longitudinal profile.

7. Profile your entire reach (20-30 bankfull channel widths is normally used as a minimum longitudinal profile length guideline).

8. Plot the longitudinal profile (as in illustration, Figure 6).

9. Draw a line through the water surface data points to represent the average water surface slope. Do the same for the bankfull data points.

10. Determine the average water surface slope and enter into forms (Wisconsin Job Sheets 811, Stream Channel Classification, and 820, Reference Reach Summary Data).

11. Once the profile is plotted, measure and record maximum depths (thalweg) of bed features and enter values on the Reference Reach Summary Data form (WI Job Sheet 820). Record the range as well as average values at mid-feature locations.

Table 4. Sample Longitudinal Profile Notes

Longitudinal Profile					
Stream			Date		Team
Station	BS	HI	FS	Elevation	Notes
BM	5.60	8025.60		8020.00	Bridge — Right Wing Wall
0			8.35	8017.25	THL—Riffle
			7.20	8018.40	WS
			5.52	8020.08	BKF
40			9.13	8016.47	THL—Run
			7.4	8018.20	WS
			5.7	8019.90	BKF

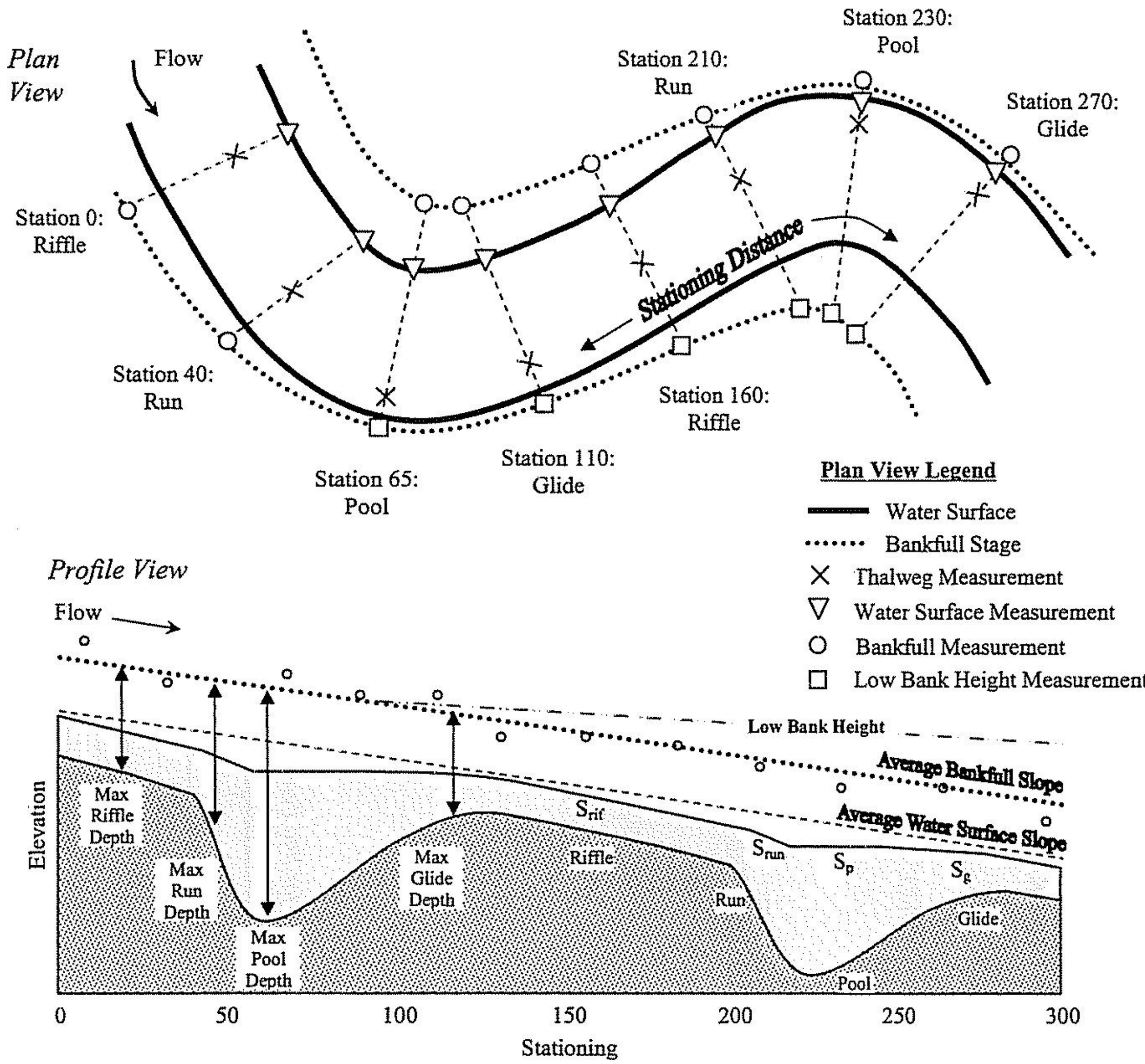


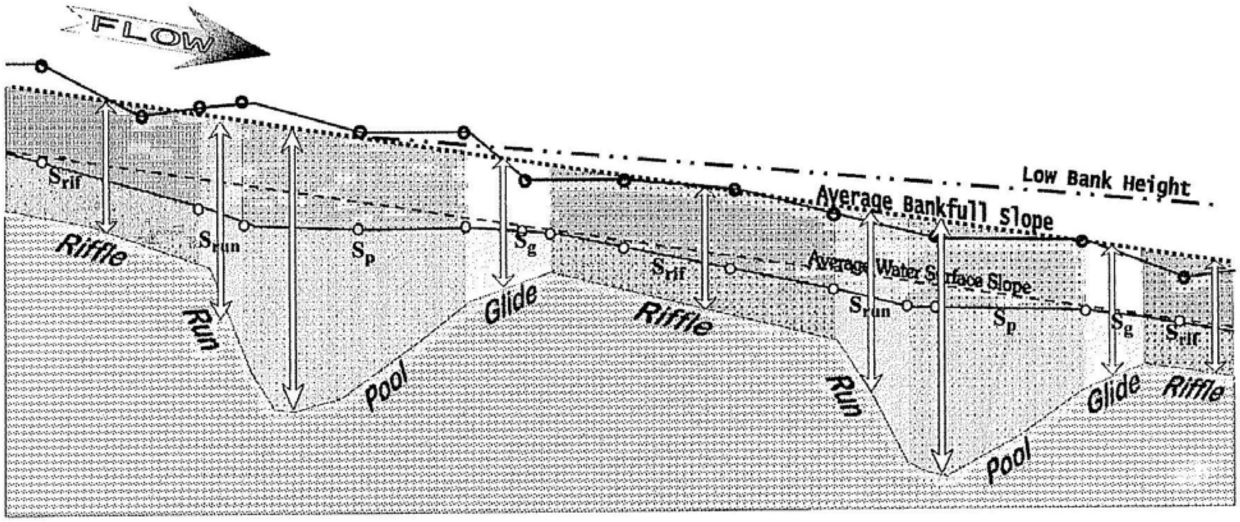
Figure 6. Plan and Profile Diagrams of a Longitudinal Profile

Average Water Surface Slope (S): Elevation of water surface over stream length at the same position above bed features for several riffle/pool or step/pool sequences (i.e., elevation difference from the top of riffle to top of next riffle over the length of the stream). This value is the same as the average bankfull slope.

Average Bankfull Slope (S_{bkf}): The elevation difference of bankfull indicators along the stream length. The elevation differences are obtained from an "average line" drawn between bankfull indicators along the longitudinal profile.

Water Surface Facet Slope: Water surface representing low flow water surface slope of individual bed features (i.e., riffle, run, pool, or glide). This slope is measured from the water surface elevation at the start and end of an individual feature for the corresponding stream length of the feature. **Riffle = (S_{rif}). Run = (S_{rif}). Pool = (S_p). Glide = (S_g).**

Figure 3. Example of Typical Longitudinal Profile Showing Locations of Glides, Riffles, Runs, and Pool Bed Features



C4 Stream Type Dimensionless Ratio Relations for Bed Features

	Pool	Riffle	Run	Glide
Depth Ratio				
Average:	3.2	1.5	2.0	1.6
Range:	2.9-4.0	1.4-1.6	1.8-2.5	1.4-1.9
Slope Ratio				
Average:	0.2	2.2	3.8	0.15
Range:	0.1-0.3	2.0-2.4	3.4-4.2	0.1-0.2

Pebble Counts

The pebble count characterizes the bed material present through a given study reach. This information is used to determine the stream type (e.g., C3 vs. C4), for hydraulic calculations (R/D84) used to estimate velocity (on riffle bed) and for calculation of sediment competence.

Representative Pebble Count

The Representative Pebble Count Procedure is a stratified systematic sample method to proportionally sample all the bed features present within the bankfull channel though a designated reach. The designated reach is divided into two categories: pools comprise the first category and riffles, runs, and glides are lumped into the second category. The total distance of the reach is divided into total pool length and total non-pool length (runs, riffles, and glides) (Figure 8).

For example, assume the total reach length is 1000 feet. To stratify the sample, collect a minimum of 100 observations proportionally based on bed features. If 300 feet (30%) of the reach is composed of pools and the other 700 feet (70%) is composed of runs, riffles, and glides, then 30 particles (or 30%) should be measured in pools and 70 particles (or 70%) should be measured within either runs, riffles, or glides. To complete a systematic sample, 10 particles across 3 different pool cross sections and 10 particles across 7 different riffle cross sections would be sampled.

Particles are collected at evenly spaced intervals across the entire bankfull channel at each of the selected cross sections. For example, if the study design is to measure 10 particles at 10 total cross sections and the bankfull width at the first cross section is 36 feet, then: 36 feet / 9 particles = 4 feet/particle. The approximate sampling interval should be 4 feet per particle. The sampling interval will vary based on the bankfull width. The intermediate axis (B-axis) of each particle is measured with a scale in the field (Figure 9) and is generally recorded in millimeters.

Riffle Pebble Count

The riffle pebble count will characterize the bed material at the surveyed riffle cross section. One hundred particles are measured at evenly spaced intervals across the wetted width of the surveyed riffle cross section. If the stream width is small, then more than one transect may be taken to obtain 100 observations as long as the values represent the surveyed riffle cross-section. The riffle pebble count data will be used in hydraulic calculations (R/D84) to estimate velocity, and in the sediment competence calculations.

<u>Representative Pebble Count Procedures</u>

1 Locate a Reach for sampling through two meander wave-lengths or cycles of a channel reach that is approximately 20 to 30 “channel widths” in length.
2. Determine the percentage of the reach length configured as riffles and pools.
3. Adjust the pebble-count transects or sampling locations so that riffles and pools are sampled on a proportional basis, where the percentage of samples taken in riffles is equal to percentage of channel reach length configured as riffles, etc.

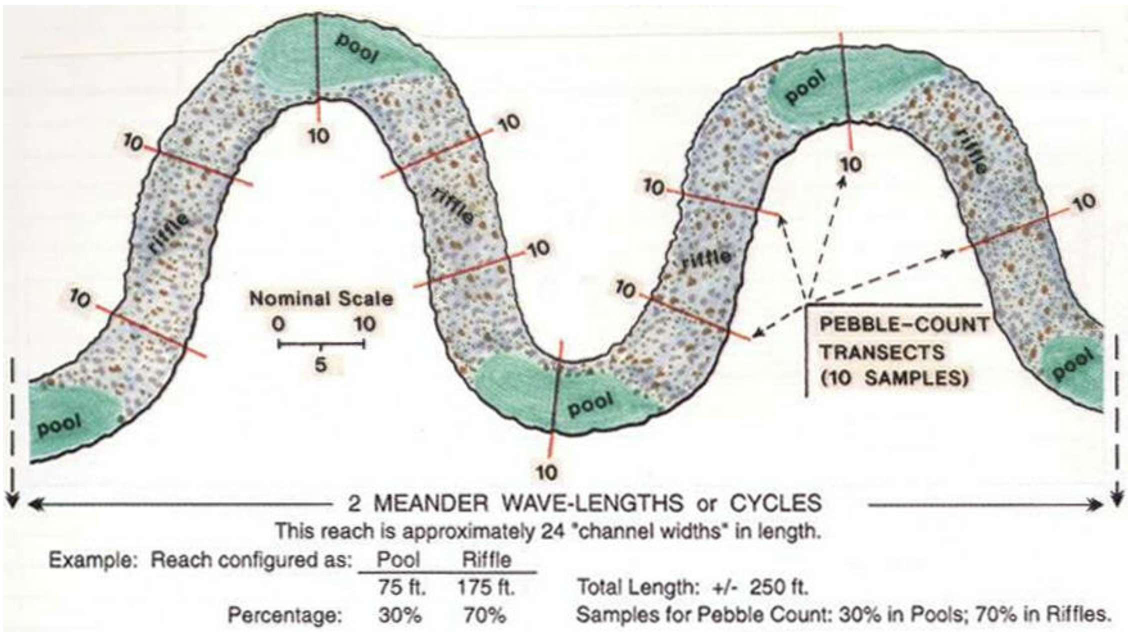


Figure 8. Representative Pebble Count Procedure

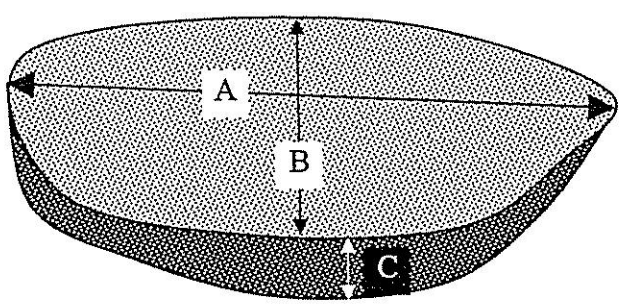


Figure 9. Comparing the Three Axes of a Particle

Pebble Count Instructions

1. Use Wisconsin Job Sheet 810, Pebble Count. An example is provided in Table 5.

2. Pace the entire study reach - record pool lengths and non-pool lengths (runs, riffles, and glides).

3. Calculate the percent of the reach composed of pool and non-pool bed features.

4. Determine the number of pool cross sections and non-pool cross sections needed (To simplify the calculations, measure 10 particles at 10 total cross sections).

5. Identify bankfull on both sides of the channel at your first cross section location and determine the sampling interval (sample at equal increments across the entire bankfull channel).

6. Begin the pebble count below the bankfull elevation. Do not include bankfull particles if the channel width is small as 20% of samples (2 out of 10) may skew the particles that make up the boundary of the channel. The observer should look away from the channel bed and select the first particle touched by the tip of your index finger at your toe. This often avoids bias of selecting larger particles.

7. Measure the length of the B-axis in millimeters and mark a dot in the correct column and row (example on form on Table 5).

8. Continue until 10 particles at 10 different cross sections have been measured in proportion to the bed features of the reach.

9. Follow the example in Table 5, then enter the data in the Ohio DNR STREAM Modules (www.dnr.state.oh.us/soilandwater/water/streammorphology) under the materials tab.

10. The spreadsheet will plot the upper limit of each size class and the corresponding cumulative percent finer than, on one side and the number of particles in each category on the other

11. When pebble count data is entered into the spreadsheet, the D16, D35, D50, D84, D95 and D100 are calculated automatically. They can be recorded on Wisconsin Job Sheet 820, Reference Reach Summary Data.

Riffle Pebble Count Instructions (on the bed, "wetted width" or "active bed")

1. Repeat steps 7-11, only sampling on the active bed of the riffle.

Table 5. Example Pebble Count Data

U.S. Department of Agriculture
Natural Resources Conservation Service

Pebble Count (Data Collection)

Wisconsin Job Sheet 810

Natural Resources Conservation Service (NRCS) **Wisconsin**

Project: ____________________ Date: ____________________

County: ____________________ Stream: ____________________

Reach No.: ____________________ Logged By: ____________________

Horizontal Datum: NAD ________ Projection: ☐ Transverse Mercator ☐ Lambert Conformal Conical

Coordinate System: ☐ __________ County Coordinates ☐ WTM ☐ State Plane Coordinates ☐ UTM

Units: ☐ Meters ☐ Feet Horizontal Control: N or Lat. __________ E or Long. __________

Elevation: __________ ☐ Assumed ☐ DOT ☐ NAVD (29 / 88) Units: ☐ Meters ☐ Feet

Inches	Millimeters	Particle	Particle Count			
			1	Total #	2	Total #
<.002	<.062	Silt/Clay				
.002 - .005	.062 - .125	Very Fine Sand		8		
.005 - .01	.125 - .25	Fine Sand		25		
.01 - .02	.25 - .50	Medium Sand		26		
.02 - .04	.50 - 1.0	Coarse Sand		10		
.04 - .08	1.0 - 2	Very Coarse Sand		2		
.08 - .16	2 - 4	Very Fine Gravel				
.16 - .22	4 - 5.7	Fine Gravel				
.22 - .31	5.7 - 8	Fine Gravel		9		
.31 - .44	8 - 11.3	Medium Gravel				
.44 - .63	11.3 - 16	Medium Gravel		5		
.63 - .89	16 - 22.6	Coarse Gravel		2		
.89 - 1.26	22.6 - 32	Coarse Gravel		4		
1.26 - 1.77	32 - 45	Very Coarse Gravel		2		
1.77 - 2.5	45 - 64	Very Coarse Gravel		3		
2.5 - 3.5	64 - 90	Small Cobbles		1		
3.5 - 5.0	90 - 128	Small Cobbles		2		
5.0 - 7.1	128 - 180	Large Cobbles		1		
7.1 - 10.1	180 - 256	Large Cobbles				
10.1 - 14.3	256 - 362	Small Boulders				
14.3 - 20	362 - 512	Small Boulders				
20 - 40	512 - 1024	Medium Boulders				
40 - 80	1024 - 2048	Large-Very Large Boulders				
		Bedrock				

Inches

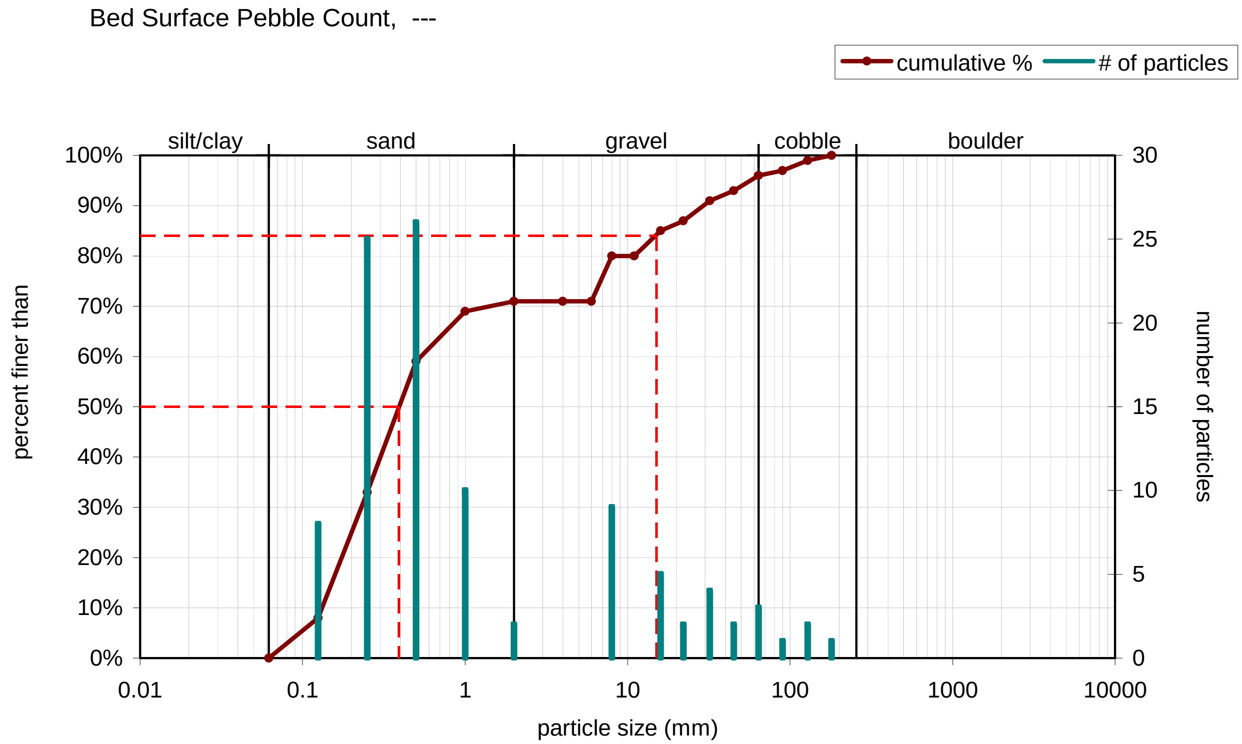
Millimeters

USDA-NRCS March 2006 Wisconsin Job Sheet 810

Bed Surface

Material	Size Range (mm)	Count
silt/clay	0 - 0.062	
very fine sand	0.062 - 0.125	8
fine sand	0.125 - 0.25	25
medium sand	0.25 - 0.5	26
coarse sand	0.5 - 1	10
very coarse sand	1 - 2	2
very fine gravel	2 - 4	
fine gravel	4 - 6	
fine gravel	6 - 8	9
medium gravel	8 - 11	
medium gravel	11 - 16	5
coarse gravel	16 - 22	2
coarse gravel	22 - 32	4
very coarse gravel	32 - 45	2
very coarse gravel	45 - 64	3
small cobble	64 - 90	1
medium cobble	90 - 128	2
large cobble	128 - 180	1
very large cobble	180 - 256	
small boulder	256 - 362	
small boulder	362 - 512	
medium boulder	512 - 1024	
large boulder	1024 - 2048	
very large boulder	2048 - 4096	
	total particle count:	100
bedrock	-------------	
clay hardpan	-------------	
detritus/wood	-------------	
artificial	-------------	
	total count:	100

Note:



Size (mm)	
D16	0.16
D35	0.26
D50	0.39
D65	0.76
D84	15
D95	57

Size Distribution	
mean	1.5
dispersion	20.4
skewness	0.43

Type	
silt/clay	0%
sand	71%
gravel	25%
cobble	4%
boulder	0%

Figure 10. Example Pebble County Plot

Stream Geometry Plan View

The measured geometry and sketch map will characterize and document the plan form of the stream through the study reach. Sinuosity, belt width, meander length, and radius of curvature will be measured (Figures 11 and 12). Plan view geometry is best measured with recent, large-scale aerial photographs. All measurements should represent the range (minimum, maximum) as well as average values for the geometry variables. Record all geometry values and ratios on the Reference Reach Summary Data form (Wisconsin Job Sheet 820).

Plan View Map

The purpose of the plan view map is to document the location of the study reach, cross-section, and measurement sites in relation to the landscape as well as verify that the plan-form of the stream has not significantly changed since the aerial photograph was taken. A broad level valley cross-section showing channel, floodplains, and terrace features in relation to the plan view should be included on the sketch map.

Sinuosity

Sinuosity is the only plan form parameter used in stream classification. Sinuosity describes how the stream has adjusted its slope in relation to the slope of the valley and is quantitatively described as the ratio of stream length to valley length and also as the ratio of valley slope to channel slope. The stream and valley lengths are measured from two common points in a direction that is parallel with the fall of the valley (Figure 11).

Belt Width

Belt width is the lateral distance (perpendicular to valley) between the outside edges of two meanders that occupy opposite sides of the valley (Figure 12). Belt width is used as an index of the lateral containment of a stream when compared with the width of the channel. Meander width ratio is the belt width divided by the bankfull width. Various meander width ratios by stream type are shown in Figure 13.

Meander Length

Meander length is the longitudinal (down/parallel with valley) distance between the apex of two sequential meanders (Figure 12). Meander length is negatively correlated with sinuosity. Meander length ratio is the meander length divided by the bankfull width.

Radius of Curvature

Radius of curvature is a measure of the “tightness” of an individual meander bend and is negatively correlated with sinuosity. Radius of curvature is measured from the center of the bankfull channel to the intersection point of two lines that perpendicularly bisect the tangent lines of each curve departure point (Figure 12). Radius of curvature is expressed as a ratio of the bankfull channel width (R_c/W_{bkf}).

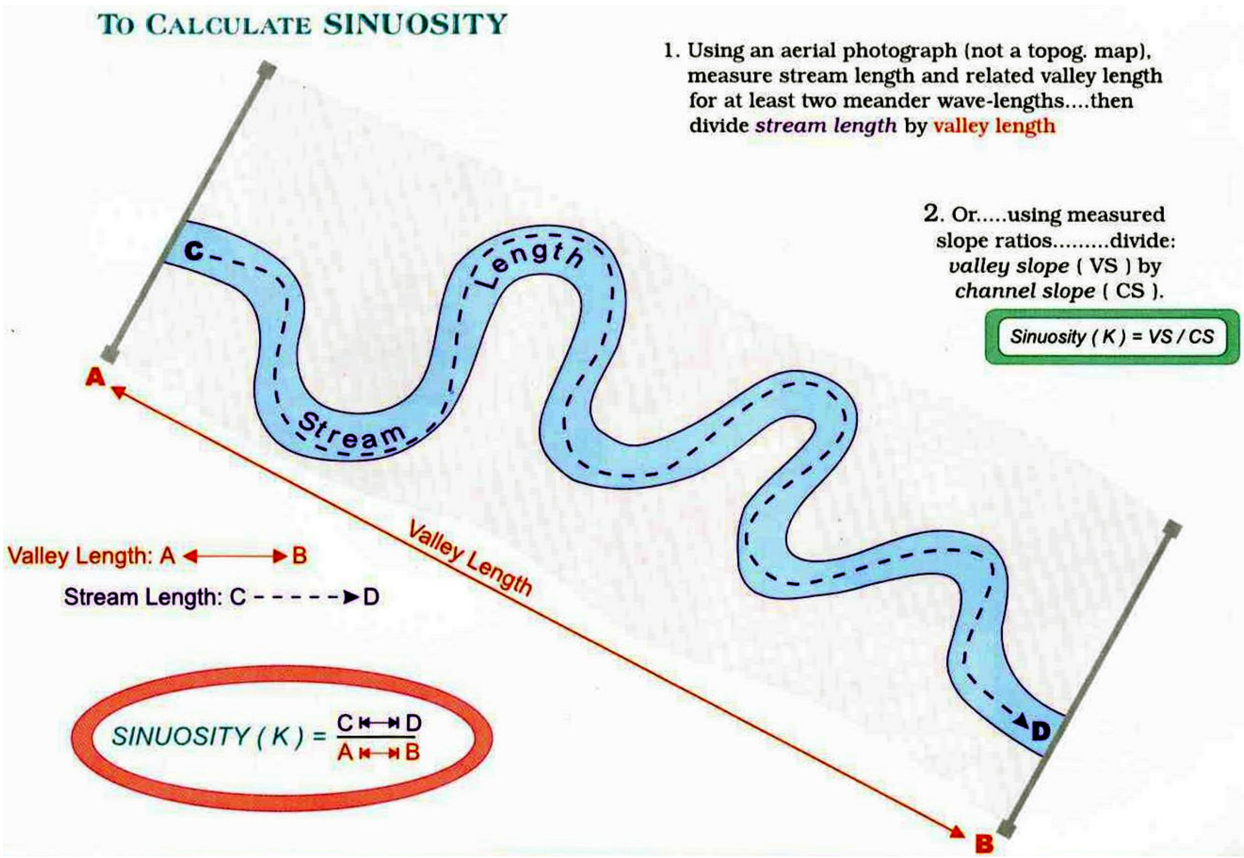


Figure 11. Sinuosity Diagram

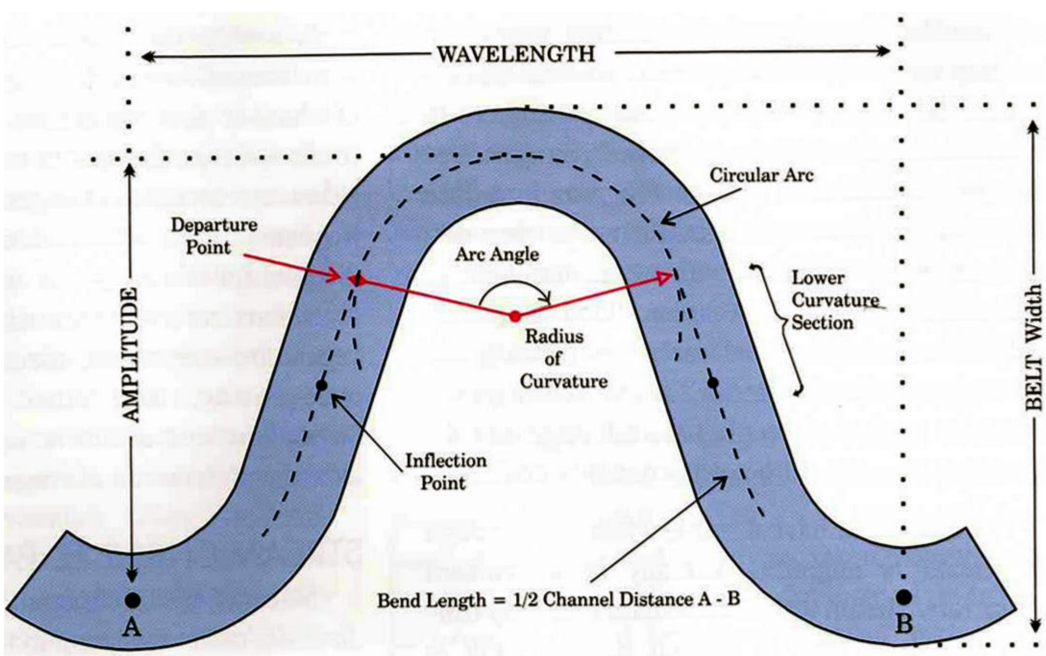


Figure 12. Meander Geometry Diagram

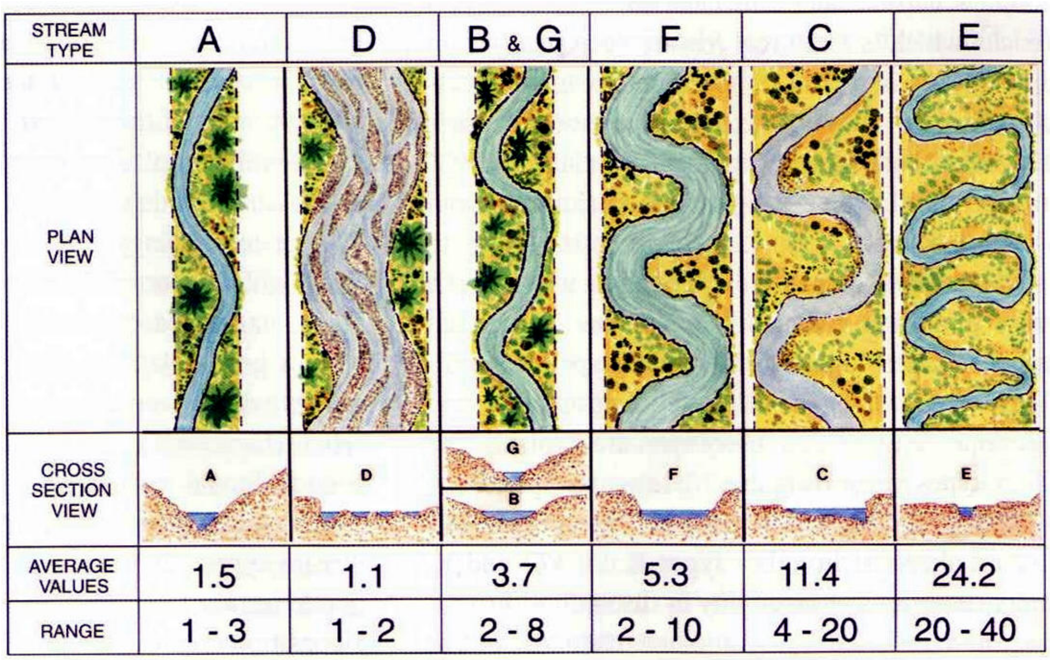


Figure 13. Meander Width Ratio (Belt Width/Bankfull Width) by Stream Type

Geometry Instructions

1. Develop familiarity of the designated reach by walking the entire length while looking at the aerial photograph (sometimes it is also helpful to view the reach from a high point).

2. Observe floodplains, terraces, abandoned channels, bedrock outcrops, and laterally confining hill slopes or roads.

3. Draw the reach to scale in your field book. Make sure to note the location of the cross sections. Note any changes that have occurred since the aerial photograph was taken.

4. Using the aerial photograph, measure sinuosity, belt width, meander length, radius of curvature and delineate the cross sections and reach boundaries. Report the geometry measurements as ranges (minimum, maximum, mean) and as ratios to the bankfull width (e.g., R_c/W_{bkf}). Measure in the field any areas where the channel has shifted substantially since the date of the aerial photograph.

5. Record all geometry data on the Reference Reach Summary Data form (Wisconsin Job Sheet 820).

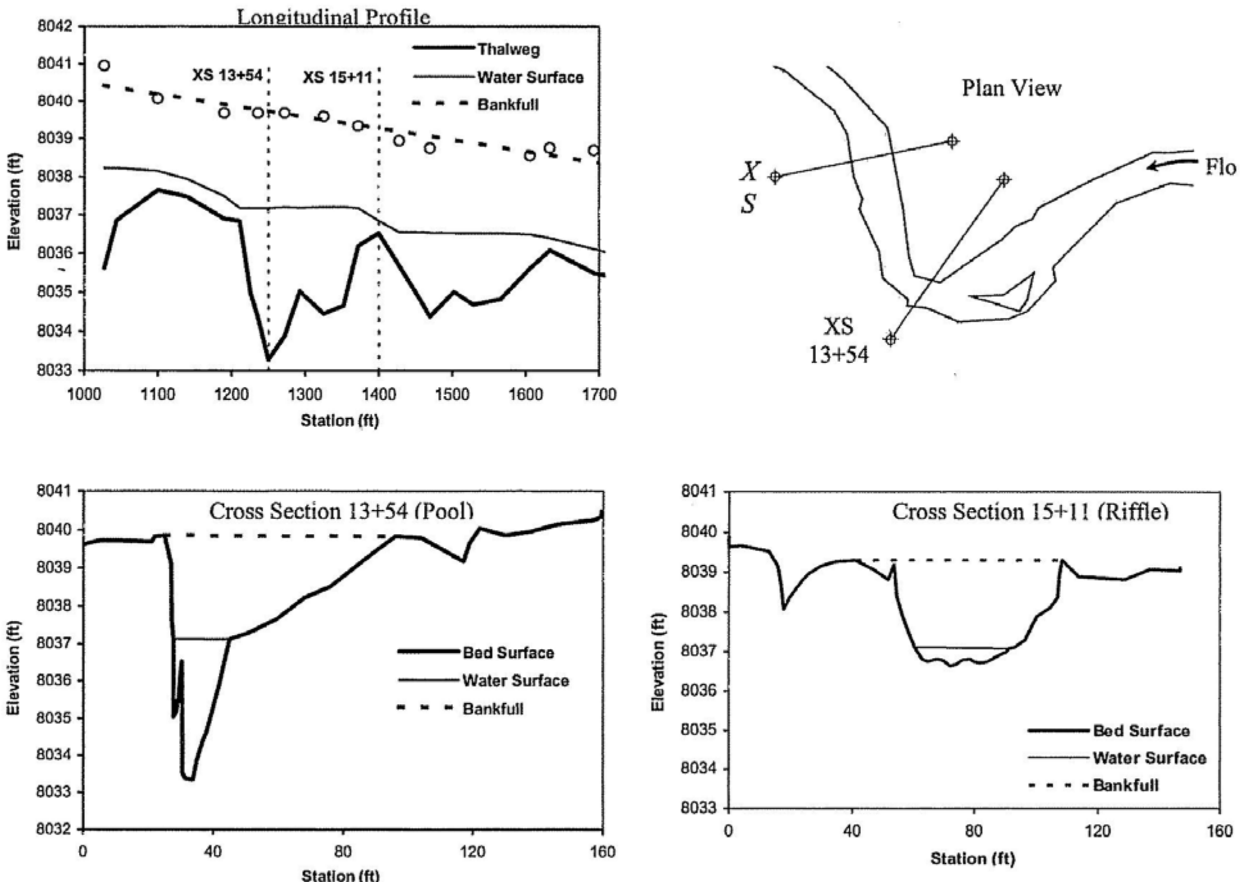


Figure 14. Combining the Profile, Cross Section, and Plan View Locations

STREAMBANK TECHNIQUES GUIDE

S = Streambank L = Lakeshore B = Both

Application or Goal	**Techniques**	Ajacks	Branch Packing	Brush Layering	Brush Mattress	Bulkheads	Coconut Fiber Log	Concrete Block	Erosion Control Fabric	Hay Bale Breakwater	Joint Planting	Jute-mat log
Access/recreation friendly	B						x		x	x		x
Adds structural support	B	x				x		x				
Adds tensile strength to the bank	B		x	x								
Aides natural regeneration and colonization	B		x	x	x		x		x	x	x	x
Appropriate above and below OHWM/bankfull	B						x					x
Bisects flow	S											
Controls Grade	S											
Creates and preserves scour holes	S											
Deflects strong or high flows	S											
Dewaters slope	B			x							x	
Enhances Fish Habitat	B											
Establishes sods and grasses	B								x	x		
Facilitates drainage on wet sites	B				x							
Filter barrier to prevent erosion and scouring of bank	B		x	x	x		x		x	x		x
Flexible, can be molded to existing contours	B						x		x			x
Good for protecting bridges, piers and abutments	S											
Good on lakes where water levels fluctuate	L									x		
Grows stronger with age	B		x	x	x						x	
Hand labor installation	B	x	x	x	x		x		x	x	x	x
Handles high velocity areas	S			x								
Handles seepage within banks	B		x	x	x							
Handles wave heights > 2 feet	L	x				x		x		x		
Immediate protective cover for the bank	B				x				x			
Increases slope stability	B	x	x	x	x			x				
Instant habitat improvement	B											
Little site disturbance	B		x				x		x	x	x	x
Maintains a natural bank appearance	B		x	x	x		x		x			x
Manufactured in the field	B		x	x	x					x	x	x
Maximum site disturbance during construction	B			x								
Protects banks from shallow slides	B		x				x				x	x
Provides aquatic habitat	B	x			x						x	
Provides shade and overhang habitat benefits	B				x							
Provides shear support in bank soils	B		x	x								
Rapid reestablishment of riparian vegetation	B		x	x	x						x	x
Redirects Flow	S	x									x	
Reduces a long beach wash into shorter segments	L											
Reduces shallow slides	B		x	x	x						x	
Reduces slope length	B		x	x			x					x
Reduces surface erosion	B			x			x					x
Reduces toe erosion	B				x		x			x		x
Reduces velocity of overland flows	B		x	x	x		x		x			x
Reduces wind and water velocities hitting bank	B									x		
Requires heavy equipment	B					x		x				
Retains moisture	B								x	x		x
Roots stabilize banks	B		x	x	x						x	
Steep banks (>1.5:1)	B	x		x		x		x			x	
Surface runoff control	B		x	x	x				x			x
Survives fluctuating water levels	L	x				x		x				
Survives high velocity flows	S	x				x		x				
Traps sediment	B		x	x	x		x		x	x	x	x
Uncemented soils and sugar sands	B	x	x	x	x	x		x			x	x
Useful where space is limited	B				x		x					x

S = Streambank **L = Lakeshore** **B = Both**

Application or Goal	Techniques	Live Cribwall	Live Fascine	Live Post	Live Siltation	Live Stake	Log Breakwater	Native Forbs & Shrubs	Native Grasses	Non-native seeding	Pilings	Plant Mat
Access/recreation friendly	B											
Adds structural support	B				X			X	X	X		X
Adds tensile strength to the bank	B	X		X		X	X				X	
Aides natural regeneration and colonization	B			X	X	X						
Appropriate above and below OHWM/bankfull	B	X	X	X	X	X	X	X	X			X
Bisects flow	S			X								
Controls Grade	S											
Creates and preserves scour holes	S											
Deflects strong or high flows	S	X										
Dewaters slope	B			X								
Enhances Fish Habitat	B	X	X	X		X		X	X	X		X
Establishes sods and grasses	B											
Facilitates drainage on wet sites	B											X
Filter barrier to prevent erosion and scouring of bank	B		X									
Flexible, can be molded to existing contours	B		X			X						X
Good for protecting bridges, piers and abutments	S											
Good on lakes where water levels fluctuate	L											
Grows stronger with age	B			X			X					
Hand labor installation	B	X	X	X	X	X		X	X			X
Handles high velocity areas	S	X	X	X	X	X		X	X	X		X
Handles seepage within banks	B											
Handles wave heights > 2 feet	L		X	X		X		X	X			
Immediate protective cover for the bank	B				X		X				X	
Increases slope stability	B	X										X
Instant habitat improvement	B	X	X	X		X		X	X		X	
Little site disturbance	B						X					X
Maintains a natural bank appearance	B		X									X
Manufactured in the field	B		X	X	X	X	X					X
Maximum site disturbance during construction	B	X	X	X	X	X	X					
Protects banks from shallow slides	B	X										
Provides aquatic habitat	B	X	X	X		X						
Provides shade and overhang habitat benefits	B	X	X			X	X					
Provides shear support in bank soils	B	X	X		X							
Rapid reestablishment of riparian vegetation	B	X										
Redirects Flow	S	X	X	X	X	X						X
Reduces a long beach wash into shorter segments	L	X	X		X		X					
Reduces shallow slides	B		X		X							
Reduces slope length	B	X	X	X		X		X	X			X
Reduces surface erosion	B		X	X		X						
Reduces toe erosion	B		X									X
Reduces velocity of overland flows	B	X	X			X						X
Reduces wind and water velocities hitting bank	B		X			X		X	X			X
Requires heavy equipment	B			X	X		X					
Retains moisture	B						X				X	
Roots stabilize banks	B											X
Steep banks (>1.5:1)	B	X	X	X	X	X						X
Surface runoff control	B		X	X		X		X	X		X	X
Survives fluctuating water levels	L	X	X	X		X		X	X	X		X
Survives high velocity flows	S			X							X	
Traps sediment	B			X							X	
Uncemented soils and sugar sands	B	X	X		X							X
Useful where space is limited	B	X	X	X		X		X	X		X	X

S = Streambank L = Lakeshore B = Both

Application or Goal	**Techniques**	Plant Roll	Rock Gabions	Rock Riprap	Root Wad	Rooted Stock	Snow Fence	Stream barbs, rock vanes	Submerged Vanes	Temporary Seeding	Terraced Crib	Tree and Log Revetment
Access/recreation friendly	B											
Adds structural support	B									X		
Adds tensile strength to the bank	B		X	X				X			X	X
Aides natural regeneration and colonization	B											
Appropriate above and below OHWM/bankfull	B	X			X	X	X		X		X	X
Bisects flow	S	X			X							X
Controls Grade	S											
Creates and preserves scour holes	S							X				
Deflects strong or high flows	S							X				
Dewaters slope	B				X			X				
Enhances Fish Habitat	B	X				X				X		
Establishes sods and grasses	B							X				
Facilitates drainage on wet sites	B	X			X				X			
Filter barrier to prevent erosion and scouring of bank	B	X			X							
Flexible, can be molded to existing contours	B	X					X		X		X	
Good for protecting bridges, piers and abutments	S	X			X							
Good on lakes where water levels fluctuate	L											
Grows stronger with age	B						X					
Hand labor installation	B	X				X						
Handles high velocity areas	S	X				X	X		X	X		
Handles seepage within banks	B				X							
Handles wave heights > 2 feet	L	X				X						
Immediate protective cover for the bank	B		X	X								X
Increases slope stability	B										X	
Instant habitat improvement	B	X	X	X	X	X					X	
Little site disturbance	B						X					
Maintains a natural bank appearance	B					X			X			
Manufactured in the field	B	X				X	X					X
Maximum site disturbance during construction	B	X							X		X	X
Protects banks from shallow slides	B				X							
Provides aquatic habitat	B										X	
Provides shade and overhang habitat benefits	B			X	X			X			X	X
Provides shear support in bank soils	B								X			
Rapid reestablishment of riparian vegetation	B											
Redirects Flow	S	X				X						
Reduces a long beach wash into shorter segments	L							X			X	X
Reduces shallow slides	B	X			X	X						
Reduces slope length	B	X				X	X				X	
Reduces surface erosion	B	X									X	
Reduces toe erosion	B											
Reduces velocity of overland flows	B	X			X	X			X		X	X
Reduces wind and water velocities hitting bank	B	X		X	X	X		X			X	X
Requires heavy equipment	B				X		X		X			
Retains moisture	B		X	X	X			X				X
Roots stabilize banks	B	X										
Steep banks (>1.5:1)	B	X				X			X			
Surface runoff control	B	X	X	X	X						X	X
Survives fluctuating water levels	L	X				X	X			X		
Survives high flows	S		X	X	X							X
Traps sediment	B		X	X	X							X
Uncemented soils and sugar sands	B	X			X	X	X		X			X
Useful where space is limited	B	X	X	X		X	X			X	X	

S = Streambank **L = Lakeshore** **B = Both**

Application or Goal	Techniques	Trench Pack	Vegetated Gabions	Vegetated Geogrid	W-weirs
Access/recreation friendly	B				
Adds structural support	B				
Adds tensile strength to the bank	B		X	X	X
Aides natural regeneration and colonization	B			X	
Appropriate above and below OHWM/bankfull	B	X		X	
Bisects flow	S				
Controls Grade	S				X
Creates and preserves scour holes	S				X
Deflects strong or high flows	S			X	X
Dewaters slope	B				
Enhances Fish Habitat	B	X		X	
Establishes sods and grasses	B				
Facilitates drainage on wet sites	B				
Filter barrier to prevent erosion and scouring of bank	B				
Flexible, can be molded to existing contours	B	X		X	
Good for protecting bridges, piers and abutments	S			X	
Good on lakes where water levels fluctuate	L				X
Grows stronger with age	B				
Hand labor installation	B			X	
Handles high velocity areas	S				
Handles seepage within banks	B				
Handles wave heights > 2 feet	L			X	
Immediate protective cover for the bank	B		X		
Increases slope stability	B			X	
Instant habitat improvement	B	X	X	X	
Little site disturbance	B				
Maintains a natural bank appearance	B				
Manufactured in the field	B	X			
Maximum site disturbance during construction	B	X		X	
Protects banks from shallow slides	B			X	
Provides aquatic habitat	B				
Provides shade and overhang habitat benefits	B			X	
Provides shear support in bank soils	B			X	
Rapid reestablishment of riparian vegetation	B			X	
Redirects Flow	S	X		X	
Reduces a long beach wash into shorter segments	L				X
Reduces shallow slides	B	X			
Reduces slope length	B	X	X	X	
Reduces surface erosion	B			X	
Reduces toe erosion	B			X	
Reduces velocity of overland flows	B	X		X	
Reduces wind and water velocities hitting bank	B	X	X	X	
Requires heavy equipment	B	X			X
Retains moisture	B		X		
Roots stabilize banks	B				
Steep banks (>1.5:1)	B	X		X	
Surface runoff control	B	X	X	X	
Survives fluctuating water levels	L	X		X	
Survives high velocity flows	S				
Traps sediment	B				
Uncemented soils and sugar sands	B	X		X	
Useful where space is limited	B	X		X	

Notes:

All techniques will require a "structural" measure in the toe zone as described in EFH Chapter 16.

Most practices require a permit from the Wisconsin Department of Natural Resources and other local agencies. Plan for the ability to get such permits when choosing a treatment option - some may be difficult to acquire (i.e. Ajacks, Bulkheads, Concrete Block, Rock Gabions, Stream Barbs, etc.).

DO NOT USE SOIL BIOENGINEERING ALONE ON STREAMS THAT ARE UNSTABLE FROM A GEOMORPHIC PERSPECTIVE (i.e. widening or downcutting).

DO NOT USE SOIL BIOENGINEERING ALONE ON LAKESHORES WHERE ICE DAMAGE IS A PROBLEM.

ALLOWABLE VELOCITY AND MAXIMUM SHEAR STRESS
Streambank and Shoreland Protection Code 580

Type of Treatment	Allowable Shear lb/sq ft	Velocity ft/sec
Brush Mattresses[1]		
Staked only w/ rock riprap toe (initial)	0.8 - 4.1	5
Staked only w/ rock riprap toe (grown)	4.0 - 8.0	12
Coir Geotextile Roll[2]		
Roll with coir rope mesh staked only without rock riprap toe	0.2 - 0.8	< 5
Roll with Polypropylene rope mesh staked only without rock riprap toe	0.8 - 3.0	< 8
Roll with Polypropylene rope mesh staked and with rock riprap toe	3.0 - 4.0	< 12
Live Fascine[3]		
LF Bundle w/ rock riprap toe	2.0 - 3.1	8
Soils[4]		
Fine colloidal sand	0.02-0.03	1.5
Sandy loam (noncolloidal)	0.03-0.04	1.75
Alluvial silt (noncolloidal)	0.045-0.05	2
Silty loam (noncolloidal)	0.045-0.05	1.75-2.25
Firm loam	0.075	2.5
Fine gravels	0.075	2.5
Stiff clay	0.26	3-4.5
Alluvial silt (colloidal)	0.26	3.75
Graded loam to cobbles	0.38	3.75
Graded silts to cobbles	0.43	4
Shales and hardpan	0.67	6
Gravel/Cobble[4]		
1-inch	0.33	2.5-5
2-inch	0.67	3-6
6-inch	2	4-7.5
12-inch	4	5.5-12
Vegetation[4]		
Class A turf (ret class)	3.7	6-8
Class B turf (ret class)	2.1	4-7
Class C turf (ret class)	1	3.5
Retardance Class D	0.6	Design of roadside channels HEC-15
Retardance Class E	0.35	
Long native grasses	1.2-1.7	4-6
Short native and bunch grass	0.7-0.95	3-4

Type of Treatment	Allowable Shear lb/sq ft	Velocity ft/sec
Soil Bioengineering[4]		
Wattles	0.2-1.0	3
Reed fascine	0.6-1.25	5
Coir roll	3-5	8
Vegetated coir mat	4-8	9.5
Live brush mattress (initial)	0.4-4.1	4
Live brush mattress (grown)	3.90-8.2	12
Brush layering (initial/grown)	0.4-6.25	12
Live fascine	1.25-3.10	6-8
Live willow stakes	2.10-3.10	3-10
Hard Surfacing[4]		
Gabions	10	14-19
Concrete	12.5	>18
Boulder Clusters[5]		
Boulder		
Very large (>80-inch diameter)	37.4	25
Large (>40-in diameter)	18.7	19
Medium (>20-inch diameter)	9.3	14
Small (>10-inch diameter)	4.7	10
Cobble		
Large (>5-inch diameter)	2.3	7
Small (>2.5-inch diameter)	1.1	5
Gravel		
Very Course (>1.25-inch diameter)	0.54	3
Course (>.63-inch diameter)	0.25	2.5

[1] Brush mattresses (ERDC TN EMRRP-SR-23): http://el.erdc.usace.army.mil/emrrp/pdf/sr23.pdf.
[2] Coir Geotextile roll (ERDC TN EMRRP-SR-04): http://el.erdc.usace.army.mil/emrrp/pdf/sr04.pdf.
[3] Live Fascine (ERDC TN EMRRP-SR-31): http://el.erdc.usace.army.mil/emrrp/pdf/sr31.pdf.
[4] Stream Restoration Materials (ERDC TN EMRRP-SR-29): http://el.erdc.usace.army.mil/emrrp/pdf/sr29.pdf.
[5] Boulder Clusters (ERDC TN EMRRP-SR-11): http://el.erdc.usace.army.mil/emrrp/pdf/sr11.pdf.

Additional Sources:

Wisconsin Department of Transportation, Erosion Control - Product Acceptability List (PAL):
http://www.dot.wisconsin.gov/library/research/docs/finalreports/tau-finalreports/erosion.pdf

Texas Department of Transportation, Approved Products List:
http://www.dot.state.tx.us/mnt/erosion/contents.htm

GUIDELINES FOR TREATING HIGH ERODING STREAMBANKS (GREATER THAN EIGHT FEET)

High streambanks are generally unstable. At eight feet or higher, the critical height of the bank is often exceeded. The critical height is the height of bank that is stable for the soil types and moisture conditions occurring in that bank. Slope failure is the typical erosion process for banks that exceed critical height. Slab failures are common in silty or coarser textured soils while rotational slumps are more typical for banks with more heavy textured (clayey) soils. See Companion Document 11 for diagrams and further information on failure mechanics.

High streambanks continue to fail until the soil materials in the bank reach a stable angle of repose. This channel widening process is driven by the combination of slope failure processes and stream flows. Sloughed materials are washed away by stream flows which prevents the redistribution of loads on the bank. The toe of the bank may be eroded, or even undercut, which also helps maintain critical loads on the bank. These processes will continue until the channel is wide enough so a small capacity, bankfull channel can form with an adjacent floodplain.

Slope failure problems are typically solved by unloading the top of the bank by excavation, loading the toe of the slope or doing a combination of both. This is not always a viable approach for streambanks. Adjacent land use may limit or prohibit excavation. Placing fill, gabions, rock, or other loading materials at the toe of the bank requires large volumes of material which usually encroach on the stream's cross-section. The stream will tend to attack the toe material or blow out the opposite bank to acquire the cross-section it needs to maintain channel stability. Also, the costs of excavation, or for materials for loading the toe, may be prohibitive if the unstable bank is extremely high.

One alternative solution for stabilizing high streambanks is to construct a bench at the toe of the bank (toe bench) and excavate the opposite bank to maintain a stable channel cross-section (Figure 1). The face of the toe bench is armored if it is to be maintained as the outside boundary of a meander. The surface of the toe bench is vegetated to slow flood flows so deposition occurs on the toe bench in place of scouring of sloughed bank materials. Over time, the bank will continue to slough until the accumulated materials at the toe of the bank counter the weight at the top of the bank or until the roots of woody vegetation mature to the point that they reinforce the strength of the soils in the bank.

The elevation of the toe bench, its width and the dimensions of the stable channel cross-section are based on fluvial geomorphology principles used in the Rosgen stream classification system. Toe benches are recommended for “C”, “D”, or “E” stream types. These streams are “slightly entrenched” in Flosgen's classification system. This means that flows greater than the bankfull discharge flow onto a floodplain that is at least 2.2 times the width of the stream cross-section at the bankfull discharge.

Flows greater than the bankfull discharge must be able to access the floodplain for a toe bench to work. Generally, high banks are formed in “C”, “D”, or “E” stream types when the stream laterally migrates into a higher terrace, or the wall of the valley it lies in, In these situations, a floodplain is still accessible on the side of the stream opposite the high bank.

Toe benches are not recommended for “entrenched” stream types (“A”, “G”, or “F”). These streams have little or no floodplain at the elevation of the bankfull discharge. Rosgen's floodplain width for these stream types is 1.4 (or less) times the width of the stream cross-section at the bankfull discharge. These three stream types typically occur when a channel is downcutting.

Rosgen's “B” stream types are “moderately” entrenched. They fall between the 1 .4 and 2.2 figures for floodplain width. Toe benches may work in these stream types but the risk of failure is higher than for slightly entrenched streams.

The elevation of the surface of the toe bench should be the elevation of the bankfull discharge. The toe bench should be wide enough to maintain a flat, depositional surface adjacent to the stream after the high bank has sloughed to a more stable angle. In other words, the sloughed materials should remain at the toe of the bank and not extend to the outside edge of the toe bench. Site conditions and the channel alignment must be considered when establishing the toe bench width. Excavation on the bank opposite the toe bench should be done to maintain both the appropriate width/depth ratio for the bankfull channel cross-section and a stable meander pattern. The length of the toe bench is determined by the length of the high bank requiring protection. Construction should begin and end at stable points such as riffles.

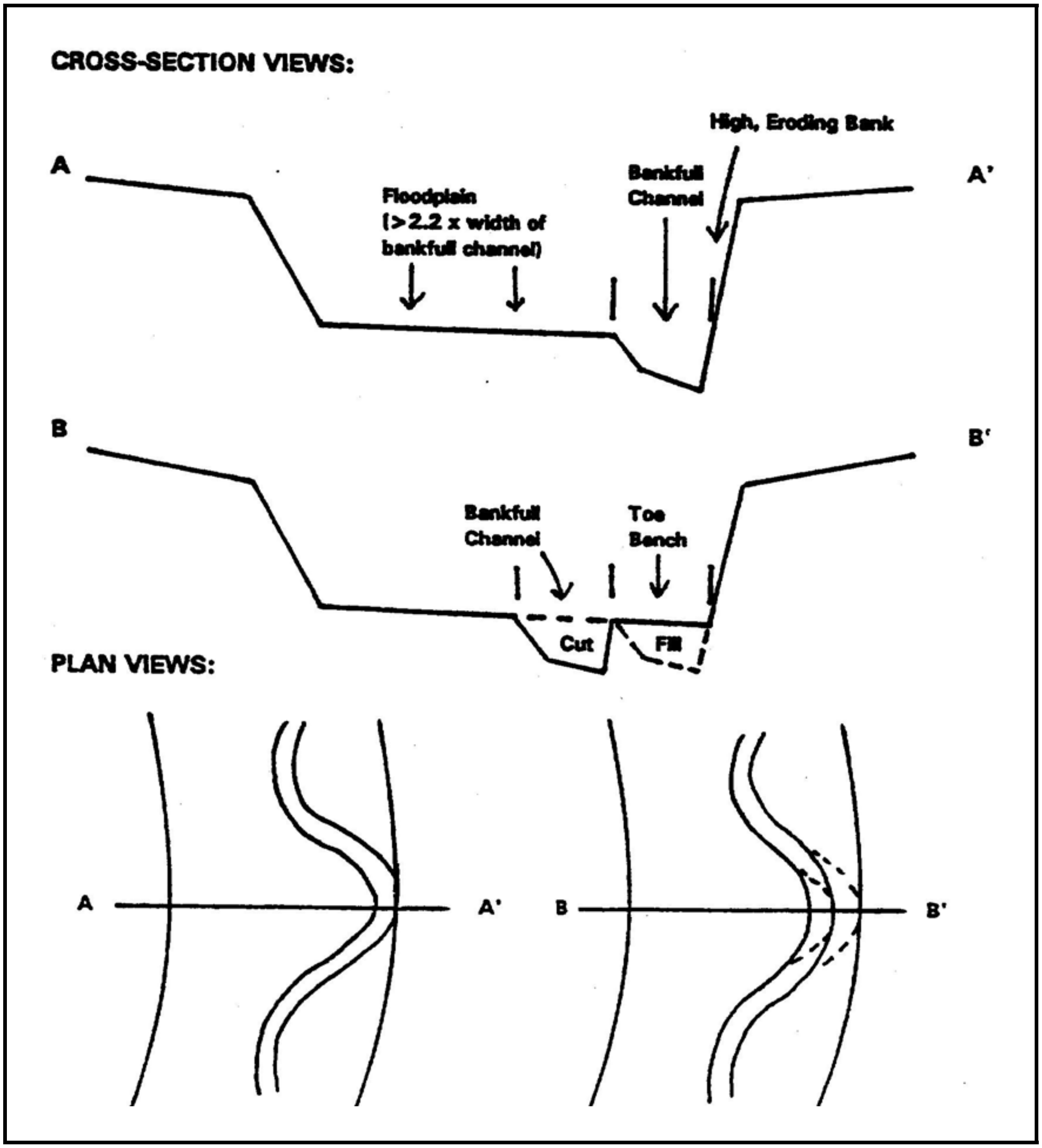


Figure 1. Treating high, unstable streambanks using a toe bench.

Source: Lyle J. Steffen, Geologist, Retired, USDA-NRCS, Lincoln, NE (11/16/95).

FISH HABITAT STRUCTURES: A SELECTION GUIDE FOR STREAM CLASSIFICATION

Adapted from Rosgen and Fittante, 1986. (Revised by Rosgen in 1994.)

Stream Type 1994	Low Stage Check Dams	Medium Stage Check Dams	Random Boulder Placement	Bank Placed Boulder	Vane, Barb, Single Wing Deflector	Double Wing Deflector	Channel Constrictor	Bank Cover	Half Log Structure	Floating Log Structure	Submerged Shelter e.g., Felled Tree		Migration Barrier	Gravel Traps		Spawn Gravel Placement	Cross Vane	W Rock Weir	Bank Root Wads	Log Spurs
											Meander	Straight		V-Shaped	Log Sill					
A1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	E	E	NA	NA	P	NA	NA	NA	NA
A2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	E	NA	NA	P	NA	NA	NA	NA
A3	F	P	P	G	P	F	NA	P	P	F	P	E	F	P	P	P	G	P	G	G
A4	F	P	P	G	P	F	NA	P	P	F	P	E	F	P	P	P	G	P	G	F
A5	F	P	P	G	P	F	NA	P	P	F	P	E	F	P	P	P	G	P	G	F
A6	F	F	P	G	P	F	NA	P	F	F	P	E	F	P	P	P	G	P	G	G
B1	P	P	P	E	P	P	P	E	G	G	G	E	G	G	G	F	NA	NA	NA	NA
B2	E	E	NA	NA	E	E	E	E	NA	NA	NA	NA	G	E	E	F	NA	NA	NA	NA
B3	E	G	E	E	E	E	E	E	E	E	G	E	G	G	G	G	E	E	E	E
B4	E	G	E	E	E	E	E	E	E	E	G	G	G	NA	NA	NA	E	E	E	E
B5	G	F	F	E	G	G	G	E	G	E	G	G	F	P	P	P	E	E	E	E
B6	G	F	F	E	G	G	G	E	E	E	G	G	F	P	P	P	G	G	E	E
C1	P	P	P	E	P	P	P	E	E	E	E	E	P	G	F	F	NA	NA	E	G
C2	G	F	NA	NA	G	G	G	G	NA	G	NA	NA	P	G	G	G	NA	NA	E	G
C3	G	F	G	E	G	G	G	G	G	G	E	E	P	G	G	G	G	E	E	G
C4	F	P	P	G	F	F	F	G	F	G	F	G	P	NA	NA	NA	G	G	E	G
C5	F	P	P	G	P	P	P	F	P	G	F	G	P	P	P	P	F	F	E	F
C6	F	P	P	G	P	P	F	G	F	G	F	G	P	P	P	P	F	G	E	G
D3	P	P	P	F	F	F	F	P	P	P	P	P	P	P	P	P	P	P	F	F
D4	P	P	P	F	F	F	F	P	P	P	P	P	P	NA	NA	NA	P	P	F	F
D5	P	P	P	F	F	F	F	P	P	P	P	P	P	P	P	P	P	P	F	F
D6	P	P	P	F	F	F	F	NA	P	P	P	P	P	P	P	P	P	P	F	F
E3	NA	P	P	G	P	F	NA	NA	NA	NA	G	G	P	F	F	F	NA	NA	G	F
E4	NA	P	P	G	P	F	NA	NA	NA	NA	G	G	P	NA	NA	NA	NA	NA	G	F
E5	NA	P	P	G	P	F	NA	NA	NA	NA	G	G	P	P	P	P	NA	NA	G	F
E6	NA	P	P	G	P	F	NA	NA	NA	NA	G	G	P	P	P	P	NA	NA	G	F
F1	P	P	P	G	F	P	P	F	F	F	G	G	P	P	P	P	NA	NA	NA	NA
F2	F	P	NA	NA	F	F	F	F	F	F	NA	NA	P	F	F	F	NA	NA	NA	NA
F3	F	P	F	G	G	G	F	F	F	F	G	G	P	F	F	F	G	F	G	G
F4	F	P	P	G	F	F	F	F	F	F	G	G	P	NA	NA	NA	G	F	G	F
F5	F	P	P	G	F	F	F	F	F	F	G	G	P	P	P	P	G	F	G	F
F6	F	P	F	G	F	F	F	F	F	F	G	G	P	P	P	P	G	F	G	F
G1	NA	NA	P	NA	NA	NA	NA	P	F	F	F	F	G	NA	NA	P	NA	NA	NA	NA
G2	NA	NA	NA	NA	NA	NA	NA	P	F	NA	NA	NA	G	NA	NA	P	NA	NA	NA	NA
G3	F	P	P	G	P	F	NA	P	P	F	F	F	P	P	P	P	G	P	G	F
G4	F	P	P	G	P	F	NA	P	P	F	F	F	P	P	P	P	G	P	G	F
G5	F	P	P	G	P	F	NA	P	P	F	F	F	P	P	P	P	G	P	G	F
G6	F	P	P	G	P	F	NA	P	P	F	F	F	P	P	P	P	G	P	G	F

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NA = Not Applicable | P = Poor | F = Fair | G = Good | E = Excellent

REFERENCE REACH DATA
AVERAGE VALUES FOR STABLE STREAMS

Due to variables such as geology, vegetation, land-use, sediment load, sediment grain size and runoff characteristics, there is natural variability to hydraulic geometry relationships so that natural channels are stable within a range of dimensions. The following values are based on measured observations from streams. These relationships can be used as a preliminary guide to stability in stream reaches, but other techniques and local data should also be considered.

Average Values for C4 Streams

Pools	Ratio Pool Slope / avg. slope	0.20 - .30
	Ratio Pool depth / mean depth	2.5 - 3.5 (median 3.0)
	Ratio Pool width / avg. width	1.3 - 1.7 (median 1.5)
Riffles	Ratio Riffle slope / avg. slope	1.5 - 2.0
	Ratio Riffle max depth / mean depth	1.2 - 1.5
Runs	Ratio run slope / avg. slope	0.5 - 0.8
	Ratio run depth / avg. depth	1.9 - 2.2
	Ratio width to depth Ratio of runs / W/D (riffle)	0.4 - 0.5
Glides	Ratio glide slope / avg. slope	0.3 - 0.5
	Ratio glide depth / avg. depth	1.4 - 1.8
	Ratio of glide width / avg. width	1.5 - 1.7
	Ratio of glide width / depth ratio of glide/W/D ratio	1.1 - 1.3

Average Values for C3, C4, and B3 Streams

	C3	C4	B3
W/D	12 – 25 (avg. 20)	12 – 18 (avg. 15)	12 – 20 (avg. 16)
R_C/W	3.0 - 3.5	2.5 - 3.0	N/A
R_C/W High Bedload V. Coarse Composite Banks	3.5 - 4.5	3.0 - 4.0	N/A
Pool to Pool Spacing	7 - 8 W	5 - 7 W	B_C 1 - 2% 4 - 5W 2 - 4% 3 - 4W 4 - 6% 2 - 3W 6 - 8% 1.5 - 2W 8+% 1 - 1.5 W
L_M/W	12 - 14	9 - 14	N/A
L_M/W (High Bedload Stress)	12	11 - 14	N/A

<u>Indicators of Instability</u>

- Width/depth ratio is less than 10 and entrenchment ratio is less than 1.4.
- If sinuosity is less than 1.2, it is likely the stream has been channelized to cause instability.

R_c = radius of curvature
W = bankfull width
D = bankfull mean depth
L_m = meander wavelength
B_c = subcategory of B3 stream type

STREAMBANK EROSION AND RECOVERY CHARACTERISTICS BY STREAM TYPE

Adapted from Rosgen and Fittante, 1986. (Revised by Rosgen in 1994.)

Stream Type	Sensitivity to Disturbance	Recovery Potential	Sediment Supply	Streambank Erosion Potential	Vegetation is a Controlling Influence
A1	very LOW	EXCELLENT	very LOW	very LOW	NEGLIGIBLE
A2	very LOW	EXCELLENT	very LOW	very LOW	NEGLIGIBLE
A3	very HIGH	very POOR	very HIGH	HIGH	NEGLIGIBLE
A4	EXTREME	very POOR	very HIGH	very HIGH	NEGLIGIBLE
A5	HIGH	very POOR	very HIGH	very HIGH	NEGLIGIBLE
A6	very LOW	POOR	HIGH	HIGH	NEGLIGIBLE
B1	very LOW	EXCELLENT	very LOW	very LOW	NEGLIGIBLE
B2	LOW	EXCELLENT	very LOW	very LOW	NEGLIGIBLE
B3	MODERATE	EXCELLENT	HIGH	LOW	MODERATE
B4	MODERATE	EXCELLENT	MODERATE	LOW	MODERATE
B5	MODERATE	EXCELLENT	MODERATE	MODERATE	MODERATE
B6	MODERATE	EXCELLENT	MODERATE	LOW	MODERATE
C1	LOW	very GOOD	very LOW	LOW	MODERATE
C2	LOW	very GOOD	LOW	LOW	MODERATE
C3	MODERATE	GOOD	MODERATE	MODERATE	very HIGH
C4	very HIGH	GOOD	HIGH	very HIGH	very HIGH
C5	very HIGH	FAIR	very HIGH	very HIGH	very HIGH
C6	very HIGH	GOOD	HIGH	HIGH	very HIGH
D3	MODERATE	POOR	very HIGH	very HIGH	MODERATE
D4	MODERATE	POOR	very HIGH	very HIGH	MODERATE
D5	MODERATE	POOR	very HIGH	very HIGH	MODERATE
D6	HIGH	POOR	HIGH	HIGH	MODERATE
DA4	MODERATE	GOOD	very LOW	LOW	very HIGH
DA5	MODERATE	GOOD	LOW	LOW	very HIGH
DA6	MODERATE	GOOD	very LOW	very LOW	very HIGH
E3	HIGH	GOOD	LOW	MODERATE	very HIGH
E4	very HIGH	GOOD	MODERATE	HIGH	very HIGH
E5	very HIGH	GOOD	MODERATE	HIGH	very HIGH
E6	very HIGH	GOOD	LOW	MODERATE	very HIGH
F1	LOW	FAIR	LOW	MODERATE	LOW
F2	LOW	FAIR	MODERATE	MODERATE	LOW
F3	MODERATE	POOR	very HIGH	very HIGH	MODERATE
F4	EXTREME	POOR	very HIGH	very HIGH	MODERATE
F5	very HIGH	POOR	very HIGH	very HIGH	MODERATE
F6	very HIGH	FAIR	HIGH	very HIGH	MODERATE
G1	LOW	GOOD	LOW	LOW	LOW
G2	MODERATE	FAIR	MODERATE	MODERATE	LOW
G3	very HIGH	POOR	very HIGH	very HIGH	HIGH
G4	EXTREME	very POOR	very HIGH	very HIGH	HIGH
G5	EXTREME	very POOR	very HIGH	very HIGH	HIGH
G6	very HIGH	POOR	HIGH	HIGH	HIGH

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