

**WISCONSIN SUPPLEMENT  
ENGINEERING FIELD HANDBOOK  
CHAPTER 16  
STREAMBANK AND SHORELINE PROTECTION**

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**REFERENCES**

- American Society of Civil Engineers Proceedings, 6/48, Common Slope Protection.
- Hunt, Robert L., Glossary of Wisconsin Trout Habitat Development Techniques, Wisconsin DNR, 1987.
- Hunt, Robert L., Trout Stream Therapy, University of Wisconsin Press, 1993.
- Leopold, Luna B., A View of the River, 1994.
- National Engineering Handbook, Section 5, NRCS (SCS), Supplement B.
- Reckendorf, Frank, PHD, Geology, Soil Science, & Fluvial Geomorphology, Salem, OR 97301-1130, Wisconsin NRCS 1996, Fluvial Geomorphology Workshop manual.
- Robbin B. Sotir & Associates, Market, GA 30064, Wisconsin, NRCS 1996 Fluvial Geomorphology Workshop manual.
- Rosgen, David L. A Practical Method of Computing Streambank Erosion Rate. Wildland Hydrology Inc., Pagosa Springs, CO, 2001.
- Rosgen, D., Applied River Morphology. 1996. Printed Media Companies, Minneapolis, Minnesota.
- Rosgen, David L., 1994. A Classification of Natural Rivers. Catena vol. 22. Elsevier Press. p. 169-199.
- Rosgen, D.L., The Cross-Vane, W-Weir and J-Hook Structures . . . Their Description, Design and Application for Stream Stabilization and River Restoration.  
<http://www.wildlandhydrology.com/assets/cross-vane.pdf>
- Rosgen, David L., River Morphology and Applications Course/Field Manual, Wildland Hydrology, 2003.
- Saele, Ellen M., Design Engineer, NRCS, Guidelines For The Design Of Stream Barbs, NRCS (SCS), Portland, OR, Wisconsin NRCS 1996 Fluvial Geomorphology Workshop manual.
- Schumm, S.A., Harvey, M.D. and Watson, C.C. 1984. Incised Channels – Morphology, Dynamics and Control. Water Resources Publications.
- Silvey, Hilton L. and Rosgen, D.L. Reference Reach Field Book. 2005.
- Simon, A., and Hupp, C.R. 1987. Channel Evolution in Modified Alluvial Streams. Transportation Research Record 1151, Transportation Research Board.
- Steffen, Lyle, Geologist, NRCS, Lincoln, Nebraska, Wisconsin, NRCS 1996 Fluvial Geomorphology Workshop manual.
- U.S. Army Corps of Engineers, Publication No. EM 1110-2-1601, Engineering and Design – Hydraulic Design of Flood Control Channels, 1994.
- U.S. Department of Agriculture, Natural Resources Conservation Service, Fluvial Geomorphology Workshop Handbook, Wisconsin 1996.

U.S. Department of Agriculture, Forest Service Technology and Development Program, A Soil Bioengineering Guide for Streambank and Lakeshore Stabilization, Eds. D. Meadows and C.E. Eubanks, October 2002.

U.S. Department of Agriculture, Natural Resources Conservation Service, Stream Restoration Design Handbook, Engineering Field Handbook, Part 654, August 2007.

U.S. Department of Agriculture, (Natural Resources Conservation Service) previously the Soil Conservation Service, 1994, Gradation Design Of Sand and Gravel Filters, National Engineering Handbook, Part 633, Chapter 26.

U.S. Department of Transportation, Federal Highway Administration, Hydraulic Engineering Circular No. 11, Design of Riprap Revetment, 1989.

Vetrano, David M., Unit Construction of Trout Habitat Improvement Structures For Wisconsin Coulee Streams, Administrative Report No. 27, 1988, Wisconsin DNR, Viroqua, Wisconsin.

Wells, Gary, Landscape Architect, NRCS, Lincoln, Nebraska, Wisconsin NRCS 1996 Fluvial Geomorphology Workshop manual.



## **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 for 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

**References**

- Chang, H. H. 1988. Fluvial processes in river engineering. John Wiley and Sons, Inc. Reprinted by Krieger Publishing Company, Malabar, FL 32950.
- Rosgen, D. L. 1994. A classification of natural rivers. *Catena*. Vol. 22. No. 3. Elsevier Science, B. V. Netherlands. pp. 169-199.
- Schumm, S. A. 1960. Shape of alluvial channels in relation to sediment type. USGS Professional Paper 352-B. pp. 17-30.
- Schumm, S. A., Harvey, M. D., and Watson, C. C. 1984. Incised channels: Morphology, dynamics, and control. Water Resources Publications, P. O. Box 2841, Littleton, CO 80161.
- Simon, A. 1989. A model of channel response in disturbed alluvial channels. *Earth Surface Processes and Landforms*. Vol. 14. pp. 11-26.

### 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.

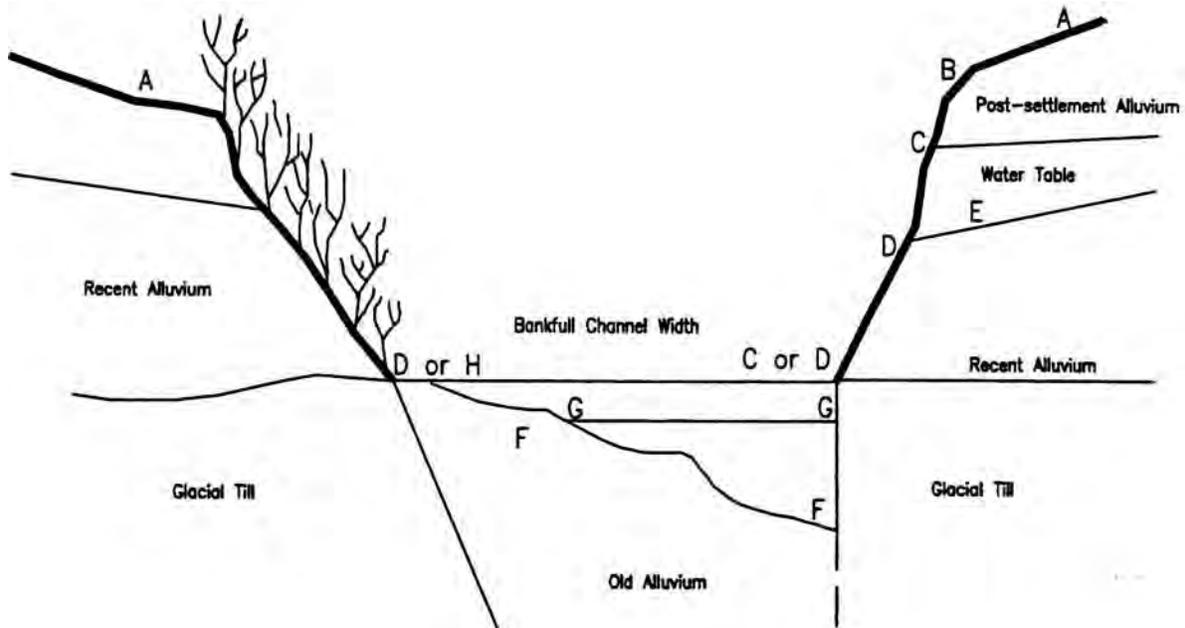


Figure WI-16-1: Suggested survey points.

## 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

### Sizing Rock Riprap

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.

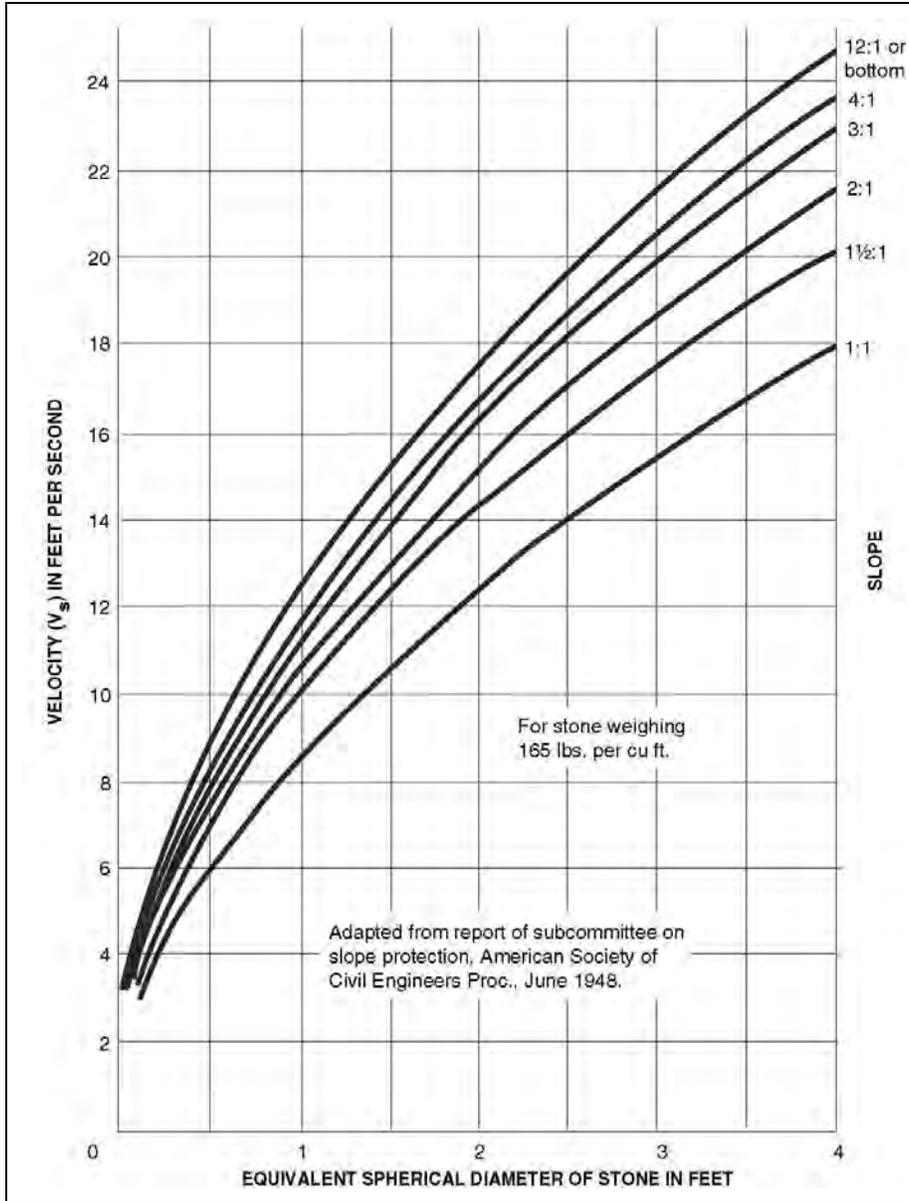


Figure WI-16-2

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

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
**Range 1.5-4.0:1	$0.470 + \left(\frac{3-z}{.5}\right) * (-.08433)$	$0.443 + \left(\frac{3-z}{.5}\right) * (.04233)$

\*\*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:  $\tau$  = shear Stress (lbs/ft<sup>2</sup>)

$\gamma$  = unit weight of fluid (62.4 lbs/ft<sup>3</sup>)

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.

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

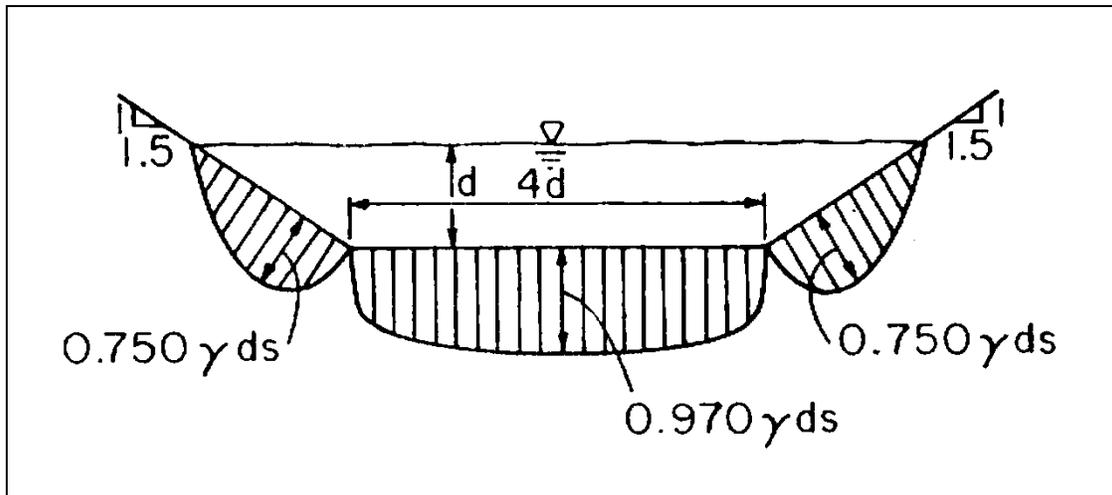


Figure WI-16-3: Shear Stress Distribution Diagram

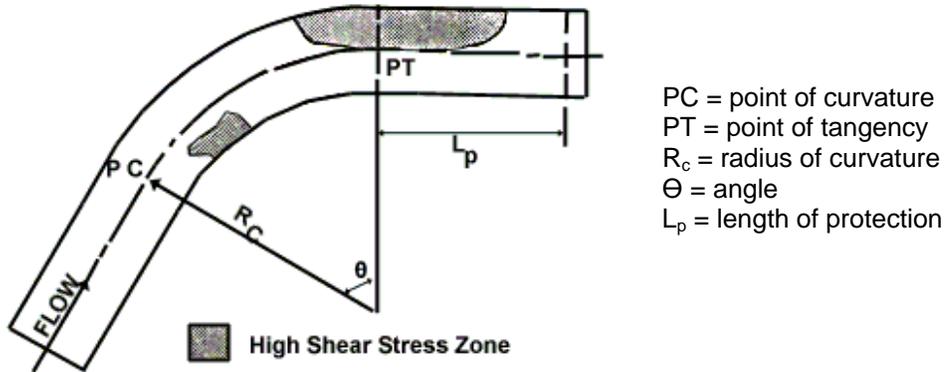


Figure WI-16-4

Shear Stress in a Channel Bend

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 ( $B$ ).

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

$$K_b = 2.4(e)^{-0.0852 \frac{R_c}{B}}$$

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 ( $\lambda_x$ ) 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
	0.9	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.		DOWNSTREAM W.S.		Design	COMPUTED	SELECTED		
STATION	ELEV	STATION	ELEV	Storm Elev.	SLOPE	SLOPE	MANNINGS	
(ft)	(ft)	(ft)	(ft)	(ft)	(%)	(%)	"n"	
0+00	95.69	12+00	90.59	101.8	0.42	0.42	0.04	
ROCK STATIONS		SLOPING STATIONS		SLOPING				
START	END	START	END	LENGTH	SIDE			
(ft)	(ft)	(ft)	(ft)	(ft)	SLOPE			
7+50	9+15	7+50	9+15	165	1.5			
ROCK	ROCK	ROCK	D50	D50		OHWM		
HEIGHT	LENGTH	TYPE	USED	MIN		Elev		
(ft)	(ft)	CU=1 SP=2	(in)	(in)		(ft)		
4	165	1	12	11.4		94.6		
FILTER OPTION TABLE		FILTER	KEYWAY	DEPTH				
1 = 2 X D50 & FILTER		OPTION	BOTTOM	BELOW	THICKNESS (in)			
2 = 3 X D50 & NO FILTER		CODE	WIDTH	SCOUR	ROCK	FILTER		
3 = 2 X D50 & GEOTEXTIII		2	(ft)	(ft)	36			
4 = 2 X D50 & FILTER & GEO.			2	2				
Above		TOTAL						
Keyway	Keyway	VOLUME/FT (cy/ft)		ROCK	FILTER			
Rock Vol/Ft	Rock Vol/Ft	ROCK	FILTER	(cy)	(cy)			
0.801234	0.3333333	1.135		187	0			
VELOCITY	Q	AREA	p	r	T =	Feet		
(fps)	(cfs)	(sq ft)	(ft)	(ft)	X =	3.0		
7.5	5754	767.4	139.6	5.50	Y =	5.4		
						3.6		
Design Q or Out of BANK		ENGR			END			
Q	V	JOB			DISTS	W.S. EL		
(cfs)	(fps)	Class			(sq yd)	101.80		
5754	7.5	VI			0	199 101.80		
RIPRAP GRADATION				NOTES				
% PASSING ROCK SIZE				1. Use only elevations for cross-sections				
(by wt)	(in)			2. Accepts up to 24 cross section pairs				
100	24			3. Select any W.S. elevation				
60-85	18			4. Use side slopes of 1.5:1 - 4.0:1				
25-50	12			5. X-section shown on WI-404A - WI-404A-ET - WI-404A-LT				
5-20	6			6. Rock and filter thicknesses can be computed or entered.				
0-5	2			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								

D50 required = 5.7 inches  
 Water surface Elevation = 97.1 (chosen to 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										
-----										
UPSTREAM W.S.		DOWNSTREAM W.S.		Design	COMPUTED	SELECTED				
STATION	ELEV	STATION	ELEV	Storm Elev.	SLOPE	SLOPE	MANNINGS			
(ft)	(ft)	(ft)	(ft)	(ft)	(%)	(%)	"n"			
0+00	95.69	12+00	90.59	97.1	0.42	0.42	0.04			
ROCK STATIONS		SLOPING STATIONS		SLOPING			SITE ID: 0+01			
START	END	START	END	LENGTH	SIDE	CROSS SECTION				
(ft)	(ft)	(ft)	(ft)	(ft)	SLOPE	DISTANCE	ELEV			
7+50	9+15	7+50	9+15	165	1.5	*****	*****			
ROCK	ROCK	ROCK	D50	D50		OHWM	0	102.3		
HEIGHT	LENGTH	TYPE	USED	MIN		Elev	60	102.2		
(ft)	(ft)	CU=1 SP=2	(in)	(in)		(ft)	80	99.6		
4	165	1	6	5.7		94.6	100	98.9		
FILTER OPTION TABLE		FILTER	KEYWAY	DEPTH			140	94.6		
1 = 2 X D50 & FILTER	FILTER	BOTTOM	BELOW	THICKNESS (in)			160	93.7		
2 = 3 X D50 & NO FILTER	OPTION	WIDTH	SCOUR	ROCK	FILTER			172	91.9	
3 = 2 X D50 & GEOTEXTILE	CODE	(ft)	(ft)	18			173	91.7		
4 = 2 X D50 & FILTER & GEO.	2	2	2					183	91.7	
		2	2					199	101.8	
								242	101.9	
Above		TOTAL								
Keyway	Keyway	VOLUME/FT	(cy/ft)	ROCK	FILTER					
Rock Vol/Ft	Rock Vol/ft	ROCK	FILTER	(cy)	(cy)					
0.400617	0.3333333	0.734		121	0					
VELOCITY	Q	AREA	p	r	T =	Feet				
(fps)	(cfs)	(sq ft)	(ft)	(ft)	X =					
5.0	1296	257.5	85.2	3.02	Y =					
Design Q or Out of BANK	ENGR			END						
Q	V	JOB	GEOTEXT	DISTS	W.S. EL					
(cfs)	(fps)	Class	(sq yd)							
1296	5.0	IV	0	108	97.10					
				192	97.10					
RIPRAP GRADATION		NOTES								
-----		-----								
% PASSING ROCK SIZE			1. Use only elevations for cross-sections							
(by wt)	(in)			2. Accepts up to 24 cross section pairs						
100		12			3. Select any W.S. elevation					
60-85		9			4. Use side slopes of 1.5:1 - 4.0:1					
25-50		6			5. X-section shown on WI-404A - WI-404A-ET - WI-404A-LT					
5-20		3			6. Rock and filter thicknesses can be computed or entered.					
0-5		1			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										

D50 required = 8.3 inches

Water surface elevation = 99.2 (chosen to 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.		DOWNSTREAM W.S.		Design	COMPUTED	SELECTED	
STATION	ELEV	STATION	ELEV	Storm Elev.	SLOPE	SLOPE MANNINGS	
(ft)	(ft)	(ft)	(ft)	(ft)	(%)	(%) "n"	
0+00	95.69	12+00	90.59	99.2	0.42	0.42 0.04	
ROCK STATIONS		SLOPING STATIONS		SLOPING			
START	END	START	END	LENGTH	SIDE	SITE ID: 0+01 CROSS SECTION DISTANCE 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	
(ft)	(ft)	(ft)	(ft)	(ft)	SLOPE		
7+50	9+15	7+50	9+15	165	1.5		
ROCK	ROCK	ROCK	D50	D50			OHWM
HEIGHT	LENGTH	TYPE	USED	MIN			Elev
(ft)	(ft)	CU=1 SP=2	(in)	(in)			(ft)
4	165	1	10	8.3			94.6
FILTER OPTION TABLE		FILTER	KEYWAY	DEPTH			
1 = 2 X D50 & FILTER		OPTION	BOTTOM	BELOW	THICKNESS (in)		
2 = 3 X D50 & NO FILTER		CODE	WIDTH	SCOUR	ROCK		FILTER
3 = 2 X D50 & GEOTEXTILE		2	(ft)	(ft)	30		
4 = 2 X D50 & FILTER & GEO.			2	2			
Above		TOTAL					
Keyway	Keyway	VOLUME/FT	(cy/ft)	ROCK	FILTER		
Rock Vol/Ft	Rock Vol/ft	ROCK	FILTER	(cy)	(cy)		
0.667695	0.3333333	1.001		165	0		
VELOCITY	Q	AREA	p	r	T =	Feet	
(fps)	(cfs)	(sq ft)	(ft)	(ft)	X =		
6.3	2805	447.0	106.3	4.21	Y =	2.5	
						4.5	
						3.0	
Design Q or Out of BANK		ENGR		END			
Q	V	JOB	GEOTEXT	DISTS	W.S. EL		
(cfs)	(fps)	Class	(sq yd)				
2805	6.3	V	0	91	99.20		
				195	99.20		
RIPRAP GRADATION			NOTES				
~~~~~			~~~~~				
% PASSING ROCK SIZE		1. Use only elevations for cross-sections					
(by wt)	(in)	2. Accepts up to 24 cross section pairs					
100	20	3. Select any W.S. elevation					
60-85	15	4. Use side slopes of 1.5:1 - 4.0:1					
25-50	10	5. X-section shown on WI-404A - WI-404A-ET - WI-404A-LT					
5-20	5	6. Rock and filter thicknesses can be computed or entered.					
0-5	2	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 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 Area <sup>1</sup>		Clear Data Entry Cells																		
Project: Example Site 1 County: SW WI By: _____ Date: _____ Checked By: _____ Date: _____																				
Watershed Area (square miles)	8.646	Area A 8.646 sq miles Forest FOR <sup>2</sup> 11 %+1 Slope S 56.7 feet/mile Intens I <sub>25</sub> <sup>4</sup> 1.1 inches Peak Flood Discharge with n-year recurrence interval <sup>3</sup>																		
Main-channel length (miles)	4.046	<table style="width: 100%; border-collapse: collapse;"> <tr><td>Q<sub>2</sub></td><td style="text-align: right;">424</td><td style="text-align: left;">cfs</td></tr> <tr><td>Q<sub>5</sub></td><td style="text-align: right;">828</td><td style="text-align: left;">cfs</td></tr> <tr><td>Q<sub>10</sub></td><td style="text-align: right;">1268</td><td style="text-align: left;">cfs</td></tr> <tr><td>Q<sub>25</sub></td><td style="text-align: right;">1808</td><td style="text-align: left;">cfs</td></tr> <tr><td>Q<sub>50</sub></td><td style="text-align: right;">2256</td><td style="text-align: left;">cfs</td></tr> <tr><td>Q<sub>100</sub></td><td style="text-align: right;">2762</td><td style="text-align: left;">cfs</td></tr> </table>	Q <sub>2</sub>	424	cfs	Q <sub>5</sub>	828	cfs	Q <sub>10</sub>	1268	cfs	Q <sub>25</sub>	1808	cfs	Q <sub>50</sub>	2256	cfs	Q <sub>100</sub>	2762	cfs
Q <sub>2</sub>	424		cfs																	
Q <sub>5</sub>	828		cfs																	
Q <sub>10</sub>	1268		cfs																	
Q <sub>25</sub>	1808		cfs																	
Q <sub>50</sub>	2256		cfs																	
Q <sub>100</sub>	2762	cfs																		
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.) <sup>5</sup>	5.29																			
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	Keyway
Cu Yds/ft	Cu Yds/ft
0.67	0.33333
Cu Yds	Cu Yds
110.17	55

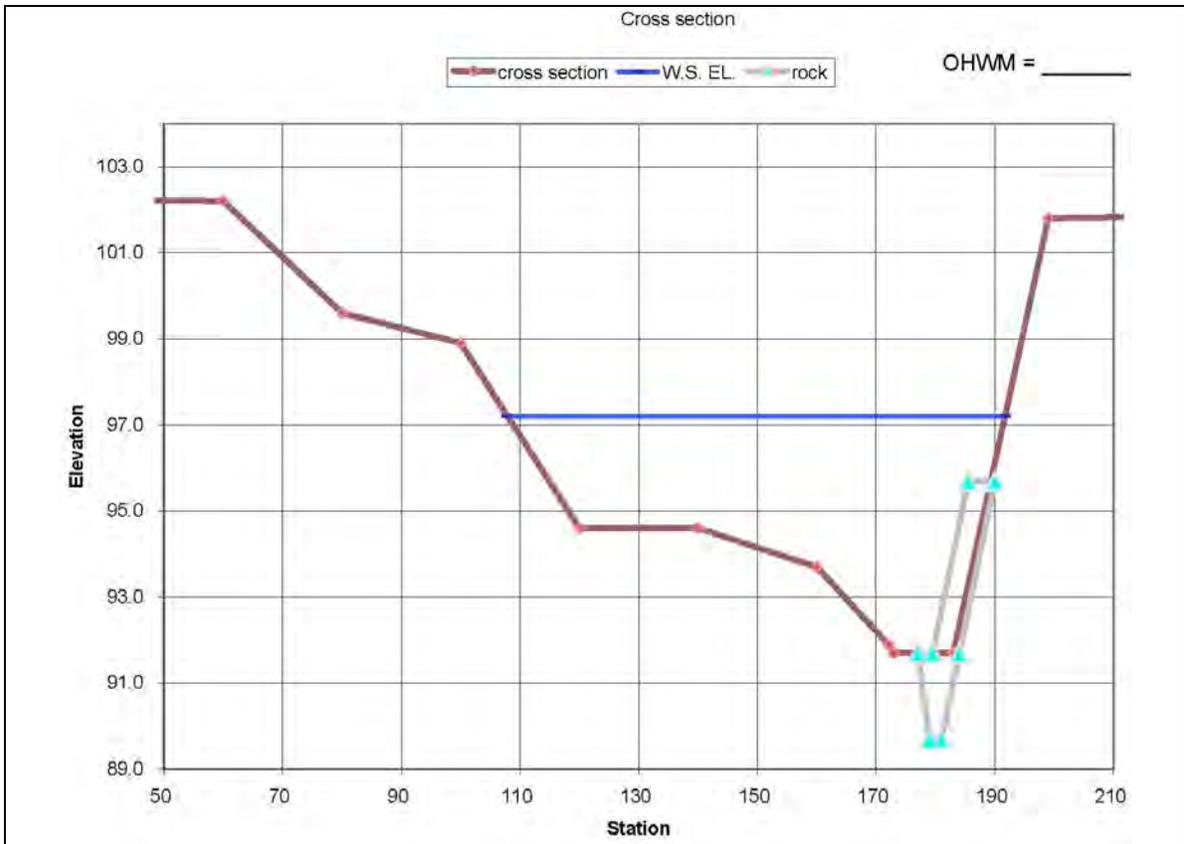
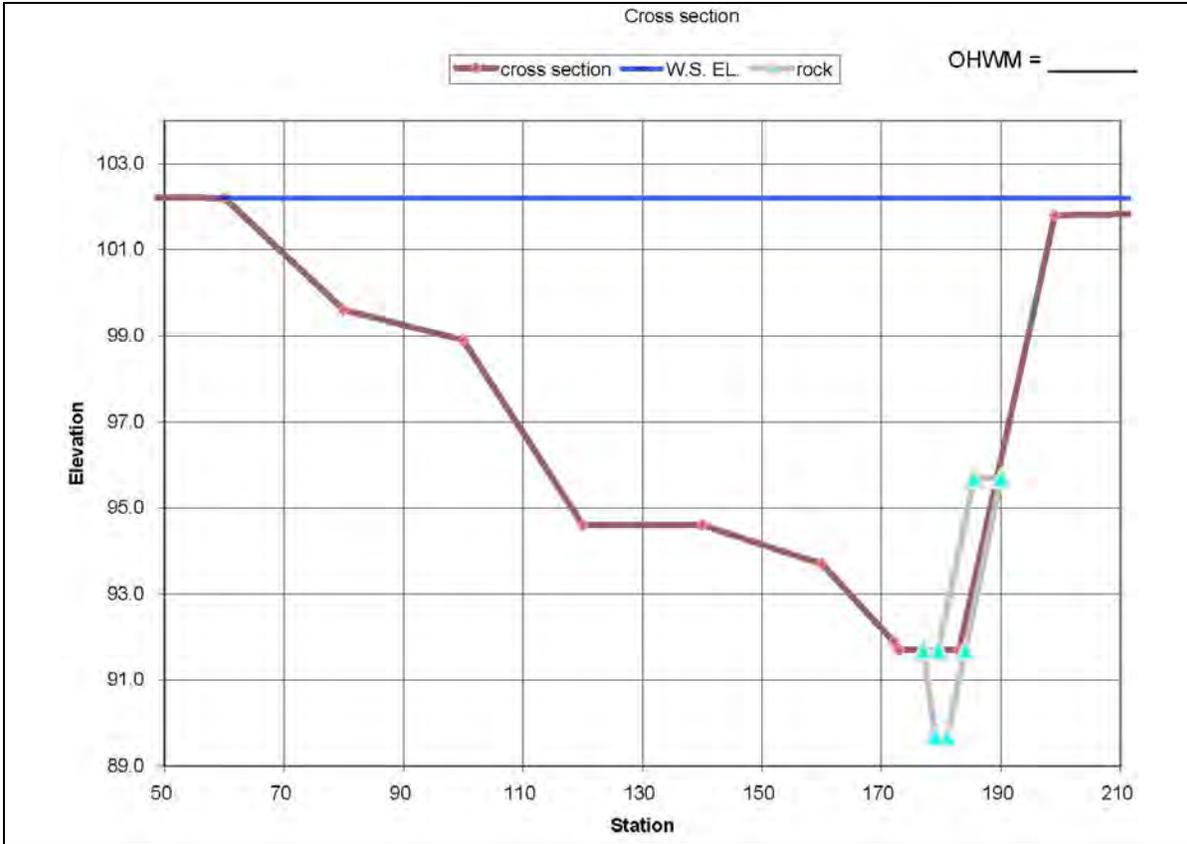
  

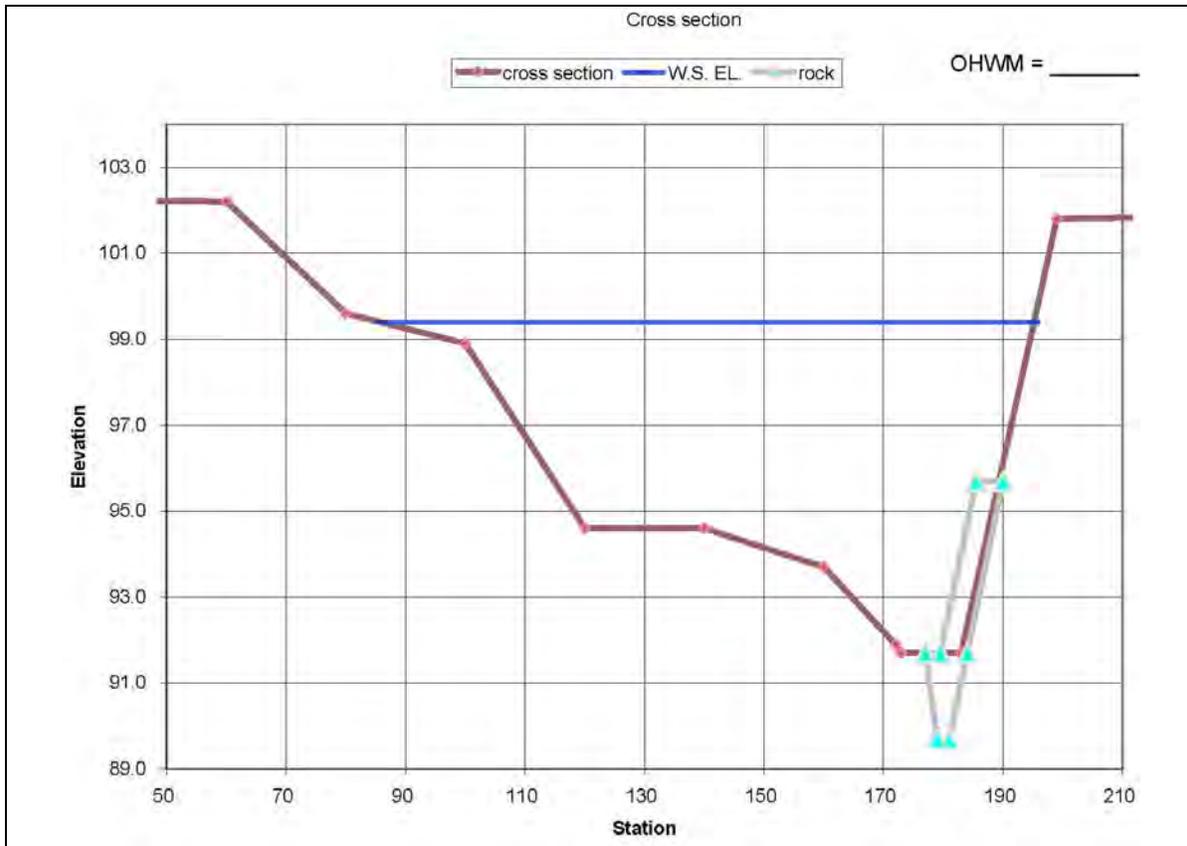
Start	End
2x thickness	
Vol - 5 Ft	
3.33847	3.33847

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.

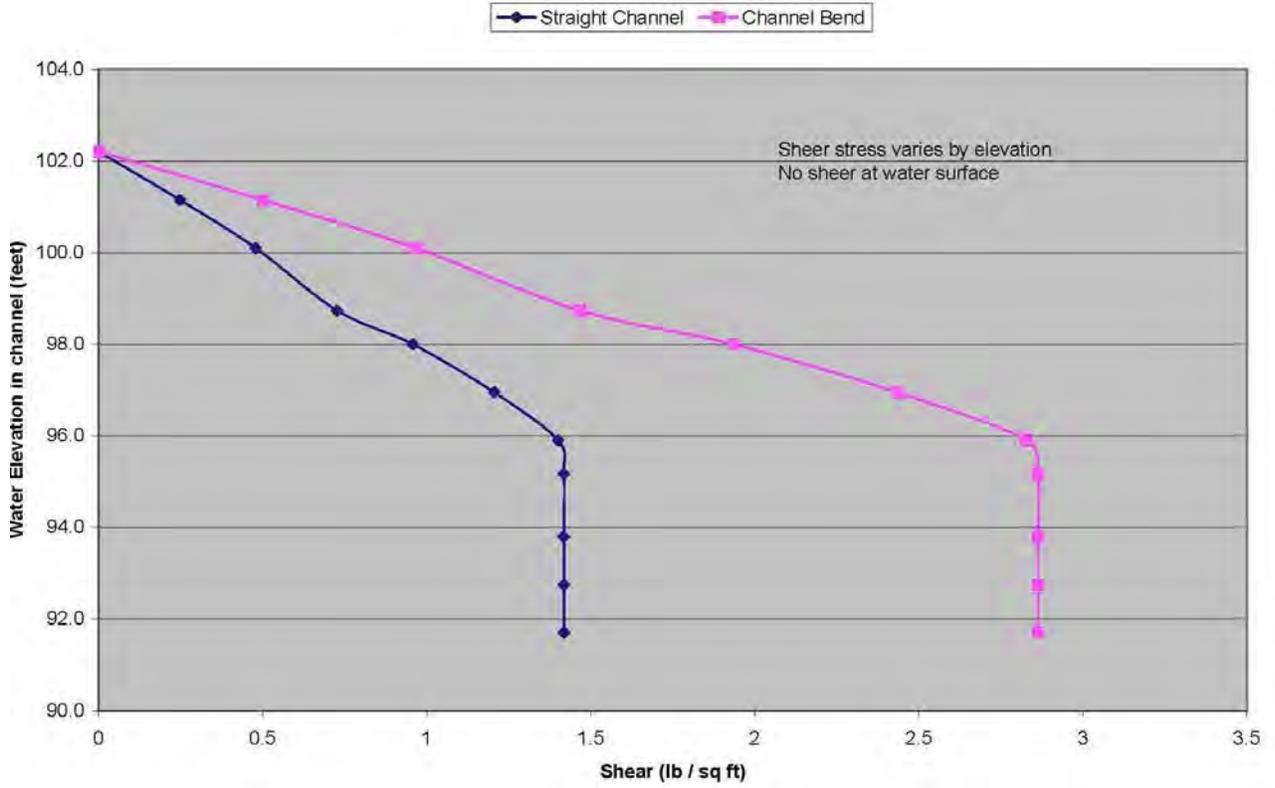




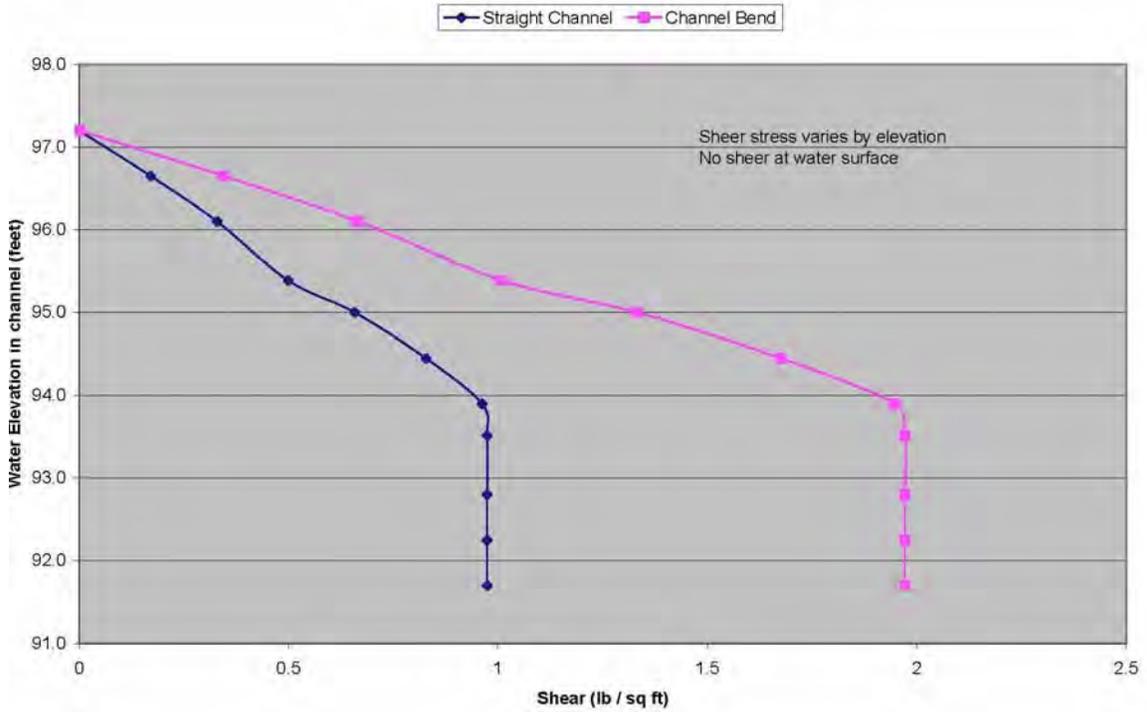
The streambank protection spreadsheet also calculates and plots the shear stress in the design reach cross section. The plots below show the distributed shear on the channel bank for the previous example site 1 data with different design water surfaces. Higher water surfaces create greater stresses on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

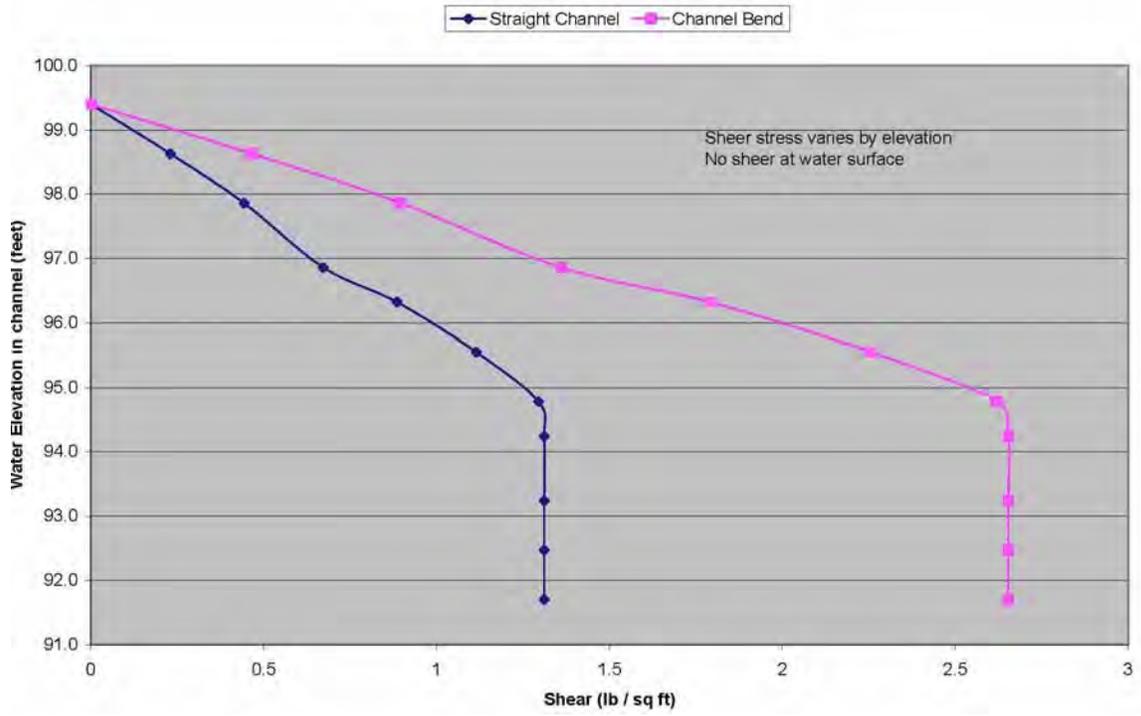
Calculated Shear Stress on Stream Bank



Calculated Shear Stress on Stream Bank



### Calculated Shear Stress on Stream Bank



**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.		DOWNSTREAM W.S.		Design	COMPUTED	SELECTED		
STATION	ELEV	STATION	ELEV	Storm Elev.	SLOPE	SLOPE	MANNINGS	
(ft)	(ft)	(ft)	(ft)	(ft)	(%)	(%)	"n"	
0+00	8.4	14+39	0	47.3	0.58	0.58	0.036	
ROCK STATIONS		SLOPING STATIONS		SLOPING				
START	END	START	END	LENGTH	SIDE			
(ft)	(ft)	(ft)	(ft)	(ft)	SLOPE			
0+00	2+00	0+00	2+00	200	2			
ROCK	ROCK	ROCK	D50	D50				
HEIGHT	LENGTH	TYPE	USED	MIN				
(ft)	(ft)	CU=1 SP=2	(in)	(in)	OHWM			
5.5	200	2	8	6.4	Elev			
FILTER OPTION TABLE		FILTER	KEYWAY	DEPTH				
1 = 2 X D50 & FILTER	OPTION	BOTTOM	BELOW	THICKNESS (in)				
2 = 3 X D50 & NO FILTER	CODE	WIDTH	SCOUR	ROCK	FILTER			
3 = 2 X D50 & GEOTEXTILE	3	(ft)	(ft)	16				
4 = 2 X D50 & FILTER & GEO.	?	?	?					
Above		TOTAL						
Keyway	Keyway	VOLUME/FT	(cy/ft)	ROCK	FILTER			
Rock Vol/Ft	Rock Vol/Ft	ROCK	FILTER	(cy)	(cy)			
0.607327	0.3703704	0.978		196	0			
VELOCITY	Q	AREA	P	r	T =	Feet		
(fps)	(cfs)	(sq ft)	(ft)	(ft)	X =	1.3		
5.3	446	83.9	38.1	2.20	Y =	3.0		
						1.5		
Design Q or Out of BANK	ENGR			END				
Q	V	JOB	GEOTEXT	DISTS	M.S. EL			
(cfs)	(fps)	Class	(sq yd)	24	47.30			
446	5.3	III	439	61	47.30			
RIPRAP GRADATION				NOTES				
-----				-----				
% PASSING ROCK SIZE	1. Use only elevations for cross-sections							
(by wt)	(in)	2. Accepts up to 24 cross section pairs						
100	16	3. Select any W.S. elevation						
60-85	12	4. Use side slopes of 1.5:1 - 4.0:1						
25-50	8	5. X-section shown on WI-404A - WI-404A-ET - WI-404A-LT						
5-20	4	6. Rock and filter thicknesses can be computed or entered.						
0-5	2	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 <span style="float: right;">(ver 3-2007)</span>																					
USGS Water Resources Investigations Report 03-4250																					
<b>Wisconsin Flood Frequency Area 2</b> <sup>Note 1.</sup>			<input type="button" value="Clear Data Entry Cells"/>																		
Project: Example Site #2 NW area County: NW WI By: _____ Date: _____ Checked By: _____ Date: _____																					
Watershed Area (square miles)	<input type="text" value="6.64"/>	Area	A <input type="text" value="6.64"/> sq miles																		
Main-channel length (miles)	<input type="text" value="5.8"/>	Soil Perm	SP <input type="text" value="1.65"/> in/hr																		
Enter Elevation <input type="text" value="0.58"/> miles upstream from point of interest	<input type="text" value="850"/>	Slope	S <input type="text" value="34.5"/> feet/mile																		
Enter Elevation <input type="text" value="4.93"/> miles upstream from point of interest	<input type="text" value="1000"/>	Peak Flood Discharge with n-year recurrence interval <sup>Note 3.</sup>																			
Enter Soil Permeability, (inches/hr) <sup>Note 2.</sup>	<input type="text" value="1.65"/>	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="padding: 2px;">Q<sub>2</sub></td> <td style="padding: 2px;">195</td> <td style="padding: 2px;">cfs</td> </tr> <tr> <td style="padding: 2px;">Q<sub>5</sub></td> <td style="padding: 2px;">336</td> <td style="padding: 2px;">cfs</td> </tr> <tr> <td style="padding: 2px;">Q<sub>10</sub></td> <td style="padding: 2px;">434</td> <td style="padding: 2px;">cfs</td> </tr> <tr> <td style="padding: 2px;">Q<sub>25</sub></td> <td style="padding: 2px;">572</td> <td style="padding: 2px;">cfs</td> </tr> <tr> <td style="padding: 2px;">Q<sub>50</sub></td> <td style="padding: 2px;">676</td> <td style="padding: 2px;">cfs</td> </tr> <tr> <td style="padding: 2px;">Q<sub>100</sub></td> <td style="padding: 2px;">780</td> <td style="padding: 2px;">cfs</td> </tr> </table>		Q <sub>2</sub>	195	cfs	Q <sub>5</sub>	336	cfs	Q <sub>10</sub>	434	cfs	Q <sub>25</sub>	572	cfs	Q <sub>50</sub>	676	cfs	Q <sub>100</sub>	780	cfs
Q <sub>2</sub>	195	cfs																			
Q <sub>5</sub>	336	cfs																			
Q <sub>10</sub>	434	cfs																			
Q <sub>25</sub>	572	cfs																			
Q <sub>50</sub>	676	cfs																			
Q <sub>100</sub>	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.

**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

**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

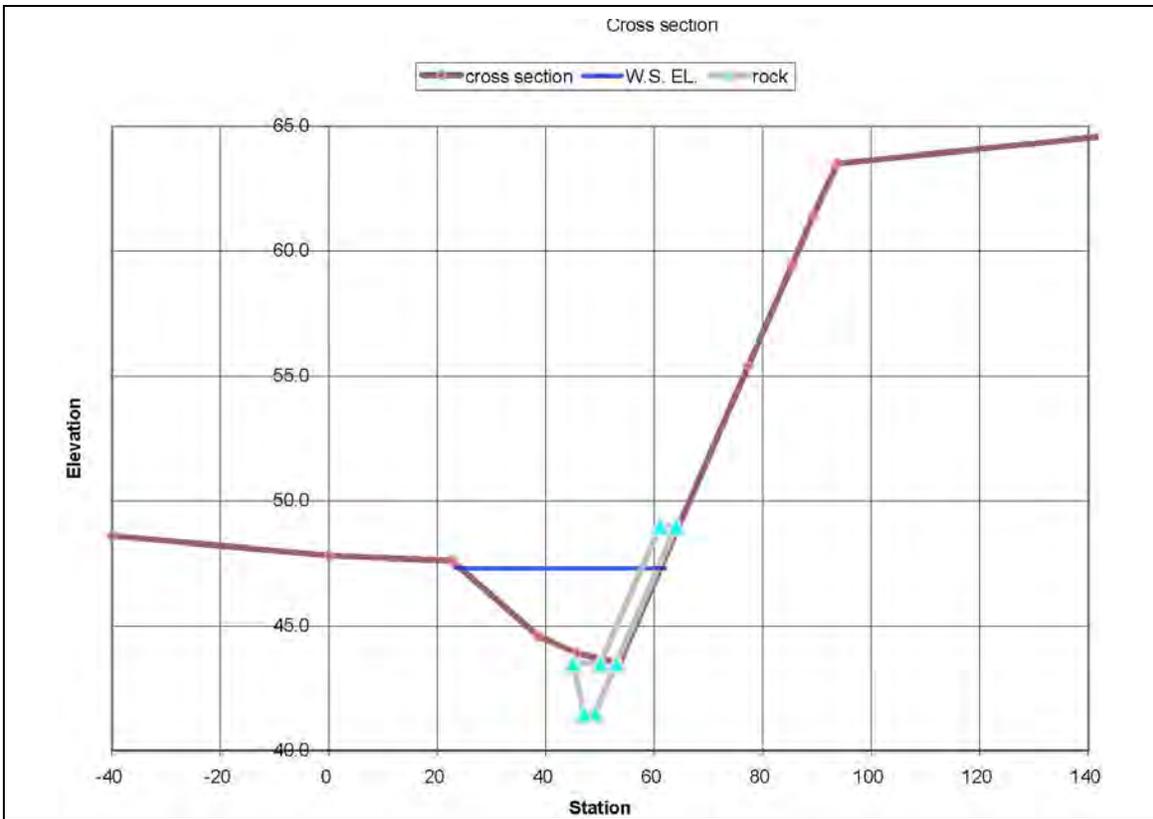
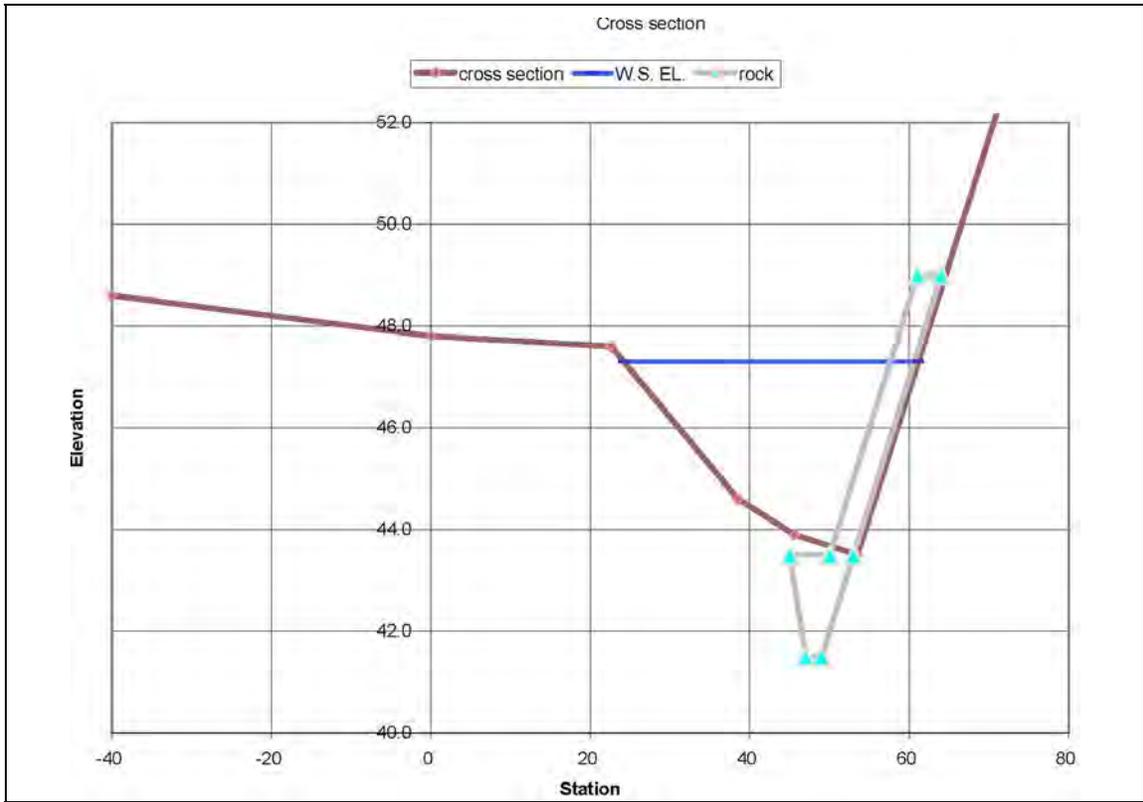
**Right Bank**

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

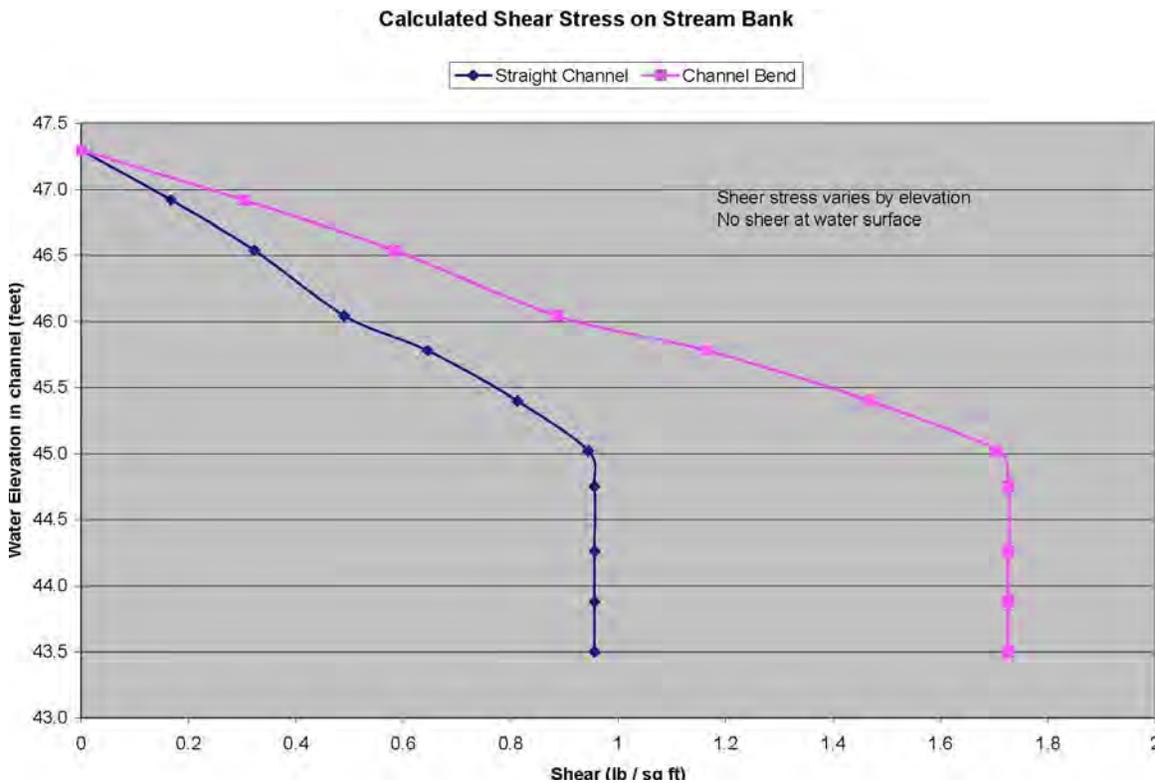
The following plotted cross sections were plotted from the previous example site 2 data. They give the designer a chance to preview the cross sections before they are manually plotted or drawn with ACAD. The second cross section had additional data entered to create the taller bank.

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February 2009



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 one of the following criteria.

**Table 3a**

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

**Table 3b**

Percent Passing by Weight	Size in Inches (round to the nearest inch)
100	$1.5 \times D_{50}$ -- $2.0 \times D_{50}$
85	$1.3 \times D_{50}$ -- $1.8 \times D_{50}$
50	$1.0 \times D_{50}$ -- $1.5 \times D_{50}$
10	$0.8 \times D_{50}$ -- $1.3 \times D_{50}$

The State of Wisconsin Department of Transportation Standard Specifications for Highway and Structure Construction has four gradations that closely represent the Table 3b gradation. Table 3c shows the  $D_{50}$  relationship with DOT riprap classifications.

**Table 3c**

$D_{50}$ (in.)	DOT Riprap Category
6	Light Riprap
8	Medium Riprap
10	Heavy Riprap
13	Extra Heavy Riprap
>13	Site Specific Gradation Required

## 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.  $T_{\text{riprap}} = 3 * D_{50}$
2. The riprap gradation is small enough (bedding) such that the rock material meets the leaching protection requirements for the bank base material.  $T_{\text{riprap}} = 2 * D_{50}$
3. A protective layer of intermediate sized material (bedding) meeting the leaching protection criteria is placed between the riprap and base material.  $T_{\text{riprap}} = 2 * D_{50}$
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.

### Leaching Protection Requirements (Bedding) Gradation Design

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

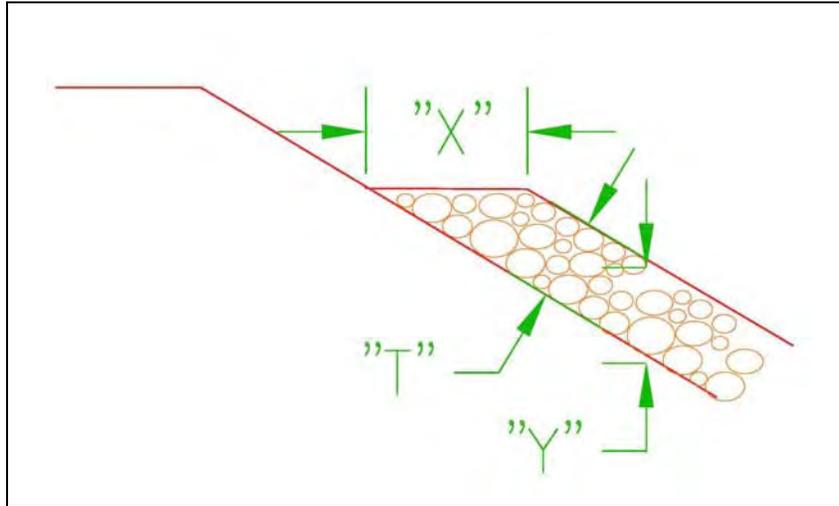
A filter is required when seepage pressures in the sides or bottom of a channel could cause detachment of soil particles and move them out through protective layers.

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.

### Geotextile Filter Design

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

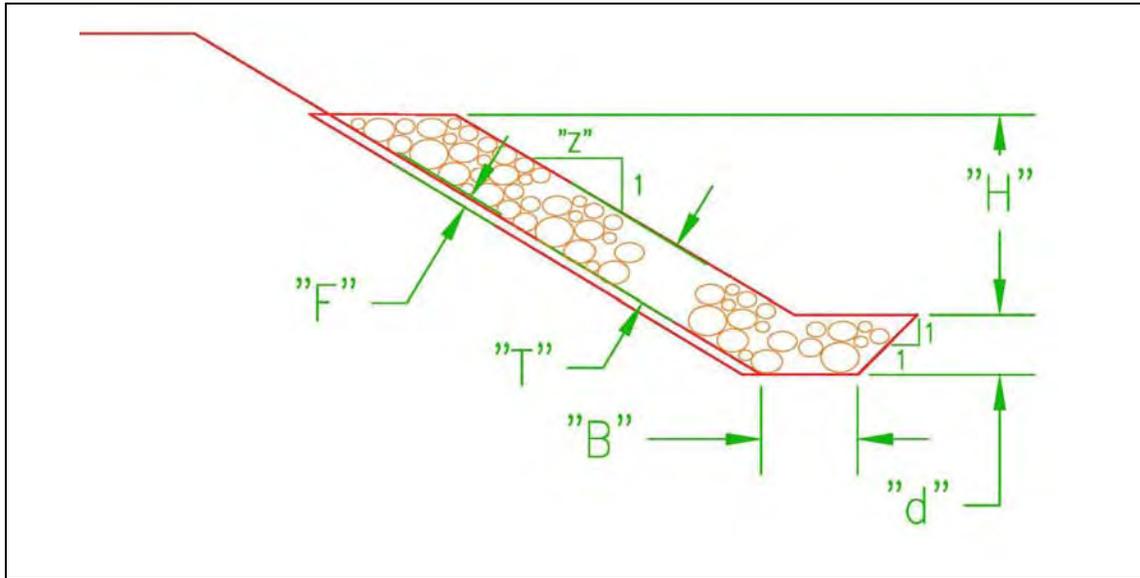


Figure WI-16-6

Formulas

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<sup>3</sup>/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

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

Thickness of Filter of Bedding Layer

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.

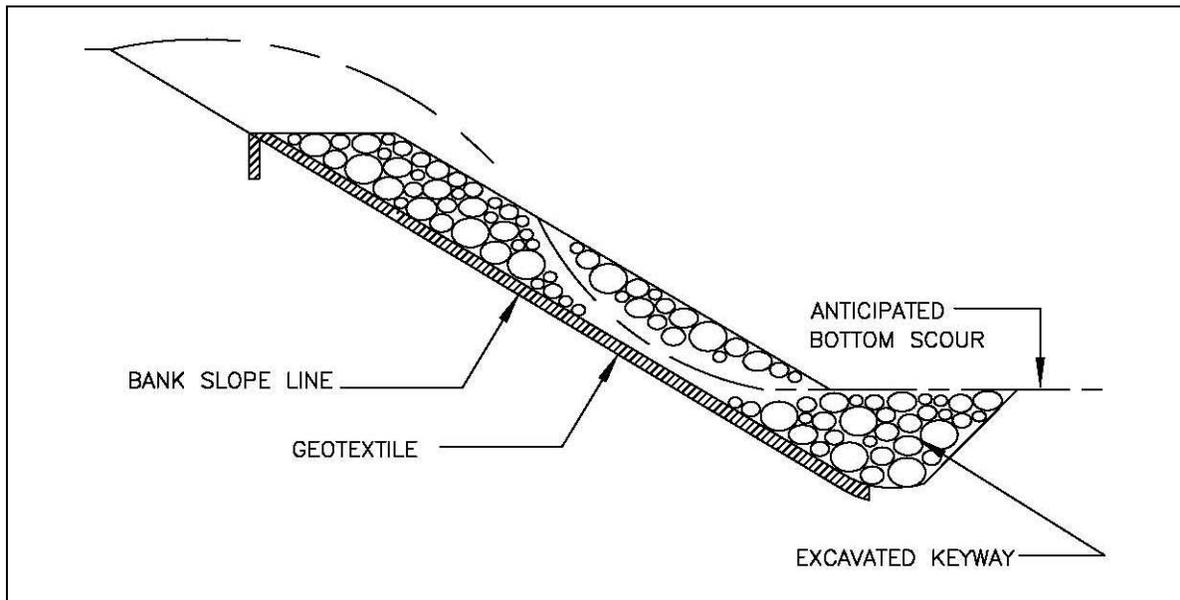
Grade control of the stream reach may be needed. Grade control of the channel depends on many factors, such as hydraulic conditions, sediment size and loading, channel morphology, flood plain and valley characteristics, and ecological objectives. These factors must all be evaluated before grade control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

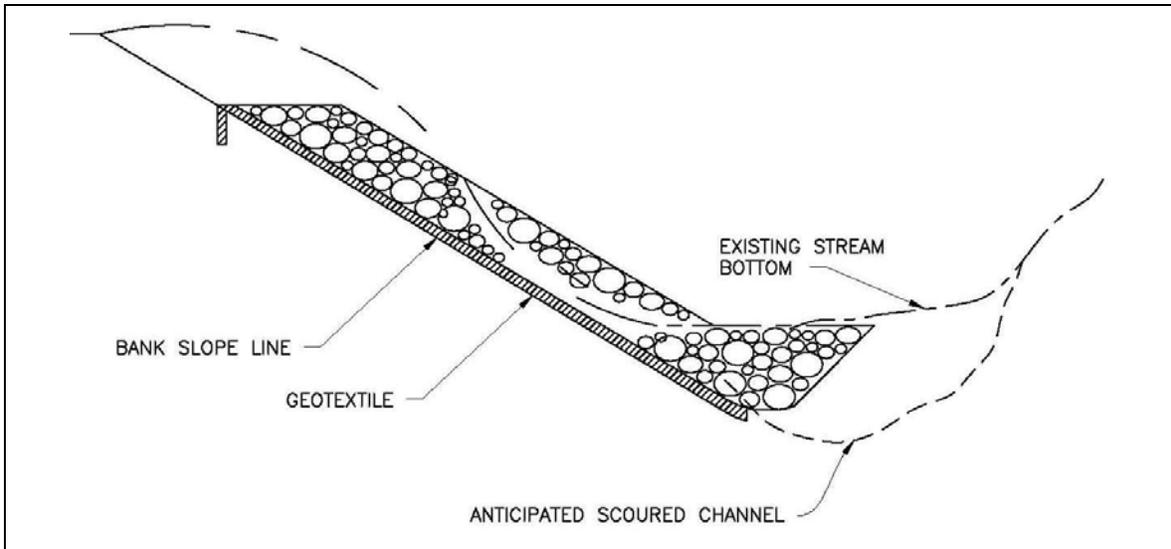


**Figure WI-16-7**

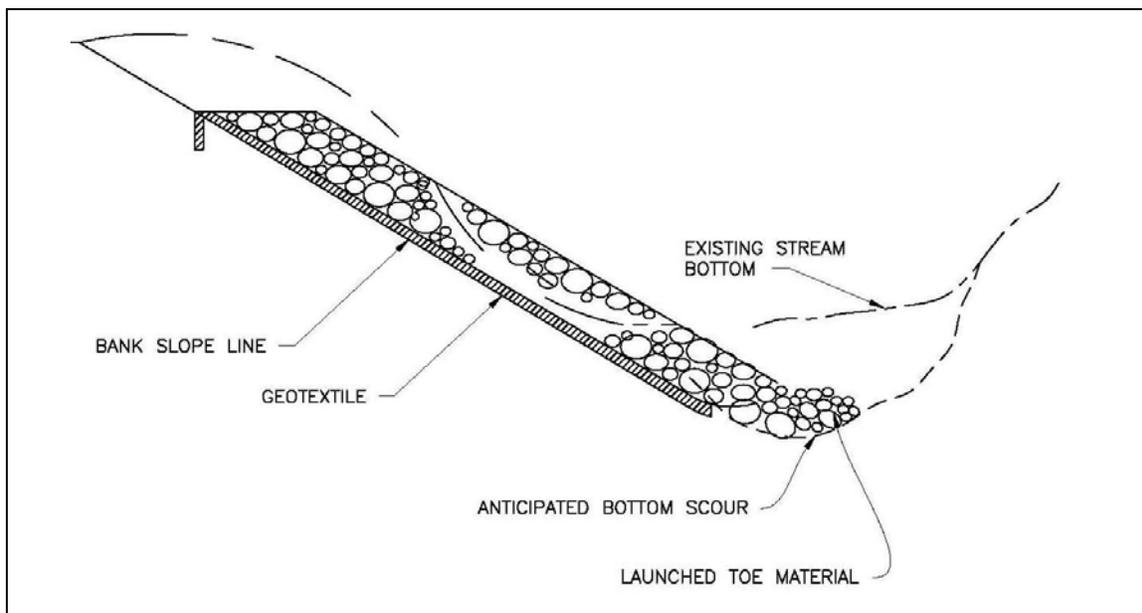
### Launchable Toe

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.



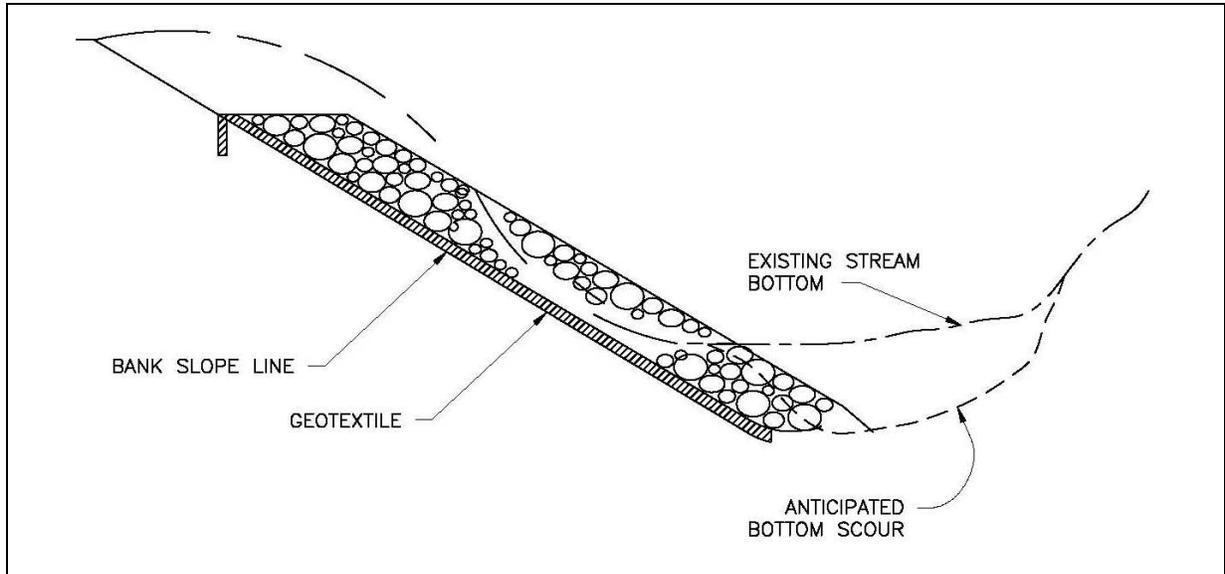
**Figure WI-16-8a (as-built)**



**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.



## 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 manufacturer'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	$4 \times D_5$
25 - 50	$2 \times D_5$
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  $\frac{1}{2}$  of the stream base flow top width. Generally, no additional barbs are needed after the thalweg position is at least  $\frac{1}{2}$  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.

### Definitions

$D_{100}$  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.

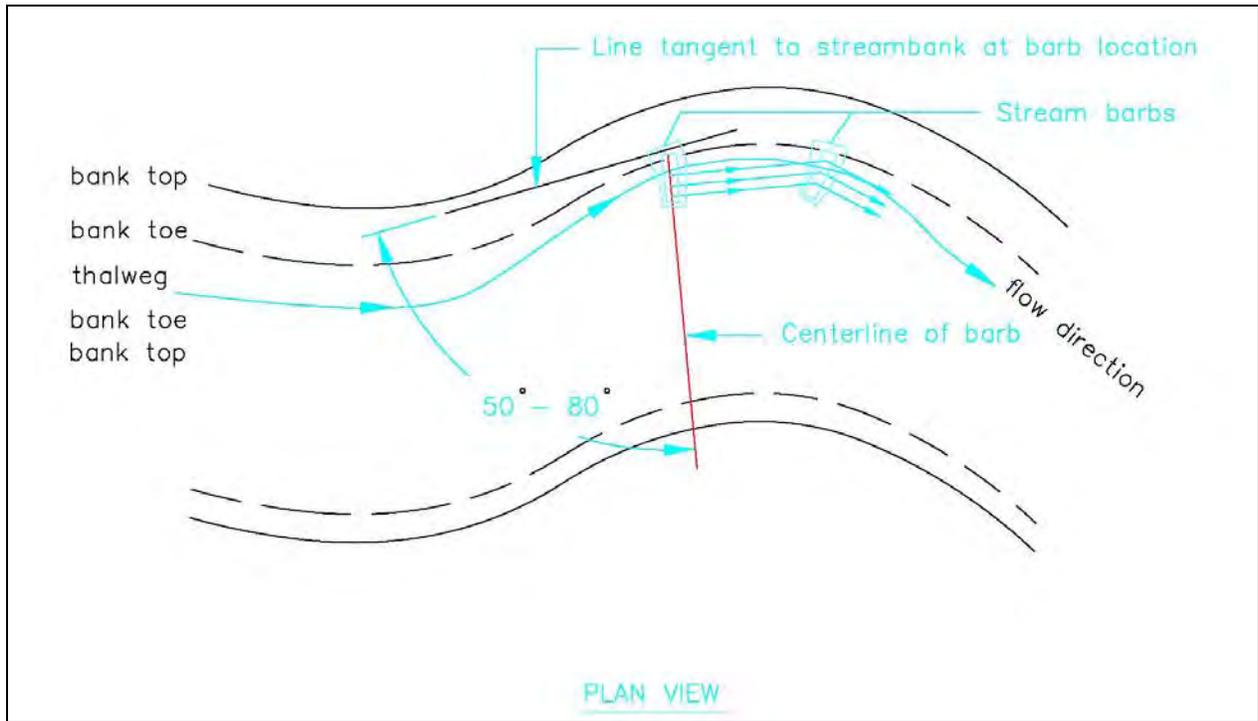
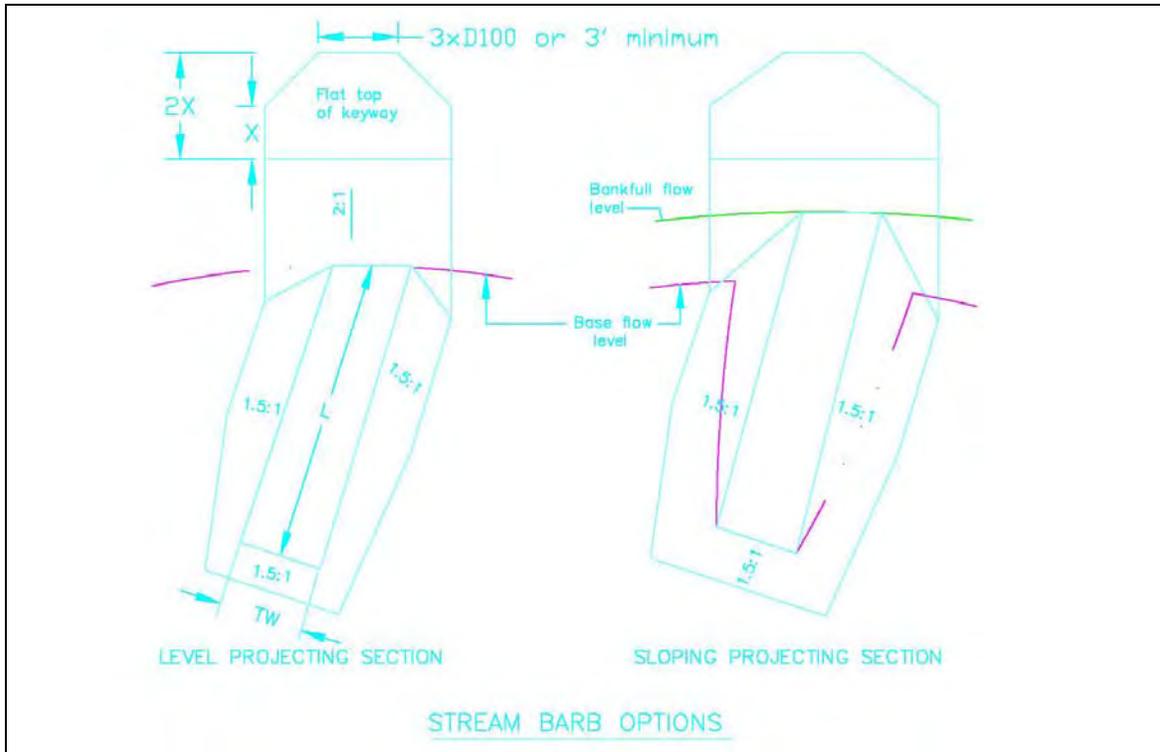
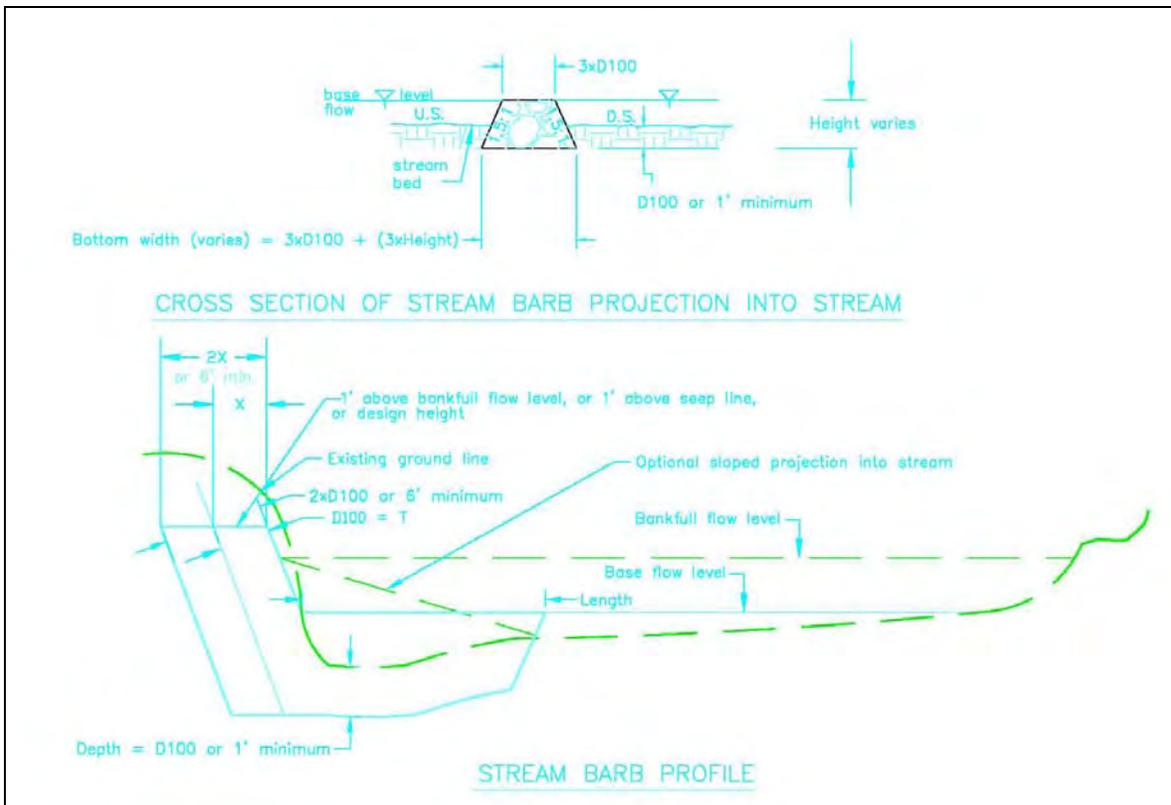


Figure WI-16-11a



**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.

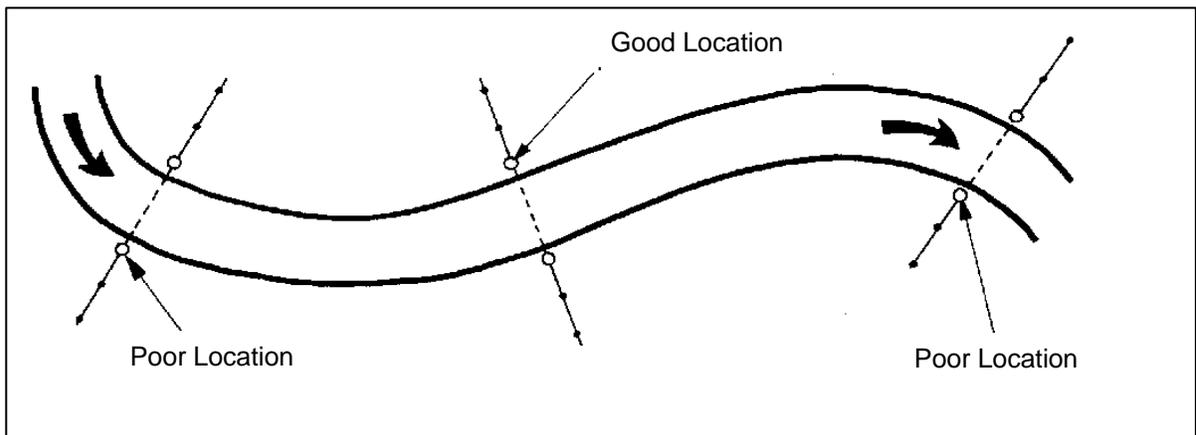


Figure WI-16-12

### 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 to 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.

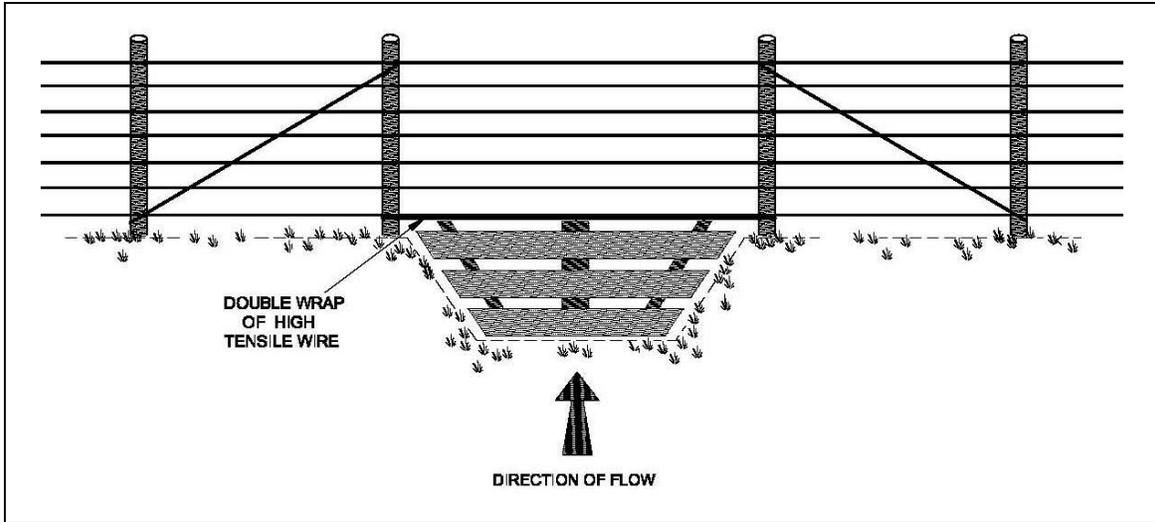


Figure WI-16- 13a: Fixed Framed Hinged Flood Gate

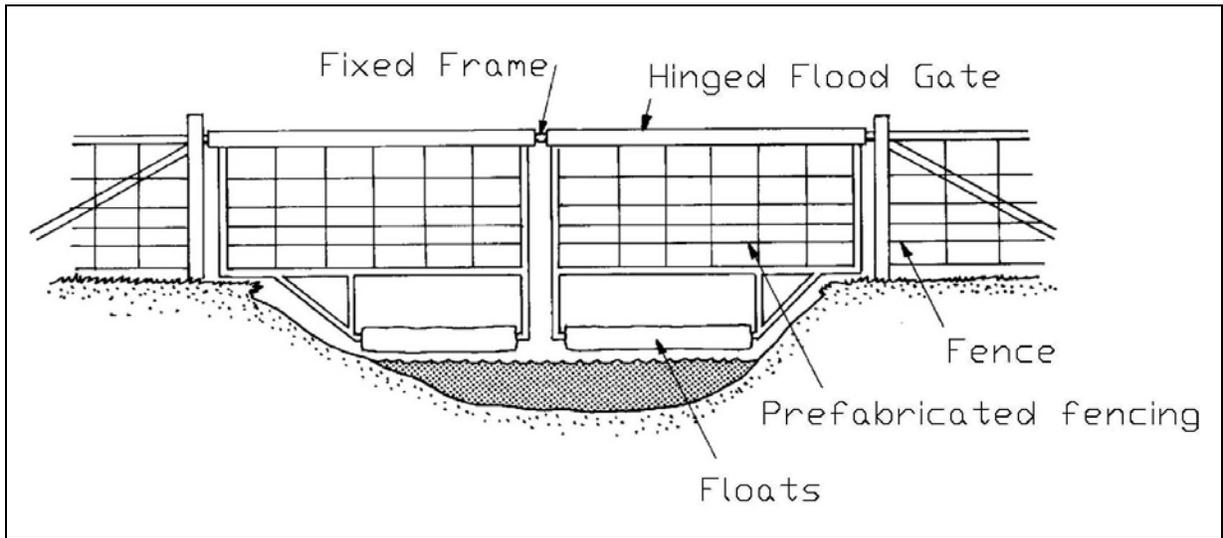
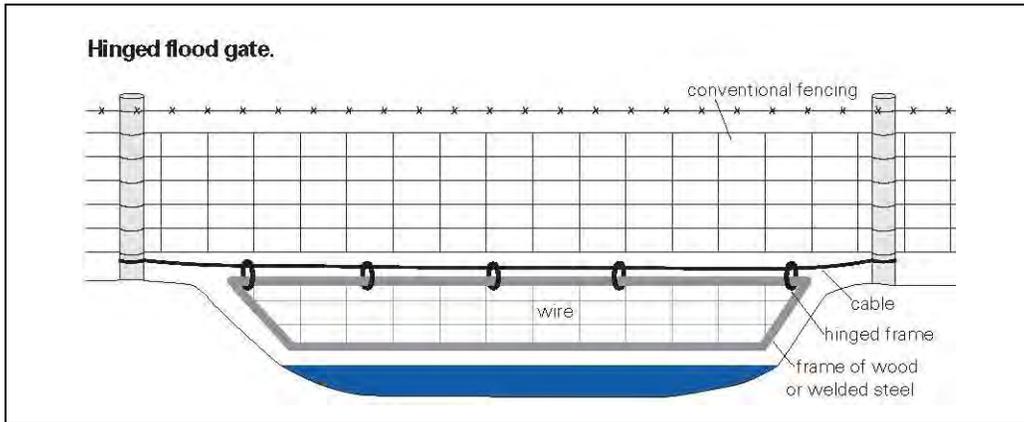
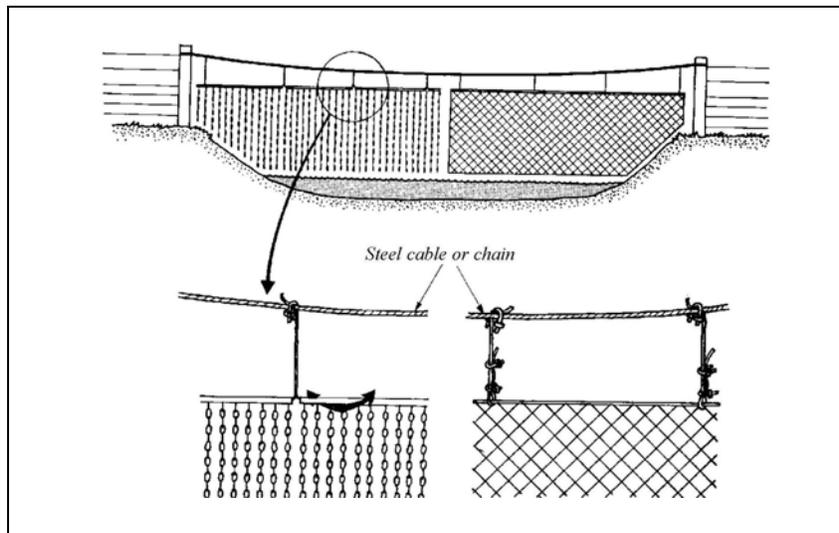


Figure WI-16-13b



**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.

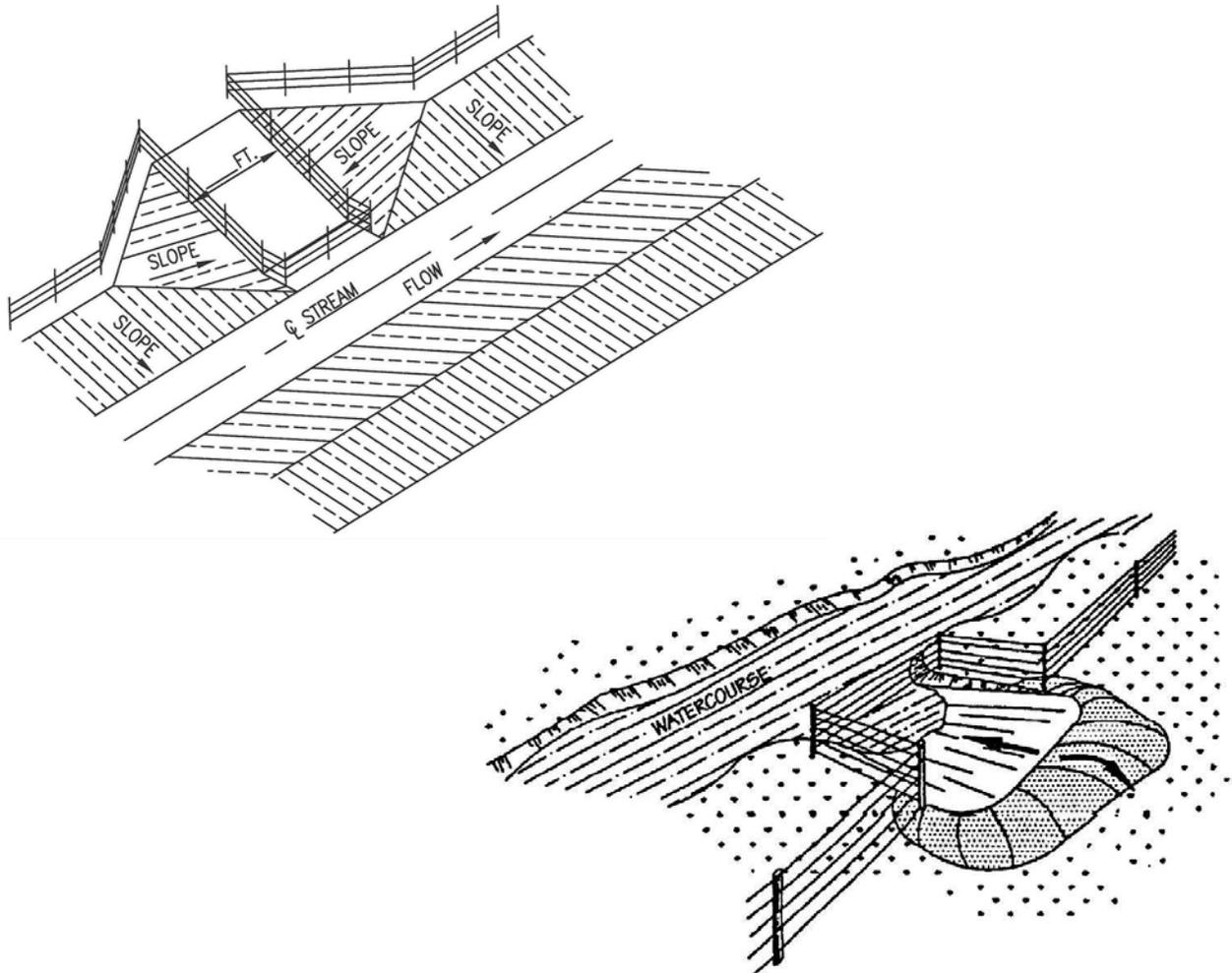


Figure WI-16-14

## 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:

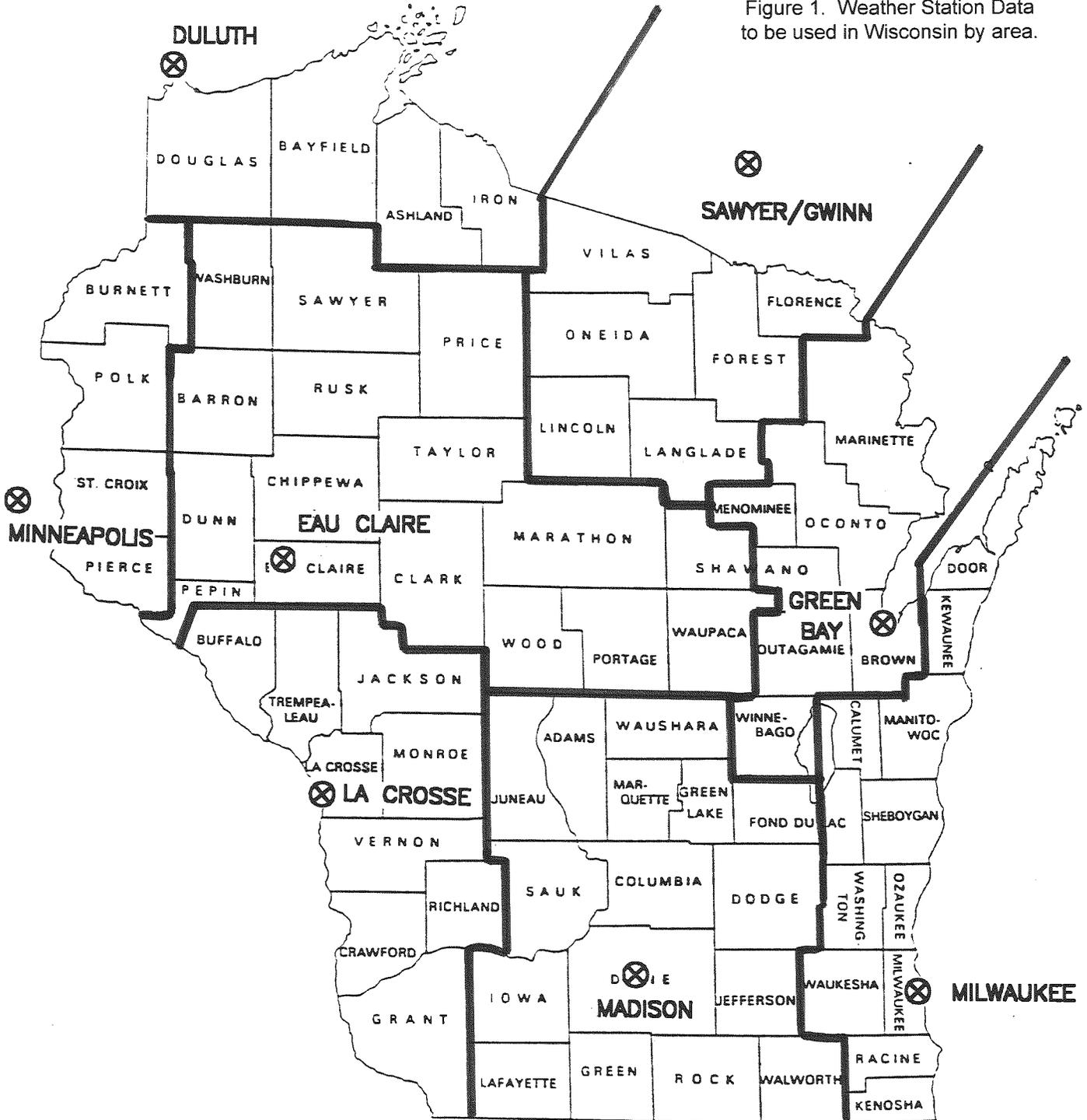
4. The wind data available for Wisconsin has been summarized in Table 1. Using the map in Figure 1, locate the region of the state which contains the design site.

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.



- 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.

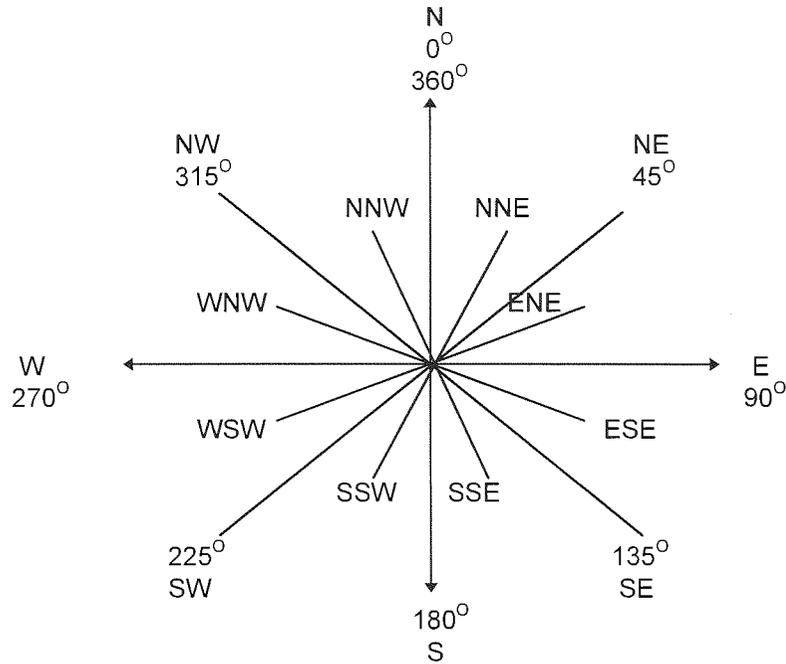


Figure 2. Compass Rose

- 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:**

- 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

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

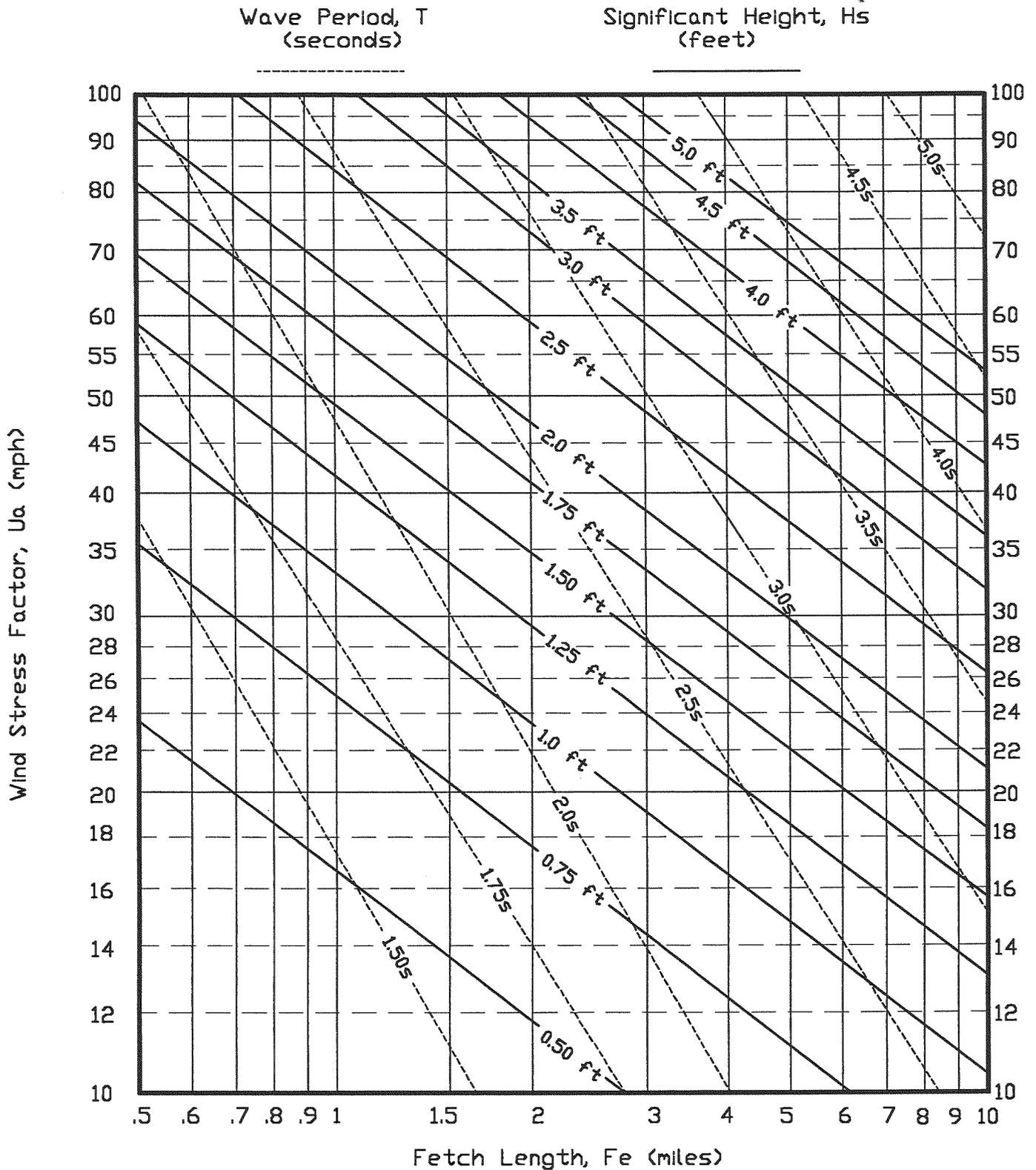


FIGURE 3. Nomograms of deepwater significant wave prediction curves as functions of wind speed and fetch length.

(Adapted from ACDE'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	
<p>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.</p>	$H_{10}$	$H_s$	$H_{10}$
<p>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.</p>	$H_5$	$H_{10}$	$H_5$
<p>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.</p>	$H_1$	$H_{10}$	$H_1$
<p>Note: When <math>H_s</math> 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.</p> <p>* WPH = Wave Protection Height</p>			

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 ratio,  $R/H_0$ , 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.

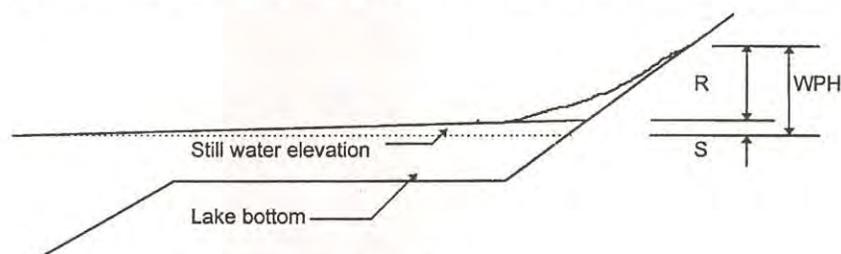


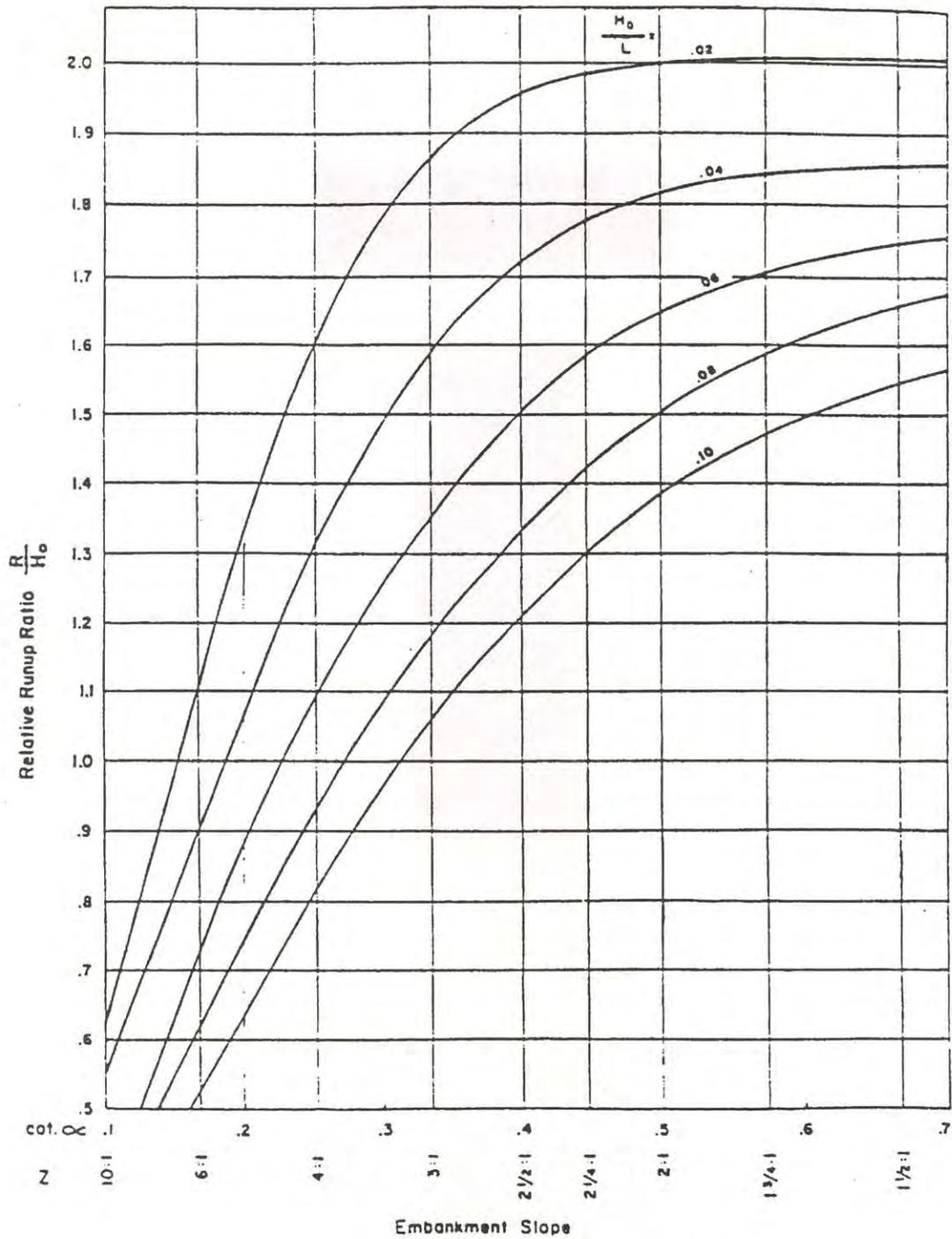
Figure 4. Runup and Setup

#### 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. Size: 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 ( $DF_{\text{riprap}}$ ) from Table 4. Multiply the  $H_s$  determined in step 9 by the  $DF_{\text{riprap}}$  to obtain a new design wave height ( $H_{\text{rock}}$ ), 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

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

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

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

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

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

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

Equations for Rounded Stone

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

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

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

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

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

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

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

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

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

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.

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

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. Gabions

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 <sub>50</sub> 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<sub>50</sub> size is percent of material passing by weight.

- A. Only material larger than 0.17 mm is to be used for obtaining the D<sub>50</sub> size of the material for the protective layer. The minimum D<sub>50</sub> 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<sub>o</sub>.
- 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<sub>50</sub> 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 x d<sub>50</sub> ) 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

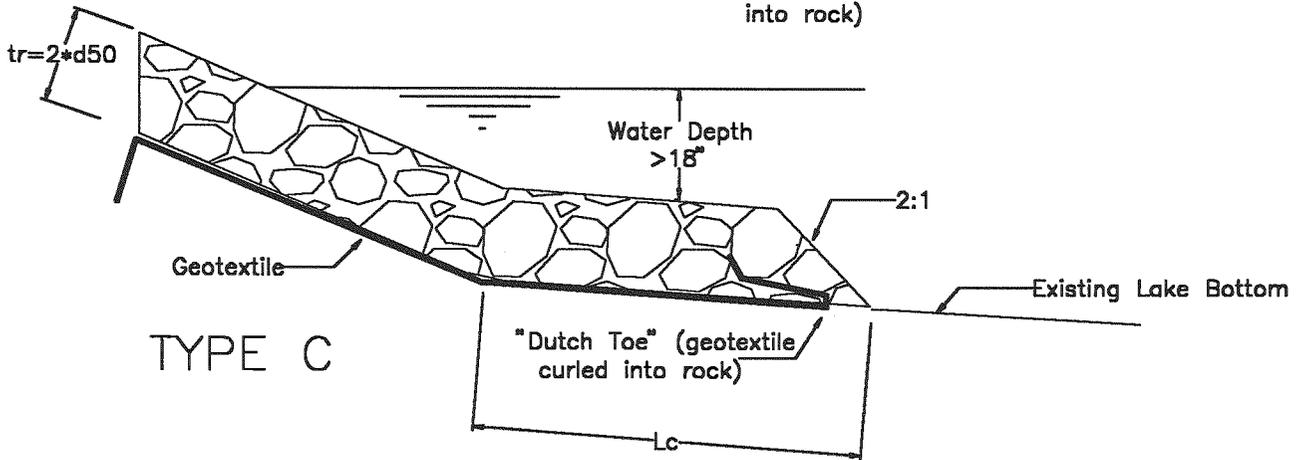
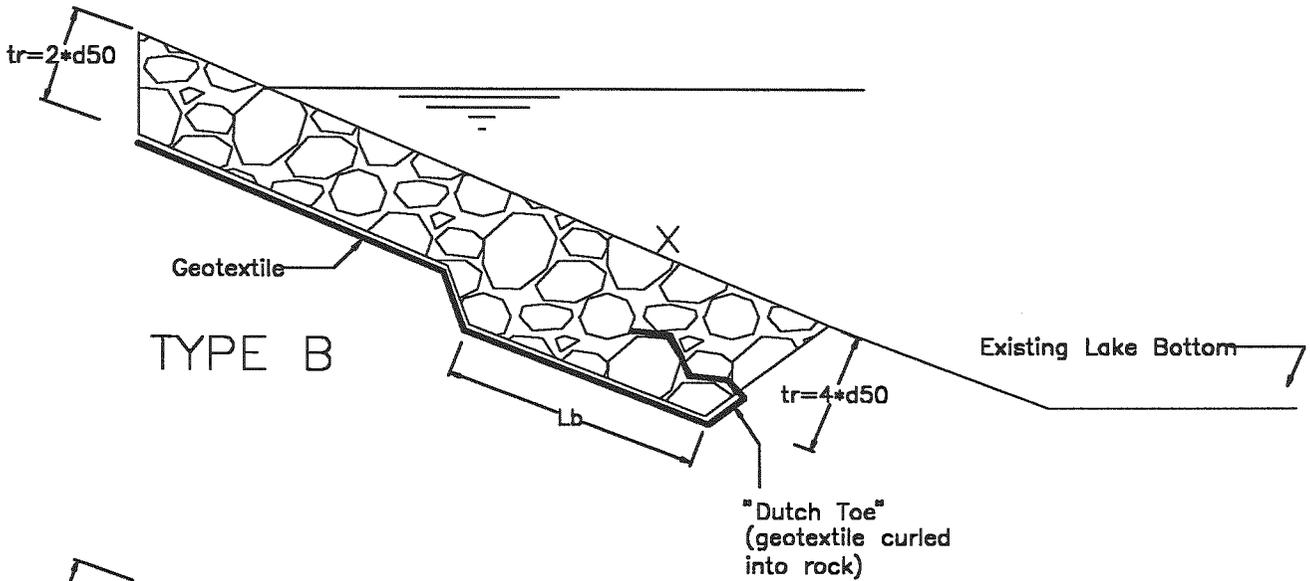
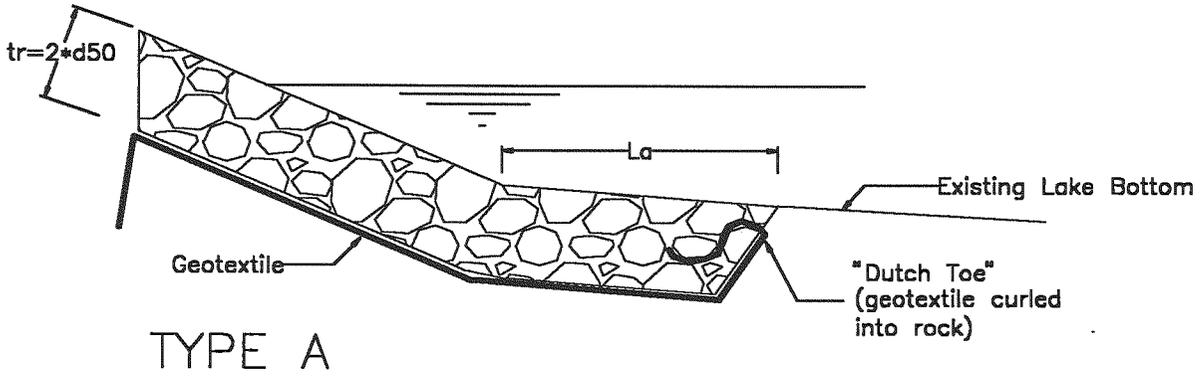
protects the bank underneath. The weight of the blocks alone cannot provide the same resistance to movement as riprap, so interlocking, cabled, or rod-tied blocks are preferred over those that merely lay side-by-side.

#### 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:

<u>Material</u>	<u>Minimum Thickness(in)</u>
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.



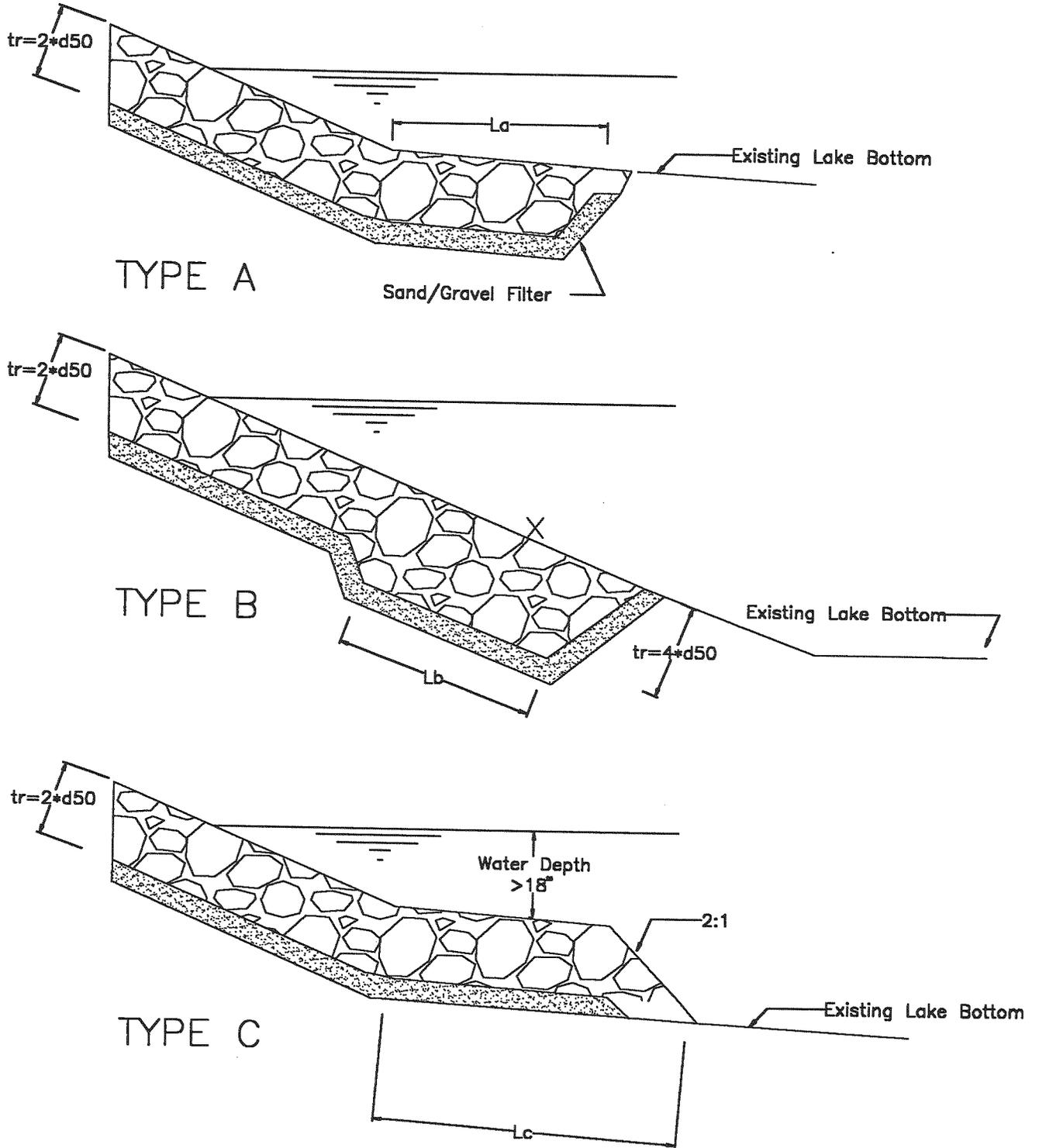
$L_b = 8 * d_{50}$

$L_a = L_c = (\text{Elevation of existing lake bottom minus elevation of lower limit}) \text{ times } 6 \text{ feet but not less than three feet or } 4 * tr, \text{ whichever is greater.}$

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



$L_b = 8 * d_{50}$   
 $L_a = L_c = (\text{Elevation of existing lake bottom minus elevation of lower limit}) \text{ times } 6 \text{ feet but not less than three feet or } 4 * tr, \text{ whichever is greater.}$   
 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

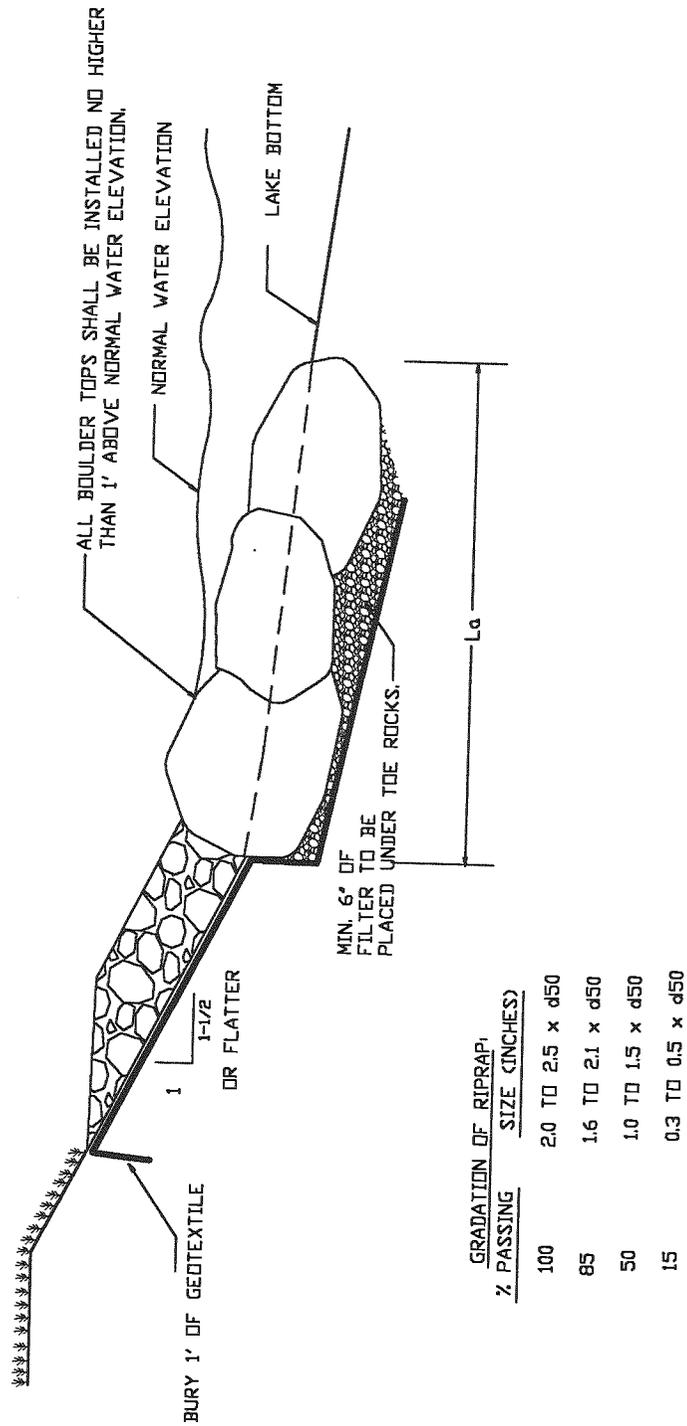
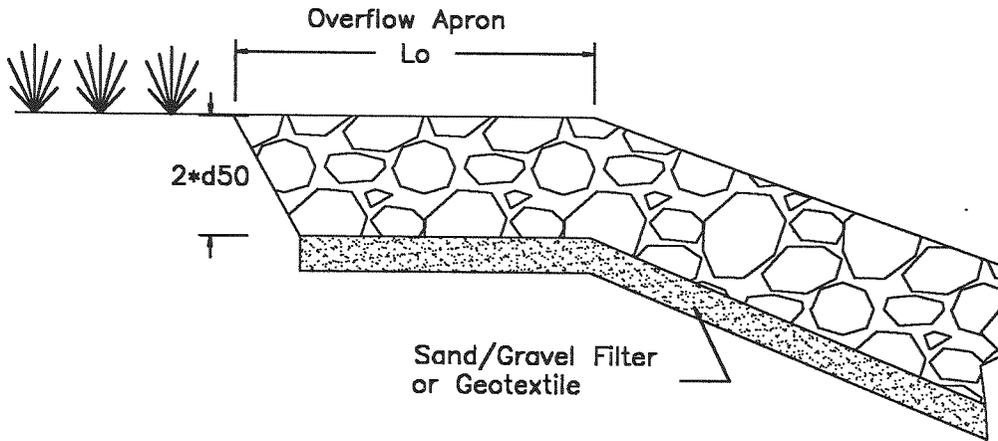
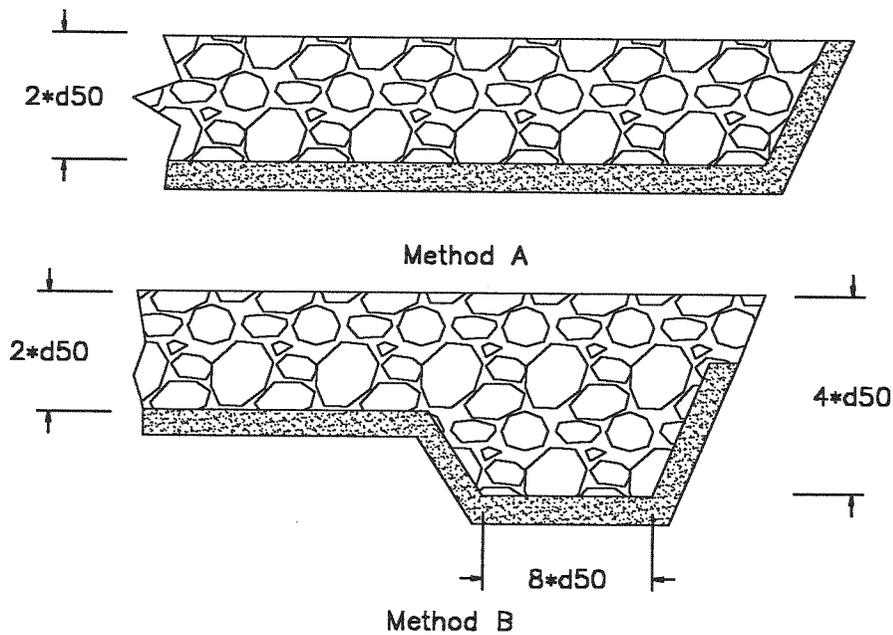


Figure 8.  
Toe Protection with Boulders



$L_o = 6 \times (\text{Wave Protection Height} - \text{Top of Bank})$ ,  
 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 ( $H_o$ ) =  $H_s \times DF_{wph}$  = \_\_\_\_\_ x \_\_\_\_\_ = \_\_\_\_\_ feet

Slope Ratio of constructed revetment (z) \_\_\_\_\_ : 1

$H_o / L$  = \_\_\_\_\_ / \_\_\_\_\_ = \_\_\_\_\_

$R / H_o$  (Figure 5) \_\_\_\_\_

If material is not rock riprap, multiply:  $R / H_o \times 1.2$  = \_\_\_\_\_ (new  $R / H_o$ )

Runup (R) =  $H_o \times R/H_o$  = \_\_\_\_\_ x \_\_\_\_\_ = \_\_\_\_\_ feet

Set-up (S) =  $0.1 \times H_o$  =  $0.1 \times$  \_\_\_\_\_ = \_\_\_\_\_ feet (but not more than 0.5 feet)

Lakeshore Protection Design Worksheet

Project Name \_\_\_\_\_

Ordinary High Water elevation (OHW) \_\_\_\_\_

Normal Yearly low lake elevation (if different from OHW) \_\_\_\_\_

Lower limit (LL) =  $1.5 \times H_o = 1.5 \times$  \_\_\_\_\_ = \_\_\_\_\_ 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

$L_o = ($  \_\_\_\_\_  $-$  \_\_\_\_\_  $) \times 6 =$  \_\_\_\_\_ feet (but not less than 3 feet)

RIPRAP DESIGN

Design Frequency (rock size) (Table 3) \_\_\_\_\_

Safety Design Factor ( $DF_{riprap}$ ) (Table 4) \_\_\_\_\_

$H_{rock} = H_s \times DF_{riprap} =$  \_\_\_\_\_  $\times$  \_\_\_\_\_  $=$  \_\_\_\_\_ feet

( $H_s$  is same as determined earlier)

$G_s =$  \_\_\_\_\_

$W_{50} =$  \_\_\_\_\_  $\times (H_{rock})^3 =$  \_\_\_\_\_  $\times ($  \_\_\_\_\_  $)^3 =$  \_\_\_\_\_ lbs. (Eqn. \_\_\_\_\_)

$d_{50} =$  \_\_\_\_\_ inches (Table 6)

Gradation calculated for this location:

$D_{100}$	$2.0 \times d_{50} =$ _____ "	$2.5 \times d_{50} =$ _____ "
$D_{85}$	$1.6 \times d_{50} =$ _____ "	$2.1 \times d_{50} =$ _____ "
$D_{50}$	$1.0 \times d_{50} =$ _____ "	$1.5 \times d_{50} =$ _____ "
$D_{15}$	$0.3 \times d_{50} =$ _____ "	$0.5 \times d_{50} =$ _____ "

Thickness of riprap =  $2.0 \times d_{50} = 2.0 \times$  \_\_\_\_\_ = \_\_\_\_\_ 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	<u>7600</u>
2	9	<u>7300</u>
3	6	<u>7400</u>
4	3	<u>7800</u>
5 (Central)	0	<u>7700</u>
6	3	<u>7500</u>
7	6	<u>6500</u>
8	9	<u>6300</u>
9	12	<u>6500</u>
Total Length =		<u>64,600</u>
Effective Fetch ( $F_e$ ) = Total / 9 = <u>64,600 / 9</u>		
Effective Fetch = <u>7178</u> ft = <u>1.36</u> 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 ( $H_o$ ) =  $H_s \times DF_{wph} =$  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:  $R / H_o \times 1.2 =$  — (new R /  $H_o$ )

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

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

Lakeshore Protection Design Worksheet

Project Name EXAMPLE

Ordinary High Water elevation (OHW) 100.0

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

Lower limit (LL) =  $1.5 \times H_o = 1.5 \times \underline{1.4} = \underline{2.1}$  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

$L_o = (\underline{\quad\quad\quad} - \underline{\quad\quad\quad}) \times 6 = \underline{\quad\quad\quad}$  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

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

( $H_s$  is same as determined earlier)

$G_s = \underline{2.50}$

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

$d_{50} = \underline{4.5}$  inches (Table 6)

Gradation calculated for this location:

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

Thickness of riprap =  $2.0 \times d_{50} = 2.0 \times \underline{4.5} = \underline{9}$  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

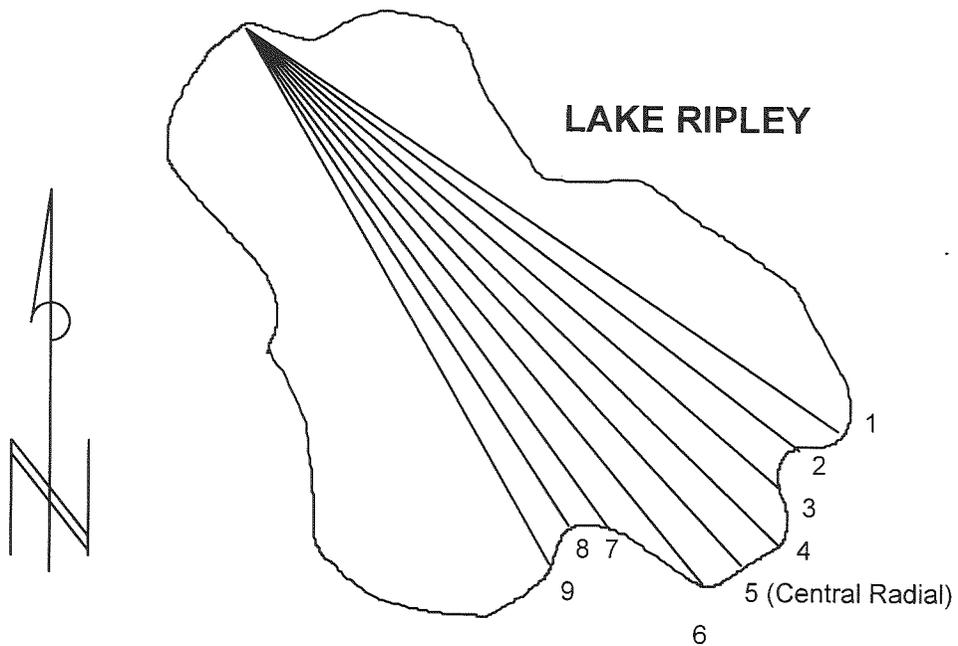


Figure 9. Example

Fetch No.	Fetch Length, Feet	
1	7600	
2	7300	
3	7400	
4	7800	
5	7700	Effective Fetch Length = $F_e =$
6	7500	$64600 / 9 = 7178 \text{ feet}$
7	6500	
8	6300	
9	6500	
<b>Total</b>	<b>64600</b>	

LAKESHORE RIPRAP DESIGN COMPUTATIONS SPREADSHEET

CLIENT: Example  
 DSN BY:  
 COMMENTS:

COUNTY: Jefferson  
 DATE: 03/07/97  
 CHK BY: \_\_\_\_\_  
 DATE: \_\_\_\_\_

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=Spherical 1  
 d50 Rock Size = 4.5 Inches (Calc)      6 Inches (Used)  
 Rock Thickness = 12.0 Inches  
 Toe Type (A,B,C, or boulder) a  
 Length of Shoreline= 60 Feet      La = 11 Feet

Quantities

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

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

**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

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

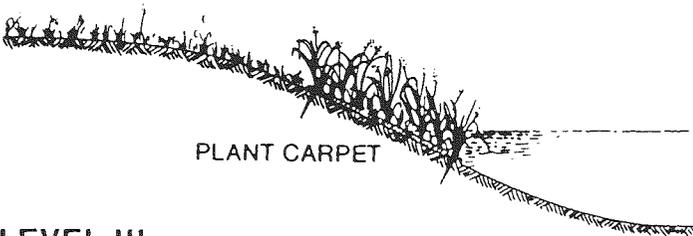
Typical Cross Sections for Stress Levels

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

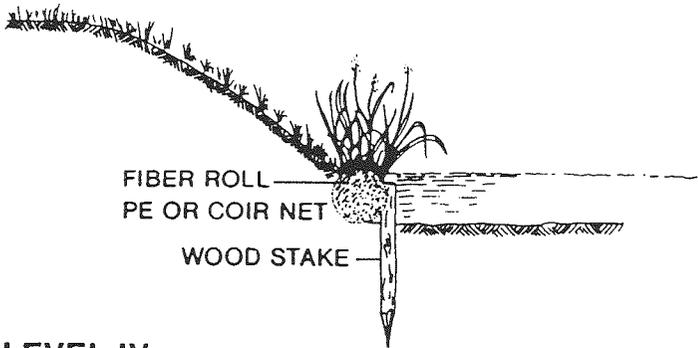
**LEVEL I**



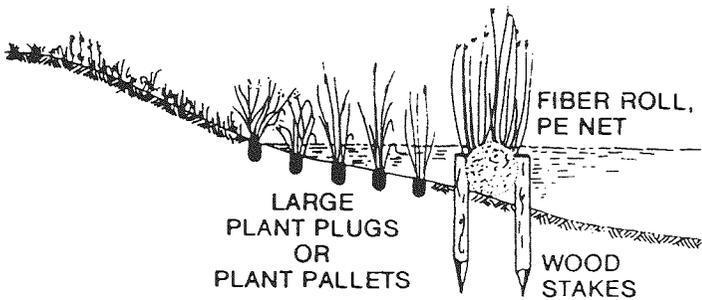
**LEVEL II**



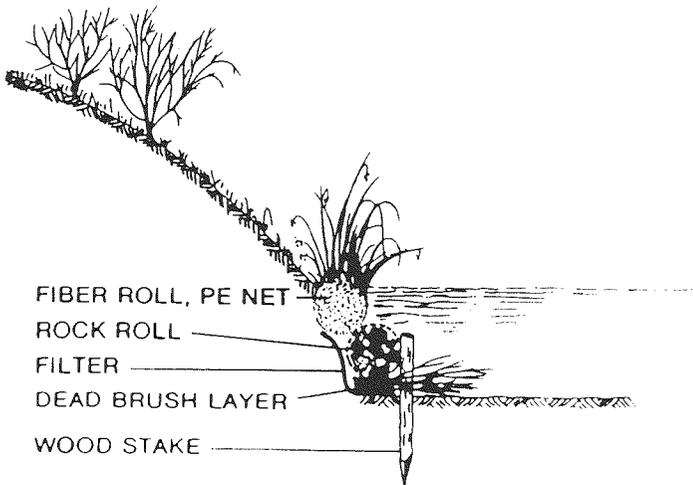
**LEVEL III**



**LEVEL IV**

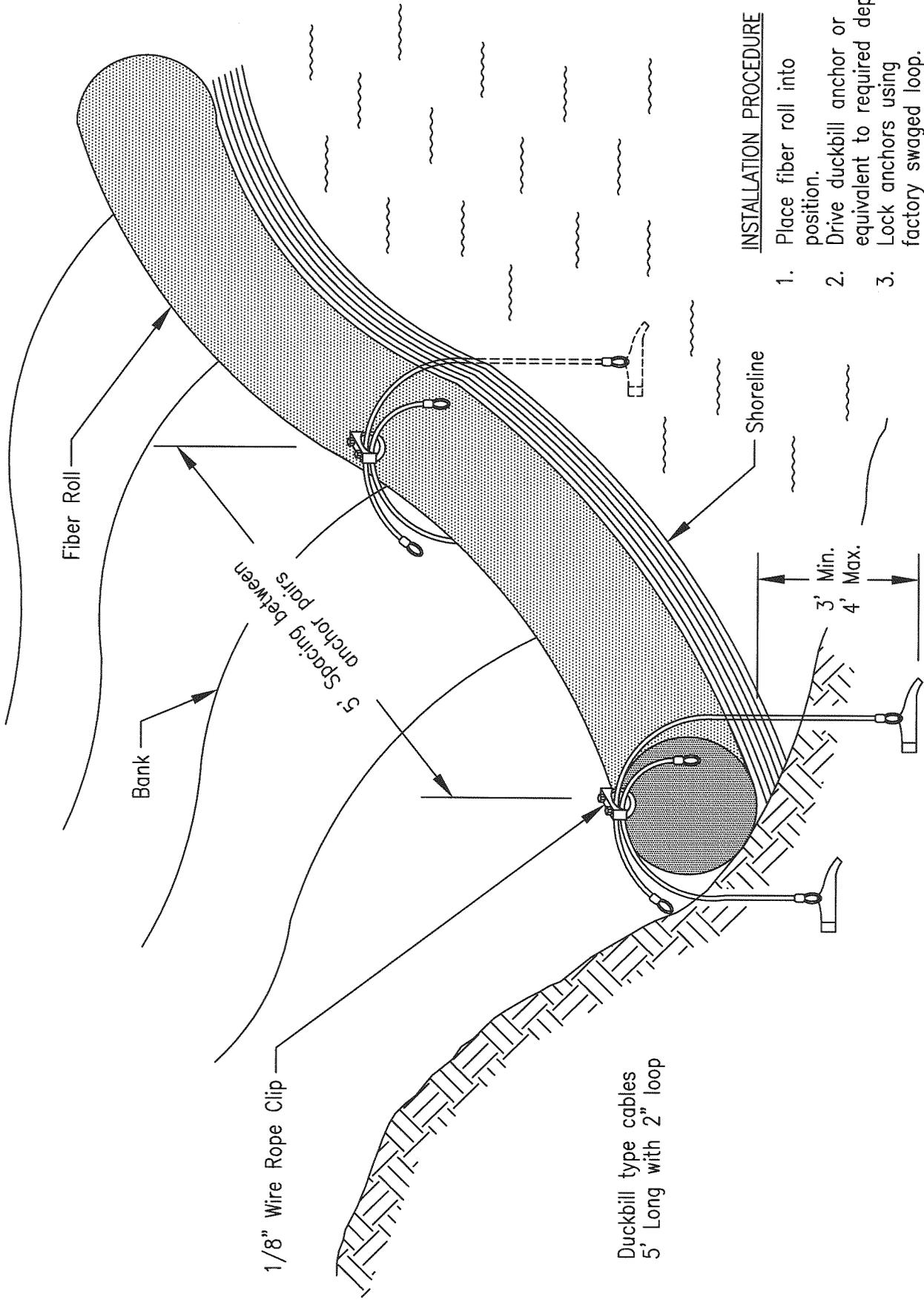


**LEVEL V**



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.

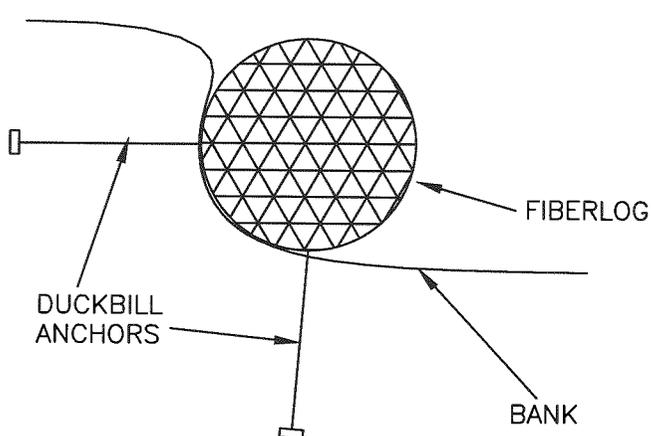


INSTALLATION PROCEDURE

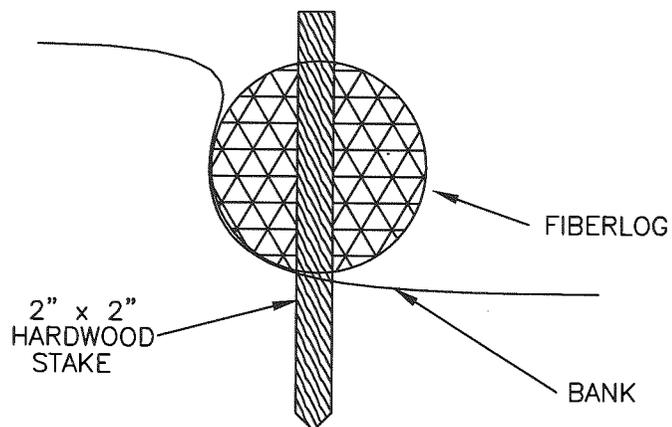
1. Place fiber roll into position.
2. Drive duckbill anchor or equivalent to required depth.
3. Lock anchors using factory swaged loop.
4. Overlap cables and secure with wire rope clip.

SHORELINE STABILIZATION  
DUCKBILL FIBER ROLL

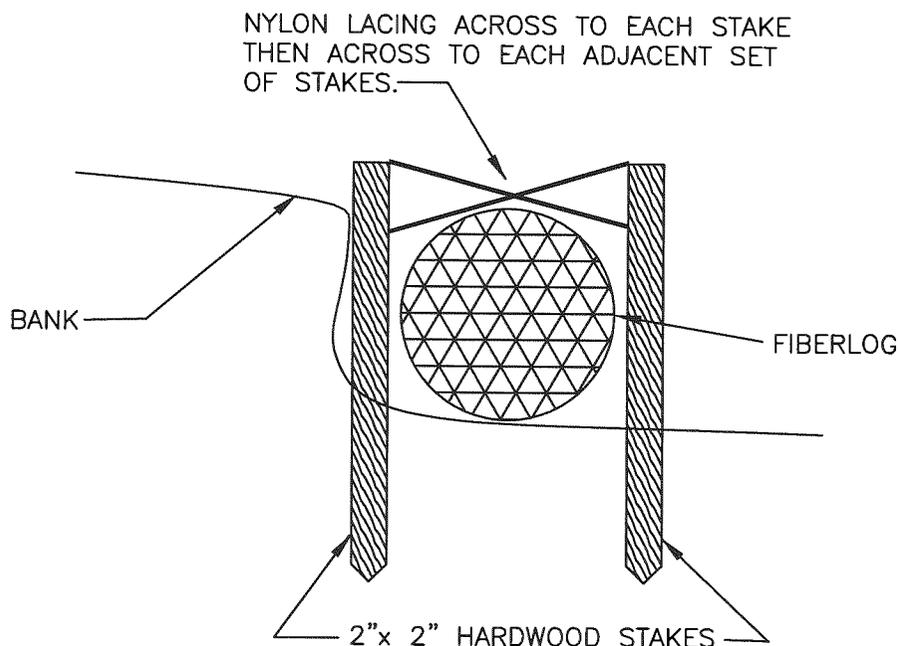
# COCONUT FIBER LOG INSTALLATION OPTIONS FOR SHORELINE PROTECTION



DUCKBILL ANCHOR SYSTEM



2" x 2" HARDWOOD STAKE

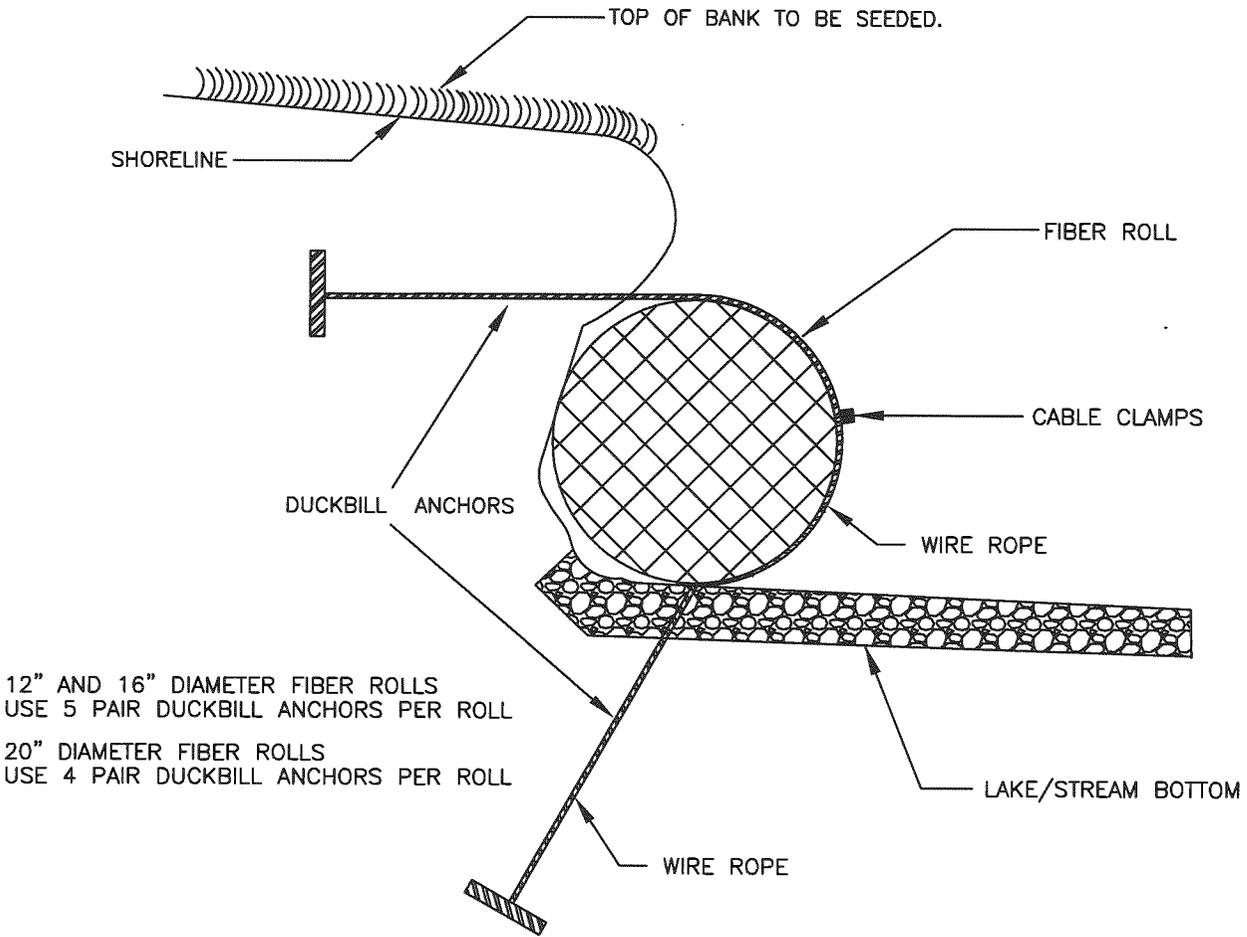


DOUBLE HARDWOOD STAKES

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

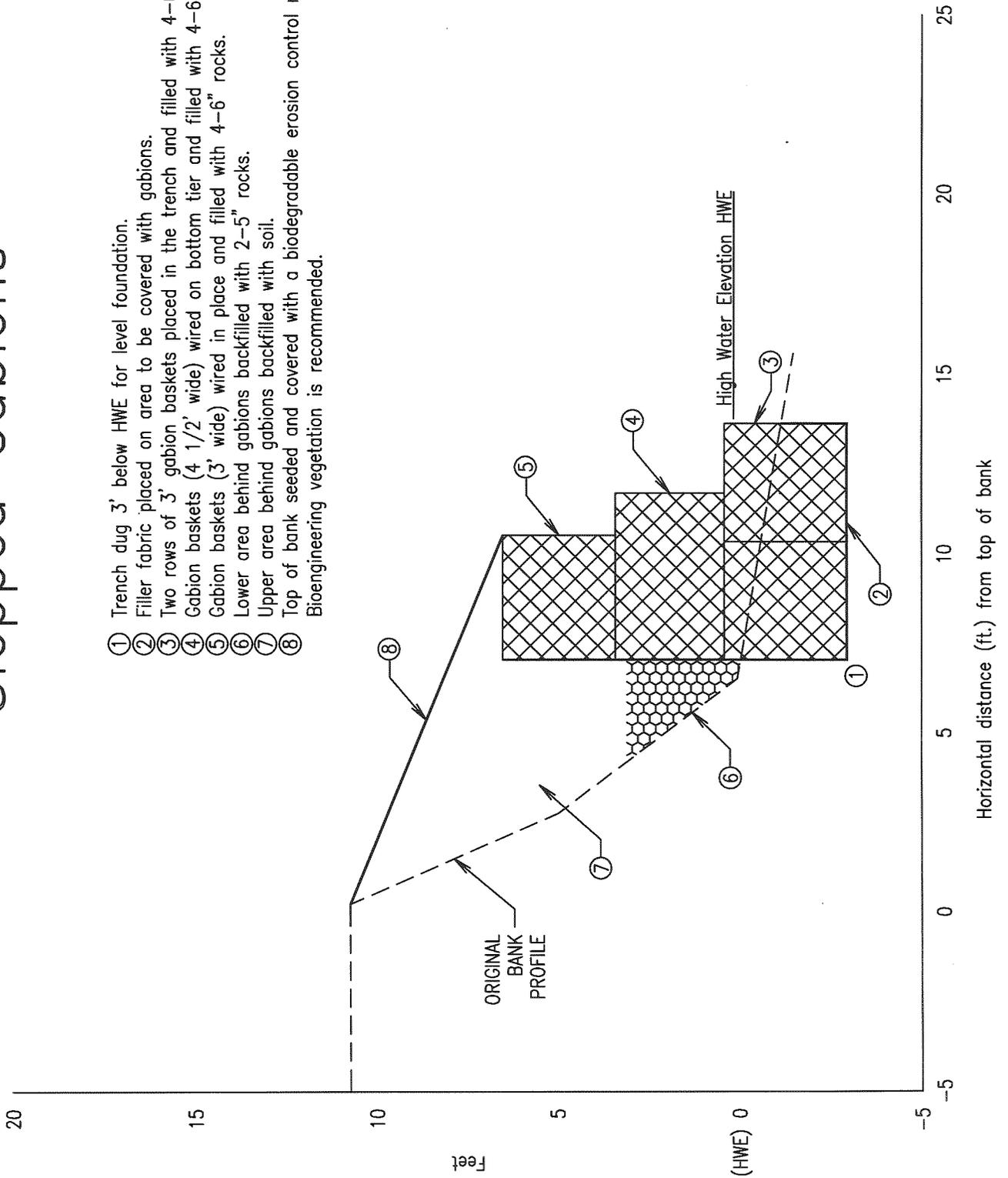
20" Fiber Logs (10' sections) each: \_\_\_\_\_  
 16" Fiber Logs (20' sections) each: \_\_\_\_\_  
 12" Fiber Logs (20' sections) each: \_\_\_\_\_  
 Duckbill Anchors \_\_\_\_\_ ft. long, each: \_\_\_\_\_  
 Connecting Clamps (4 per anchor) each: \_\_\_\_\_  
 Nylon Cord as necessary.

### 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.

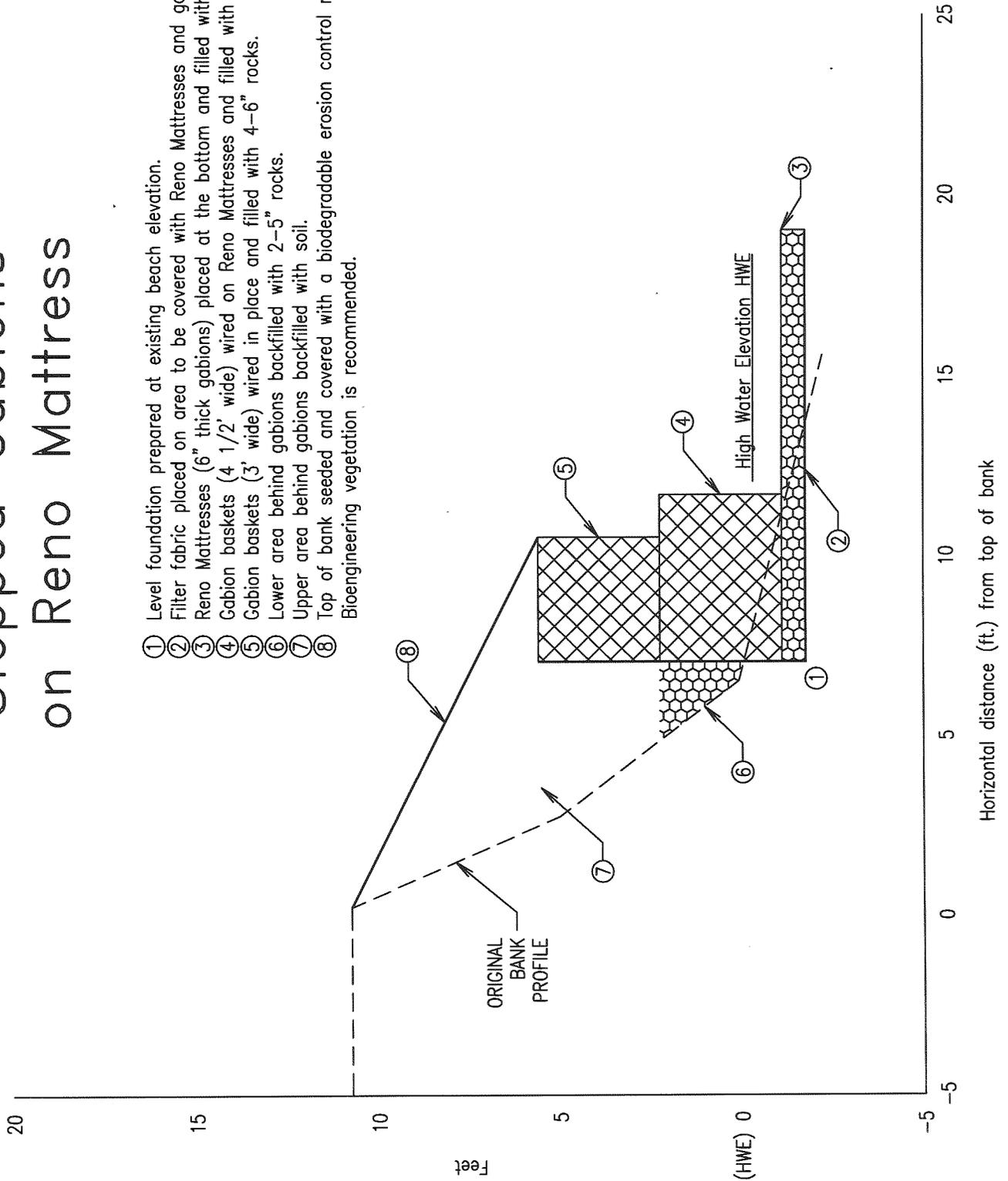
# Stepped Gabions

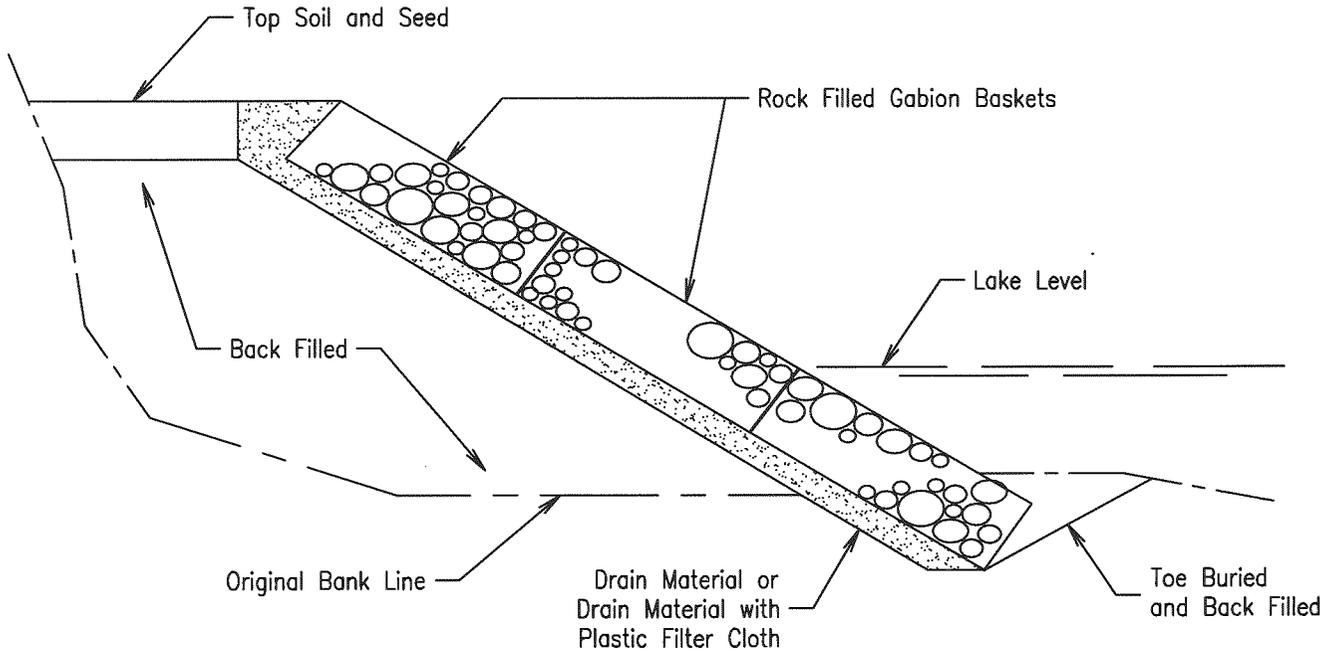
- ① Trench dug 3' below HWE for level foundation.
- ② Filler fabric placed on area to be covered with gabions.
- ③ Two rows of 3' gabion baskets placed in the trench and filled with 4-6" rocks.
- ④ Gabion baskets (4 1/2' wide) wired in the trench and filled with 4-6" rocks.
- ⑤ Gabion baskets (3' wide) 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.



# Stepped Gabions on Reno Mattress

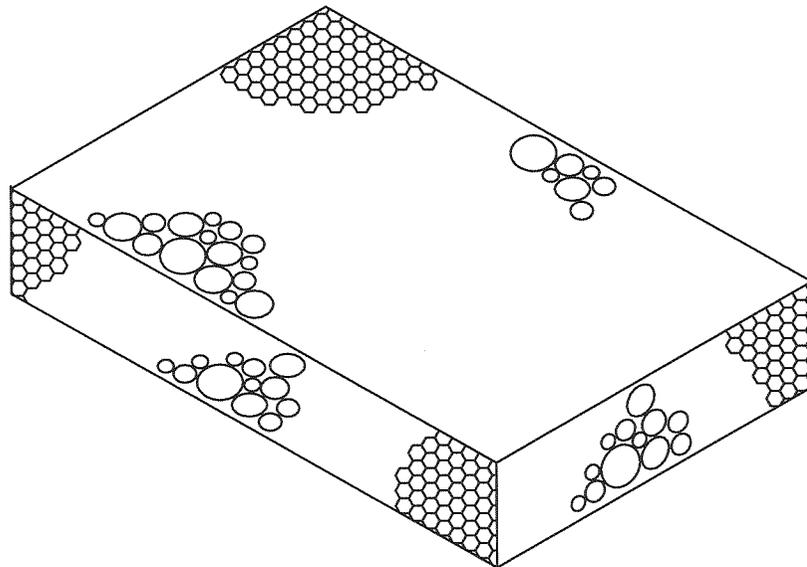
- ① Level foundation prepared at existing beach elevation.
- ② Filter fabric placed on area to be covered with Reno Mattresses and gabions.
- ③ Reno Mattresses (6" thick gabions) placed at the bottom and filled with 3-5" rocks.
- ④ Gabion baskets (4 1/2' wide) wired in place and filled with 4-6" rocks.
- 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.



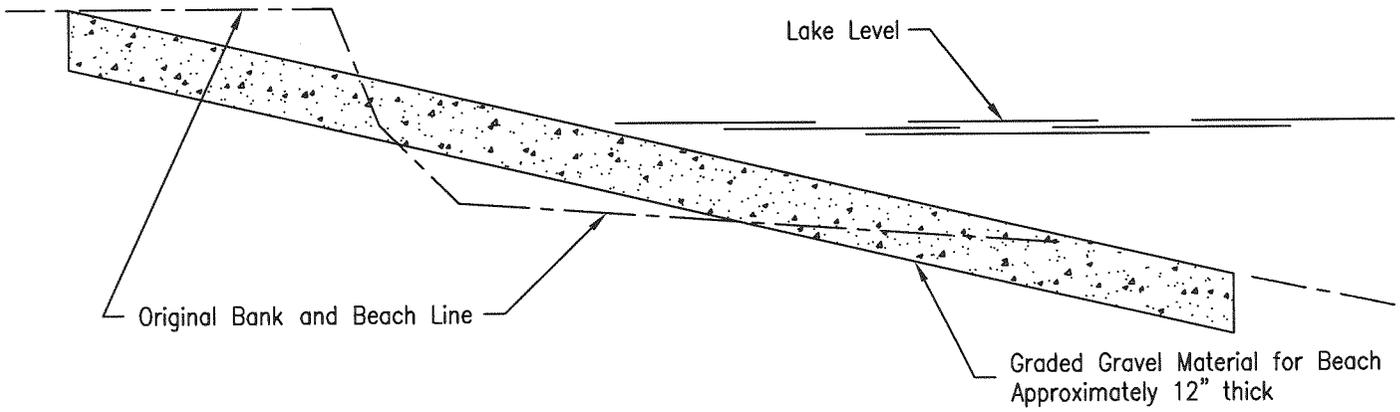


### GABIONS FOR LAKESHORE PROTECTION TYPICAL CROSS SECTION

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



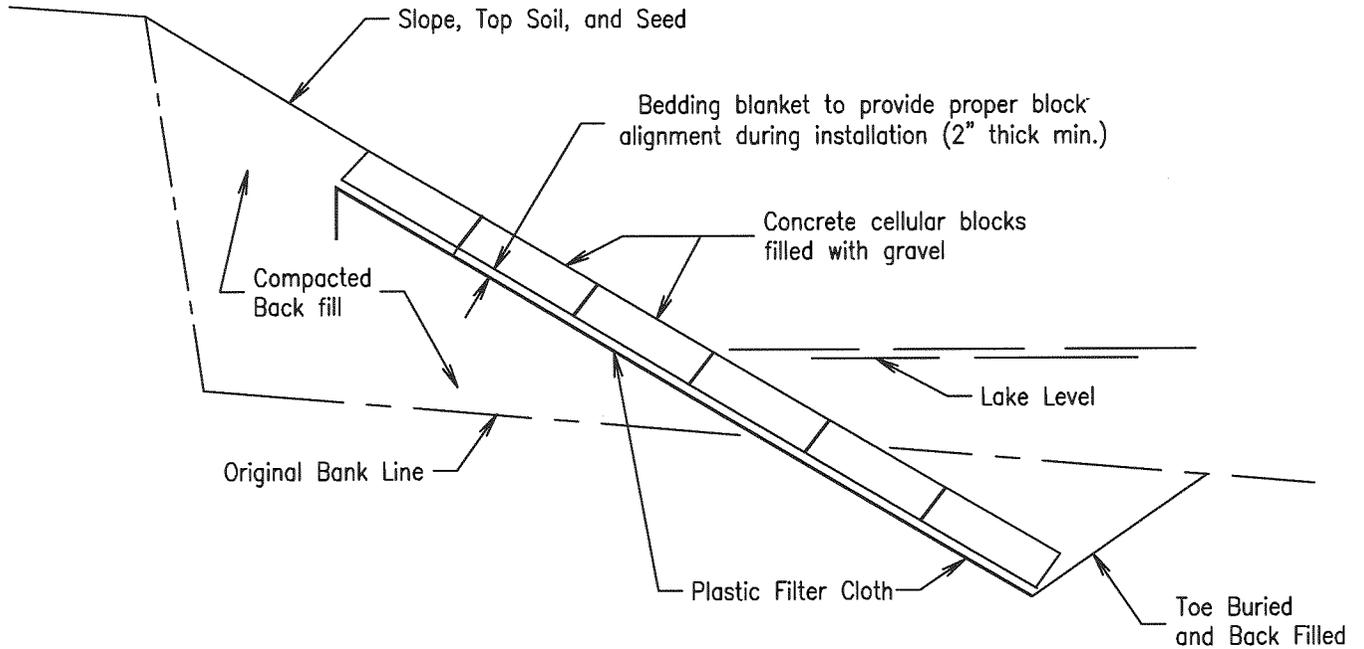
### GABIONS FOR LAKESHORE PROTECTION ISOMETRIC VIEW



TYPICAL CROSS SECTION

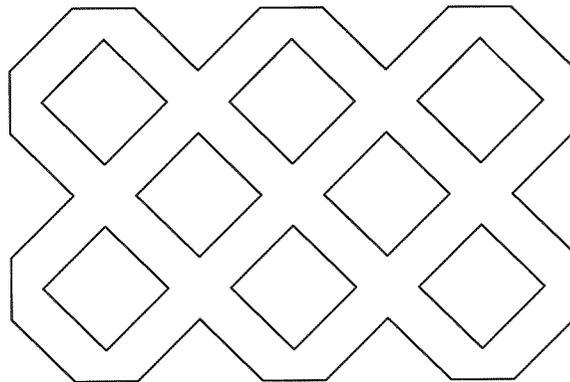
NOTE: The beaching shall range from 10 to 1 TO 4 to 1 based on the size of the graded material used.

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



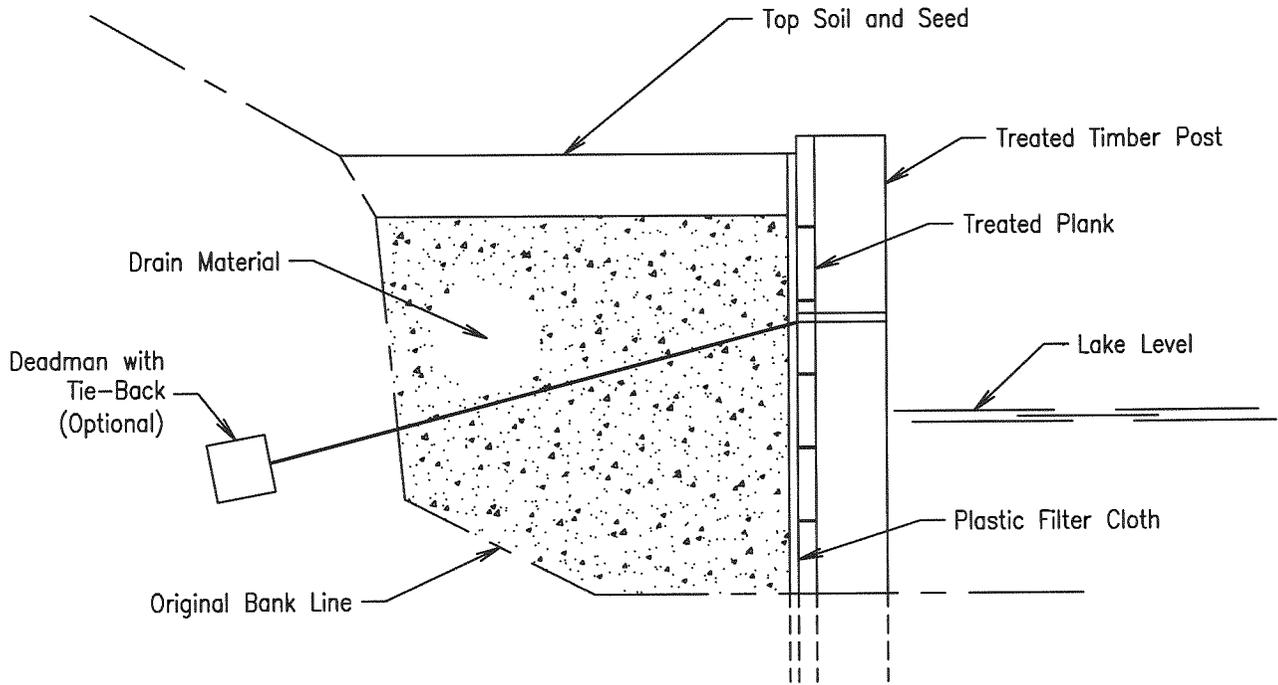
CONCRETE CELLULAR BLOCKS FOR LAKESHORE PROTECTION  
TYPICAL CROSS SECTION

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



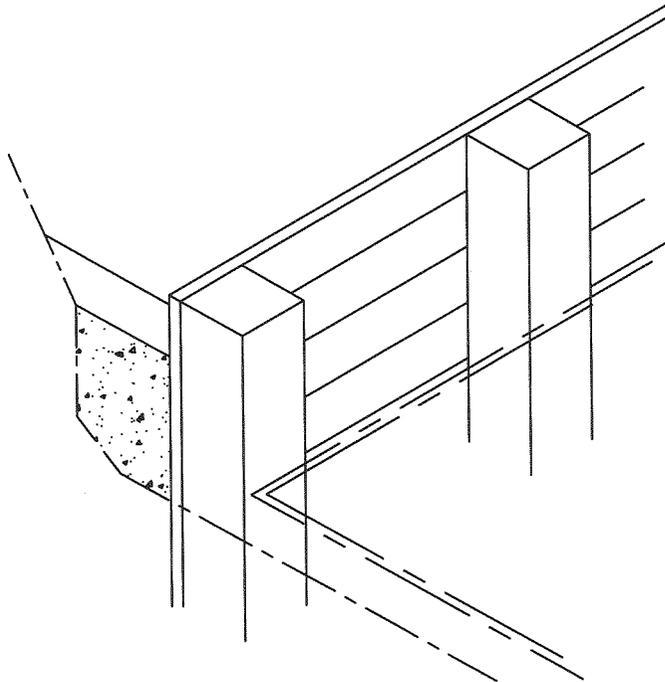
CONCRETE CELLULAR BLOCKS FOR LAKESHORE PROTECTION  
PLAN VIEW OF CONCRETE BLOCK

16-WI-124

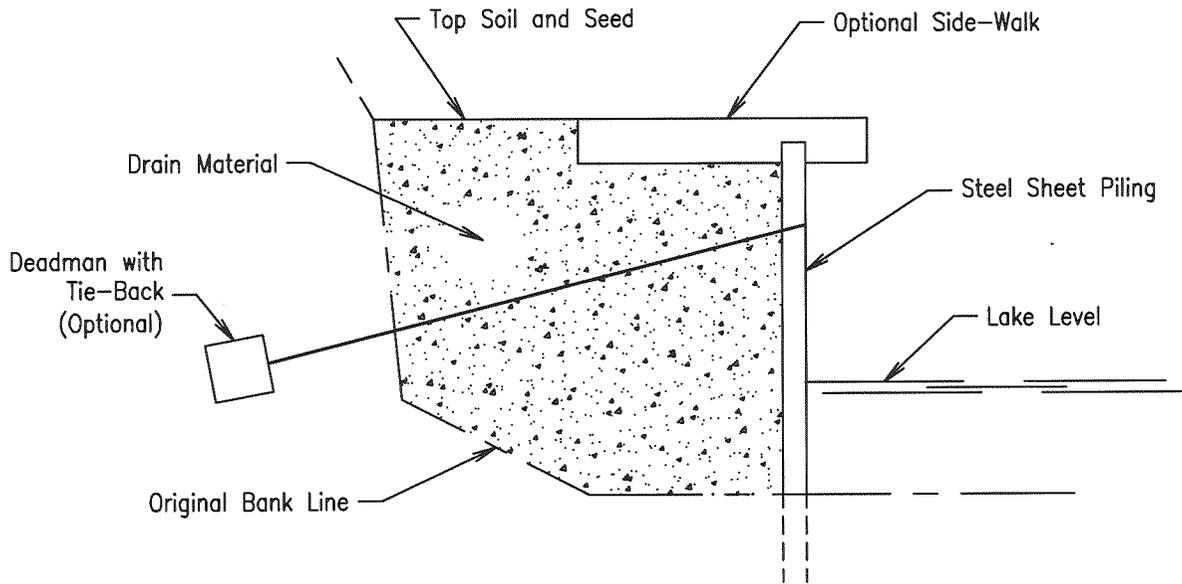


TREATED PLANK AND POST WALL FOR SHORELINE PROTECTION  
TYPICAL CROSS SECTION

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

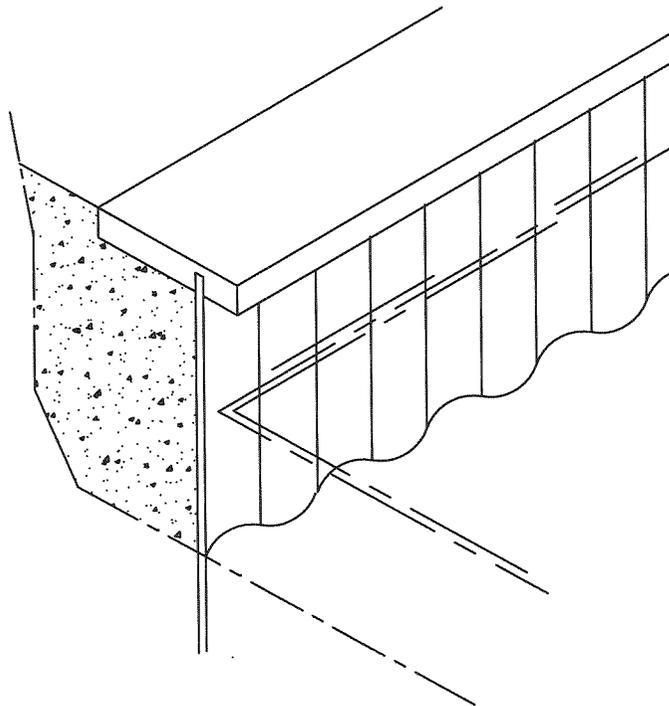


TREATED PLANK AND POST WALL FOR SHORELINE PROTECTION  
ISOMETRIC VIEW



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

16-WI-126

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16-WI-127 through 16-WI-130

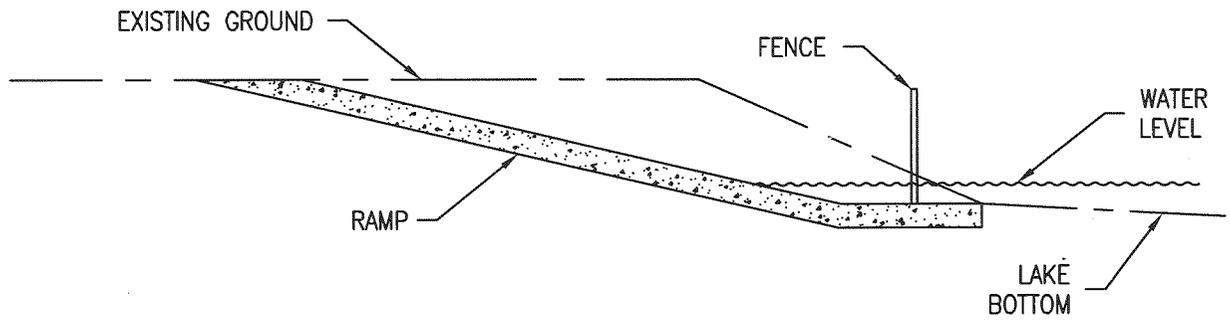
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### LIVESTOCK LAKE SHORELINE WATERING RAMP

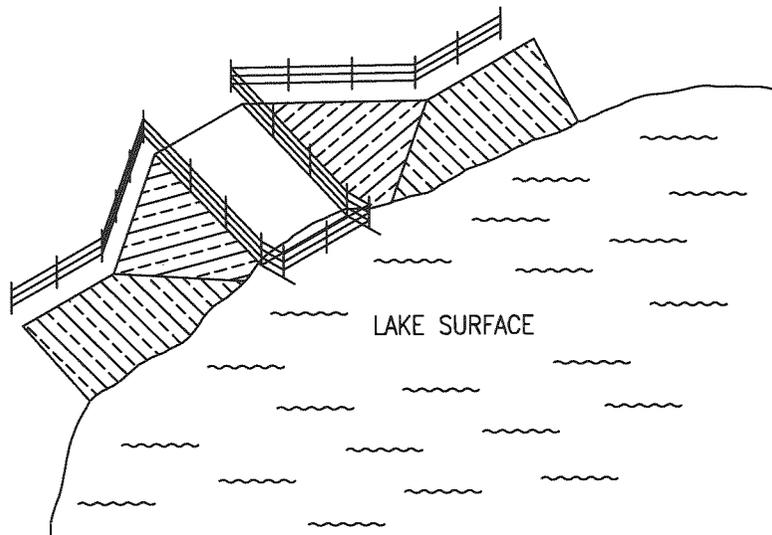
Livestock lakeshore cattle watering ramps need a ramp slope safe for the cattle to walk on in most seasons of the year. A slope of 4:1 or flatter has proven to work well. The ramp side slopes should be 2:1 or flatter. The lowest elevation of the ramp should provide about one foot of water but not extend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