MARYLAND=S WATERWAY

CONSTRUCTION GUIDELINES

MARYLAND DEPARTMENT OF THE ENVIRONMENT

WATER MANAGEMENT ADMINISTRATION

MARYLAND=S GUIDELINES TO WATERWAY CONSTRUCTION

MARYLAND DEPARTMENT OF THE ENVIRONMENT
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FORWARD

The Maryland Department of the Environment Water Management Administration is pleased to announce the issuance of the Maryland Guidelines to Waterway Construction (MGWC) to provide a set of recommended details for approaches frequently encountered in the waterway construction process. The need for this manual has been recognized over the years with the awareness that many streams and rivers require stabilization, modification, or rehabilitation of some type due to urbanization or previous channel construction. Additionally, the emphasis for in-stream projects has gradually shifted from the use of hard points, such as rock and concrete structures, to a Asofter@, more environmentally acceptable approach, commonly referred to as biotechnical engineering, thereby necessitating revision of the previous guidelines.

Maryland is composed of five distinct physiographic regions which have widely varying geology and topography. These regional and site-specific characteristics coupled with the level of watershed urbanization lend to the dissimilar behavior of streams in this state. Although the purpose of this manual is to function as a design aid for the use of structures and bio-engineering techniques in stream enhancement and restoration projects, development of a set of comprehensive design guidelines is impractical due to the highly diverse nature of these streams and their associated floodplains and watersheds. Therefore, it is suggested that project designers, engineers, inspectors, and regulatory officials view the details and construction sequences as guidelines rather than as strict requirements or design standards for the waterway construction permitting process with the additional understanding that these guidelines may require supplemental details depending on the scope of the work.

It should also be understood that the project manager or regulatory official may supersede these guidelines on the basis of practical experience and/or recent developments with relevant field work and case studies. Additionally, reference reaches in watersheds with similar physiographic, geologic, and hydraulic characteristics may indicate necessary modifications to the information presented in this document and should be used as templates for channel stabilization and restoration projects whenever possible.

INTRODUCTION

The intent of this manual is to address a wide range of common biotechnical engineering techniques and conventional, Ahard@ engineering solutions with the hope of identifying effective uses and limitations, material specifications, and installation procedures for these measures. A summary of the uses of common stabilization and restoration practices included in this document is provided in Table 1. Additionally, a listing of the principal limitations of each practice is given in Table 2. Throughout the guidelines, where applicable, the stream types for which the practices are appropriate are given in terms of the Rosgen classification scheme (see Table 3). Although not addressed in these guidelines, it is important to assess the causes of any instability problem prior to designing a channel restoration or stabilization project. For example, streambank stabilization involving the installation of a structure may also involve re-shaping the channel in order to provide for the stable distribution of energy. Additional information on causes of unstable channels can be found in the U.S. Department of Agriculture's Interagency Stream Corridor Restoration Handbook Page *(www.usda.gov/stream_restoration/*).

Design Flows

The planning of many in-stream construction, stabilization, and restoration measures depends on the magnitude and frequency of a design flow event. Many techniques used for bank stabilization, including toe protection and surface armoring, are required to accommodate bankfull flow velocities and shear stresses. Bankfull velocities for design purposes can be estimated from Manning=s equation as follows:

$$V = \frac{f}{n} R^{2/3} S^{1/2}$$

where ϕ = 1.49 or 1.0 for U.S. or metric units, respectively, n = Manning=s roughness coefficient approximated for bankfull conditions, R = the hydraulic radius associated with bankfull depth and width, and S = slope. Once the bankfull velocity is determined, the corresponding stone diameter to resist this velocity can be found in MGWC 3.1. The average boundary shear stress at a cross section can be estimated from:

$$t_o = g\ R\ S$$

where g = specific weight of water. MDE may require more extensive modeling efforts if tractive force (shear stress) regulations are to be reviewed.

Bankfull discharge (in a stable channel) is defined as the maximum discharge which can be contained within the channel without over-topping the banks (Thorne et al., 1998). The bankfull depth is the flow depth associated with the bankfull discharge. In a stable channel, the bankfull discharge is thought to be the discharge which forms and maintains the present morphology of the channel. In an unstable channel, the bankfull discharge used for design purposes should reflect the bankfull discharge that would be expected if the channel were stable. Reference reaches, effective discharge studies, or bankfull indicators can be used to determine this magnitude.

Temporary measures for dewatering and diverting flow from a reach for construction purposes should have sufficient capacity to convey 2-year flows for existing development conditions. For projects where hydrologic data is not available, bankfull flows may be substituted for the 2-year storm event. Design flows for temporary structures could be reduced to a lower flow if the project will take less than 2 weeks.

Cost Information

Approximate costs are included in the guidelines for rough planning and comparative purposes only and may vary significantly based on local conditions and constraints. The costs were derived from King, D.M., Bohlen, C.C. and Kraus, M.L. (1994), "Stream Restoration: The Costs of Engineered Bioengineered Alternatives." Costs for the November 2000 revision of the guidelines were updated from the costs provided in the 1999 draft using "Engineering News Record" Construction Cost Indexes. Annual average values of 4985, 5408, and 6060 were used for the years 1992, 1994, and 1999 respectively.

Comprehensive Stream Enhancement Plan

The planning and design of any stabilization, restoration, or in-stream construction project should include a set of clearly defined restoration objectives, a comprehensive monitoring strategy, and an adaptive management plan. Objectives vary from aesthetic improvements to habitat enhancement to safety and installation of hydraulic structures and roadways. Identifying the objective of the project must be accomplished before the design process can begin. Regardless of the nature of the objective, it should include measurable performance criteria. Performance criteria are quantitative measurements that are made in the stream corridor and compared to the project's objectives. Performance criteria can include parameters such as suspended sediment load and rate of lateral channel migration. A comprehensive monitoring strategy including appropriate baseline studies and timing, frequency, and location of field measurements, is requisite to assess the degree of project success or failure and to determine an adaptive management plan. Options for an adaptive management plan include adjustment or maintenance of individual measures, modification of project goals and objectives, and project redesign.

References

Thorne, C.R., Soar, P.J., Hey, R.D., and Watson, C.C. (1998). Dominant Discharge Calculation: A Practical Guide. US Army Research, Development, and Standardization Group - UK, London.

Rosgen, D. L. (1996). Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

TABLE 1. SUMMARY OF THE USES OF COMMON RESTORATION AND STABILIZATION PRACTICES

RESTORATION/ STABILIZATION PRACTICE	FUNCTIONAL APPLICATIONS					
	armor & protect surface	**enhance mass stability**	**propagate vegetative growth**	**filter sediment**	**provide instream habitat**	**provide riparian habitat**
Brush Layering	●	●	●	●	❍	◗
Brush Mattresses	●	❍	◗	●	❍	◗
Fascines	◗	❍	◗	●	❍	◗
Live Crib Walls	◗	●	●	❍	◗	❍
Live Stakes	◗	◗	●	◗	❍	◗
Natural Fiber Rolls	◗	❍	●	◗	❍	◗
Deflectors	❍	❍	❍	❍	◗	❍
Gabions	●	◗	❍	❍	❍	❍
Root Wads	◗	◗	◗	◗	●	◗
Riprap, dumped	●	❍	❍	◗	❍	❍
Riprap, imbricated	●	●	❍	◗	❍	❍
Boulder Placement	❍	❍	❍	❍	◗	❍
Log Weirs	❍	❍	❍	◗	◗	❍
Stone Dikes	❍	❍	❍	●	❍	❍
Rock Vanes	●	◗	❍	❍	◗	❍
Log Vanes	●	◗	❍	❍	◗	❍
J-Hooks	●	◗	❍	❍	●	❍
Vortex Rock Weirs	◗	❍	❍	❍	◗	❍
"W" Rock Weirs	●	◗	❍	❍	◗	❍

Key:

● - the approach is well suited for this functional application (primary benefit)
◗ - the approach is moderately well suited for this functional application (frequent secondary benefit)
❍ - the approach is not well suited/rarely used for this functional application (possible incidental benefit)

TABLE 1. SUMMARY OF THE USES OF COMMON RESTORATION AND STABILIZATION PRACTICES (CONTINUED)

RESTORATION/ STABILIZATION PRACTICE	FUNCTIONAL APPLICATIONS				
	provide organic material	protect bank toe	redirect flow	create flow diversity	stabilize bed
Brush Layering	◗	❍	❍	❍	❍
Brush Mattresses	❍	❍	❍	❍	❍
Fascines	❍	❍	❍	❍	❍
Live Crib Walls	●	◗	❍	❍	❍
Live Stakes	◗	❍	❍	❍	❍
Natural Fiber Rolls	◗	❍	❍	❍	❍
Deflectors	❍	◗	●	●	❍
Gabions	❍	●	❍	❍	❍
Root Wads	●	◗	●	◗	❍
Riprap, dumped	❍	●	❍	❍	❍
Riprap, imbricated	❍	●	❍	❍	❍
Boulder Placement	❍	❍	◗	●	❍
Log Weirs	◗	❍	●	●	❍
Stone Dikes	❍	❍	◗	◗	◗
Rock Vanes	❍	●	●	●	❍
Log Vanes	❍	●	●	●	❍
J-Hooks	❍	●	●	●	❍
Vortex Rock Weirs	❍	●	●	●	●
“W” Rock Weirs	❍	●	●	●	●

Key:

● - the approach is well suited for this functional application (primary benefit)
◗ - the approach is moderately well suited for this functional application (frequent secondary benefit)
❍ - the approach is not well suited/rarely used for this functional application (possible incidental benefit)

TABLE 2. LIMITATIONS OF COMMON RESTORATION AND STABILIZATION PRACTICES

RESTORATION/ STABILIZATION PRACTICE	FUNCTIONAL APPLICATIONS					
	high design velocity	**slow flow or pooled reaches**	**flashy flows**	**limited backwater effects**	**silt or fine sand bed**	**high bedload transport**
Brush Layering	◗	●	◗	●	●	●
Brush Mattresses	◗	●	◗	●	●	●
Fascines	◗	●	◗	●	●	●
Live Crib Walls	◗	❍	◗	●	●	◗
Live Stakes	◗	●	◗	●	●	●
Natural Fiber Rolls	❍	●	❍	●	●	●
Deflectors	●	◗	●	◗	❍	◗
Gabions	◗	●	◗	●	◗	●
Root Wads	◗	●	◗	◗	●	◗
Riprap, dumped	●	●	●	●	◗	●
Riprap, imbricated	●	●	●	●	◗	●
Boulder Placement	●	❍	◗	●	❍	◗
Log Weirs	●	❍	❍	◗	❍	❍
Stone Dikes	◗	◗	●	◗	◗	◗
Rock Vanes	●	◗	◗	●	❍	●
Log Vanes	●	◗	◗	●	◗	●
J-Hooks	●	◗	◗	◗	◗	◗
Vortex Rock Weirs	●	❍	◗	◗	❍	◗
“W” Rock Weirs	●	❍	●	◗	❍	●

Key:

● - the approach can be used effectively in (is well suited to) reaches with this constraint
◗ - with supporting measures, the approach is not severely limited by this constraint (use cautiously)
❍ - the approach should not be used in reaches with this constraint

TABLE 2. LIMITATIONS OF COMMON RESTORATION AND STABILIZATION PRACTICES (CONTINUED)

RESTORATION/ STABILIZATION PRACTICE	FUNCTIONAL APPLICATIONS				
	bedrock	lateral channel adjustments	highly erodible banks	rigid/fixed banks	steep bank grade
Brush Layering	❍	◗	◗	◗	❍
Brush Mattresses	❍	◗	◗	◗	❍
Fascines	❍	◗	◗	◗	❍
Live Crib Walls	❍	●	◗	●	●
Live Stakes	❍	◗	◗	◗	❍
Natural Fiber Rolls	❍	◗	◗	◗	❍
Deflectors	◗	❍	❍	◗	●
Gabions	●	●	●	●	◗
Root Wads	❍	●	◗	◗	◗
Riprap, dumped	◗	●	●	●	❍
Riprap, imbricated	◗	●	●	●	●
Boulder Placement	❍	●	◗	●	●
Log Weirs	❍	◗	●	●	●
Stone Dikes	●	◗	◗	◗	●
Rock Vanes	❍	●	●	●	●
Log Vanes	❍	●	●	●	●
J-Hooks	❍	●	●	●	●
Vortex Rock Weirs	◗	●	◗	●	●
"W" Rock Weirs	❍	●	●	◗	●

Key:

● - the approach can be used effectively in and is well suited to reaches with this constraint
◗ - with supporting measures, the approach is not severely limited by this constraint
❍ - the approach should not be used in reaches with this constraint

TABLE 3. THE ROSGEN STREAM CLASSIFICATION SCHEME

	Single-Thread Channels														Multiple Channels			
Entrenchment Ratio	Entrenched (< 1.4)						Moderately Entrenched (1.4-2.2)			Slightly Entrenched (>2.2)								
Width/Depth Ratio	Low (< 12)				Moderate to high (>12)		Moderate (>12)			Very low (<12)		Moderate to high (>12)			Very high (>40)			Low (<40)
Sinuosity	Low (<1.2)		Moderate (>1.2)		Moderate (>1.2)		Moderate (>1.2)			Very high (>1.5)		High (>1.2)			Low (<1.2)			Lo-Hi (1.2-1.5)
Stream Type	**A**		**G**		**F**		**B**			**E**		**C**			**D**			**DA**
Slope	>0.10	0.04-0.099	0.02-0.039	<0.02	0.02-0.039	<0.02	0.04-0.099	0.02-0.039	<0.02	0.02-0.039	<0.02	0.02-0.039	0.001-0.02	< 0.001	0.02-0.039	0.001-0.02	<0.001	<0.005
Channel Material																		
Bedrock	A1a+	A1	G1	G1c	F1b	F1	B1a	B1	B1c			C1b	C1	C1c				
Boulders	A2a+	A2	G2	G2c	F2b	F2	B2a	B2	B2c			C2b	C2	C2c				
Cobbles	A3a+	A3	G3	G3c	F3b	F3	B3a	B3	B3c	E3b	E3	C3b	C3	C3c	D3b	D3		
Gravel	A4a+	A4	G4	G4c	F4b	F4	B4a	B4	B4c	E4b	E4	C4b	C4	C4c	D4b	D4	D4c	DA4
Sand	A5a+	A5	G5	G5c	F5b	F5	B5a	B5	B5c	E5b	E5	C5b	C5	C5c	D5b	D5	D5c	DA5
Silt/Clay	A6a+	A6	G6	G6c	F6b	F6	B6a	B6	B6c	E6b	E6	C6b	C6	C6c	D6b	D6	D6c	DA6

Reference

Rosgen, D. *Applied River Morphology*, Classification Key for Natural Rivers, 1996.

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SECTION 1

TEMPORARY INTREAM CONSTRUCTION MEASURES

MGWC 1.1: DEWATERING BASINS

Temporary measure for filtering sediment-laden water

DESCRIPTION

The work should consist of installing dewatering basins jointly with channel diversion measures to filter sediment-laden water from in-stream construction sites before the water re-enters the downstream reach.

EFFECTIVE USES & LIMITATIONS

Undersized dewatering basins will not adequately filter sediment-laden water from the construction site.

MATERIAL SPECIFICATIONS

Materials for dewatering basins should meet the following requirements:

- *Riprap*: Riprap should be washed and have a diameter ranging from 4 to 6 inches (10 to 15 centimeters).
- *Filter Cloth*: Filter cloth should be a woven or non-woven fabric consisting only of continuous chain polymeric filaments or yarns of polyester. The fabric should be inert to commonly encountered chemicals, hydro-carbons, ultraviolet light, and mildew and should be rot resistant.
- *Straw Bales/Silt Fence*: Straw bales should meet the criteria as specified in the *1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control*.

INSTALLATION GUIDELINES

Due to the danger of overtopping by events greater than the design flow, dewatering basins require a vegetative buffer strip to filter sediment-laden overflow. A 50-foot (15-meter) minimum grass-covered buffer width is required for slopes less than 20 degrees (1:2.7) when right-of-way is not limited. For slopes greater than 20 degrees, basins should have a 100-foot (30-meter) minimum buffer width when practical.

All erosion and sediment control devices should be installed as the first order of business according to a plan approved by the Water Management Administration (WMA) or local authority. Dewatering basins should be constructed as follows (refer to Detail 1.1):

1. Excavated subsoil and topsoil should be stored separately and replaced in their natural order. Additionally, the excavated sediments should be prevented from entering the waterway by using sediment perimeter controls or other measures.

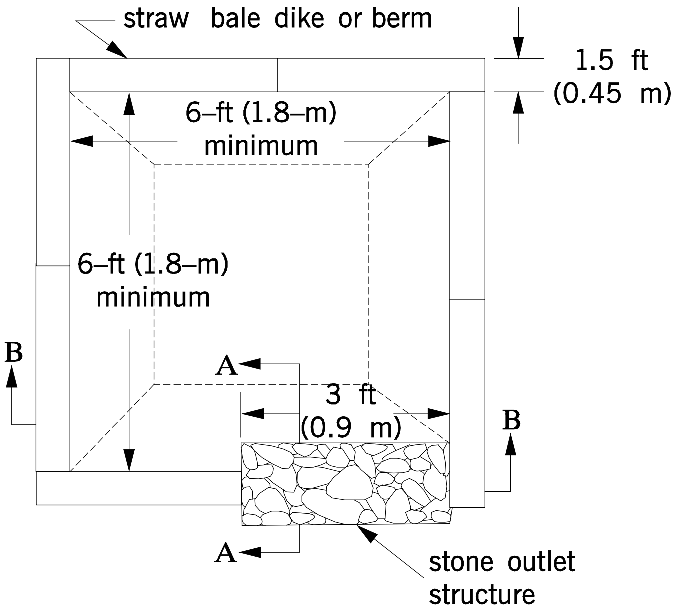
2. The dewatering basin should have a minimum depth of 3 feet (1 meter) where basin depth is measured from the top of the straw bales to the bottom of the excavation.

3. Once the dewatering basin becomes filled to one-half of the excavated depth, accumulated sediment should be removed and disposed of in an approved area outside the 100-year floodplain unless otherwise authorized by the WMA.

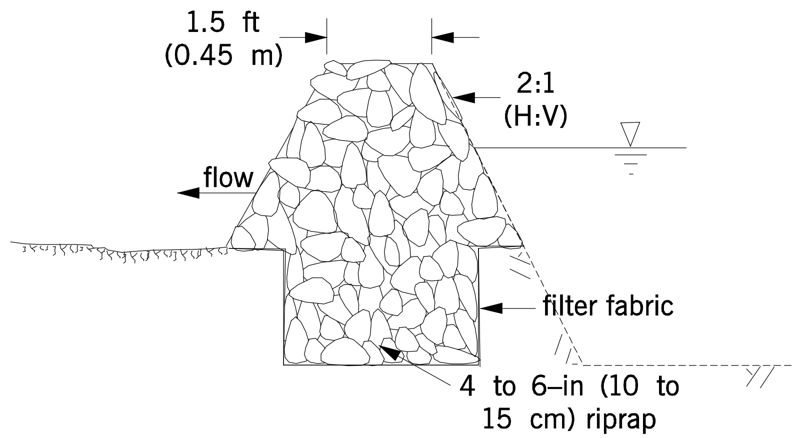
4. Sediment control devices should remain in place until all disturbed areas are stabilized and the inspecting authority approves their removal. All disturbed ground contours should be returned to their original condition unless otherwise approved by the WMA or local authority.

DETAIL 1.1: DEWATERING BASINS

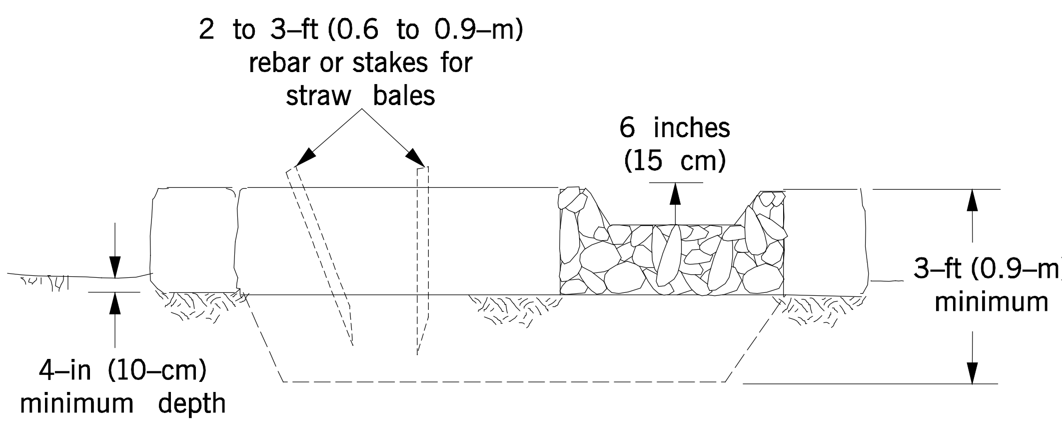
PLAN VIEW



SECTION A–A



SECTION B–B



MGWC 1.2: PUMP-AROUND PRACTICE

Temporary measure for dewatering in-channel construction sites

DESCRIPTION

The work should consist of installing a temporary pump around and supporting measures to divert flow around in-stream construction sites.

IMPLEMENTATION SEQUENCE

Sediment control measures, pump-around practices, and associated channel and bank construction should be completed in the following sequence (refer to Detail 1.2):

1. Construction activities including the installation of erosion and sediment control measures should not begin until all necessary easements and/or right-of-ways have been acquired. All existing utilities should be marked in the field prior to construction. The contractor is responsible for any damage to existing utilities that may result from construction and should repair the damage at his/her own expense to the county's or utility company's satisfaction.

2. The contractor should notify the Maryland Department of the Environment or WMA sediment control inspector at least 5 days before beginning construction. Additionally, the contractor should inform the local environmental protection and resource management inspection and enforcement division and the provider of local utilities a minimum of 48 hours before starting construction.

3. The contractor should conduct a pre-construction meeting on site with the WMA sediment control inspector, the county project manager, and the engineer to review limits of disturbance, erosion and sediment control requirements, and the sequence of construction. The contractor should stake out all limits of disturbance prior to the pre-construction meeting so they may be reviewed. The participants will also designate the contractor's staging areas and flag all trees within the limit of disturbance which will be removed for construction access. Trees should not be removed within the limit of disturbance without approval from the WMA or local authority.

4. Construction should not begin until all sediment and erosion control measures have been installed and approved by the engineer and the sediment control inspector. The contractor should stay within the limits of the disturbance as shown on the plans and minimize disturbance within the work area whenever possible.

5. Upon installation of all sediment control measures and approval by the sediment control inspector and the local environmental protection and resource management inspection and enforcement division, the contractor should begin work at the upstream section and proceed downstream beginning with the establishment of stabilized construction entrances. In some cases, work may begin downstream if appropriate. The sequence of construction must be followed unless the contractor gets written approval for deviations from the WMA or local authority. The contractor should only begin work in an area which can be completed by the end of the day including grading adjacent to the channel. At the end of each work day, the work area must be stabilized and the pump around removed from the channel. Work should not be conducted in the channel during rain events.

6. Sandbag dikes should be situated at the upstream and downstream ends of the work area as shown on the plans, and stream flow should be pumped around the work area. The pump should discharge onto a stable velocity dissipater made of riprap or sandbags.

<u>MGWC 1.2: PUMP-AROUND PRACTICE</u>

7. Water from the work area should be pumped to a sediment filtering measure such as a dewatering basin, sediment bag, or other approved source. The measure should be located such that the water drains back into the channel below the downstream sandbag dike.

8. Traversing a channel reach with equipment within the work area where no work is proposed should be avoided. If equipment has to traverse such a reach for access to another area, then timber mats or similar measures should be used to minimize disturbance to the channel. Temporary stream crossings should be used only when necessary and only where noted on the plans or specified. (*See Section 4, Stream Crossings, Maryland Guidelines to Waterway Construction*).

9. All stream restoration measures should be installed as indicated by the plans and all banks graded in accordance with the grading plans and typical cross- sections. All grading must be stabilized at the end of each day with seed and mulch or seed and matting as specified on the plans.

10. After an area is completed and stabilized, the clean water dike should be removed. After the first sediment flush, a new clean water dike should be established upstream from the old sediment dike. Finally, upon establishment of a new sediment dike below the old one, the old sediment dike should be removed.

11. A pump around must be installed on any tributary or storm drain outfall which contributes baseflow to the work area. This should be accomplished by locating a sandbag dike at the downstream end of the tributary or storm drain outfall and pumping the stream flow around the work area. This water should discharge onto the same velocity dissipater used for the main stem pump around.

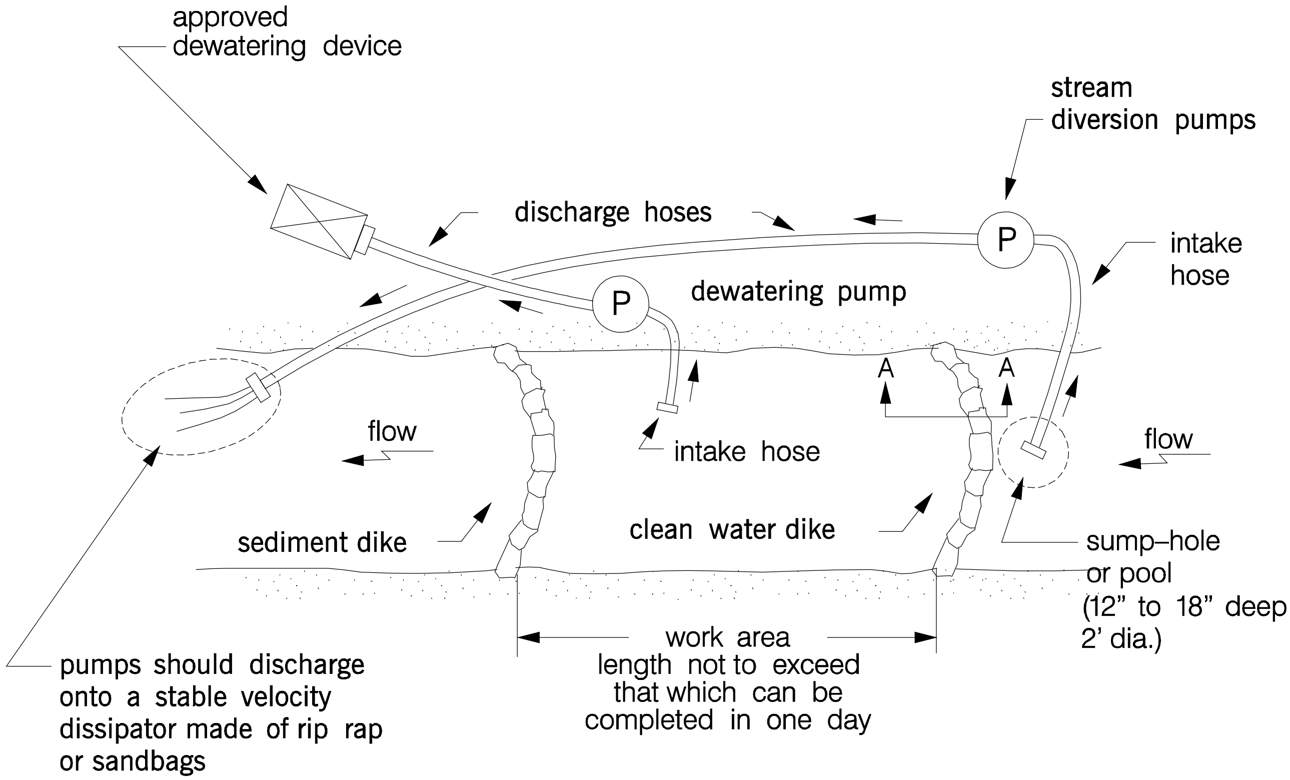
12. If a tributary is to be restored, construction should take place on the tributary before work on the main stem reaches the tributary confluence. Construction in the tributary, including pump around practices, should follow the same sequence as for the main stem of the river or stream. When construction on the tributary is completed, work on the main stem should resume. Water from the tributary should continue to be pumped around the work area in the main stem.

13. The contractor is responsible for providing access to and maintaining all erosion and sediment control devices until the sediment control inspector approves their removal.

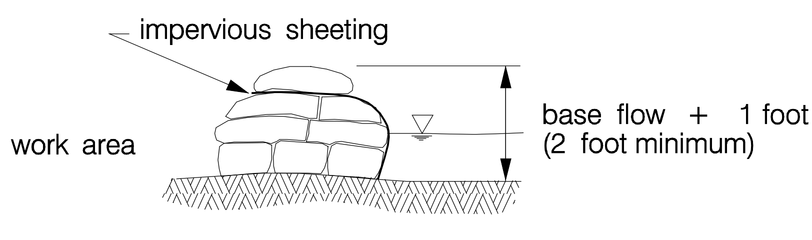
14. After construction, all disturbed areas should be regraded and revegetated as per the planting plan.

Maryland's Guidelines To Waterway Construction
DETAIL 1.2: PUMP–AROUND PRACTICE

PLAN VIEW



SECTION A–A



cross section of sandbag dike

MGWC 1.3: CULVERT PIPE WITH ACCESS ROAD

Temporary measure for providing access to stream enhancement sites

DESCRIPTION

The work should consist of installing a culvert pipe and associated access road for the purpose of erosion control when construction activities occur within the stream corridor.

EFFECTIVE USES & LIMITATIONS

Culvert pipes with access roads can be used effectively for installation of utility lines at stream crossings.

Diversions which have an insufficient flow capacity can fail and severely erode the disturbed channel section under construction. Therefore, in-channel construction activities should occur only during periods of low rainfall.

MATERIAL SPECIFICATIONS

Materials for culverts with temporary access roads should meet the following requirements:

- *Riprap*: Riprap should be sized to resist a stream's baseflow if the duration of the project is less than one month. Otherwise, the riprap should be design to resist bankfull discharge.
- *Sandbags*: Sandbags should consist of materials which are resistant to ultra-violet radiation, tearing, and puncture and should be woven tightly enough to prevent leakage of fill material (i.e., sand, fine gravel, etc.).
- *Sheeting*: Sheeting should consist of polyethylene or other material which is impervious and resistant to puncture and tearing.

INSTALLATION GUIDELINES

All erosion and sediment control devices including mandatory dewatering basins should be installed as the first order of business according to a plan approved by the WMA or local authority. Installation should proceed from upstream to downstream during low flow conditions. Additionally, all excavated material should be deposited and stabilized in an approved area outside the 100-year floodplain unless otherwise authorized by the WMA or local authority.

A culvert pipe with a temporary access road should be constructed as follows (refer to Detail 1.3):

1. Culverts should have a minimum capacity sufficient to convey the stream's base flow for projects with duration of 2 weeks or less. For projects of longer duration, culverts should have a capacity sufficient to convey the 2-year flow.

2. Sandbag or stone flow barriers should be sized and installed as detailed in MGWC 1.5: Sandbag/Stone Channel Diversion. The materials should be sized to withstand normal streamflow velocities.

3. All sediment laden flow from the construction site should be pumped to a dewatering basin built according to MGWC 1.1: Dewatering Basins prior to re-entering the stream.

4. Temporary culvert crossings should be constructed in accordance with the *1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control* (refer to *Section 4, Stream Crossings, Maryland's Guidelines to Waterway Construction*).

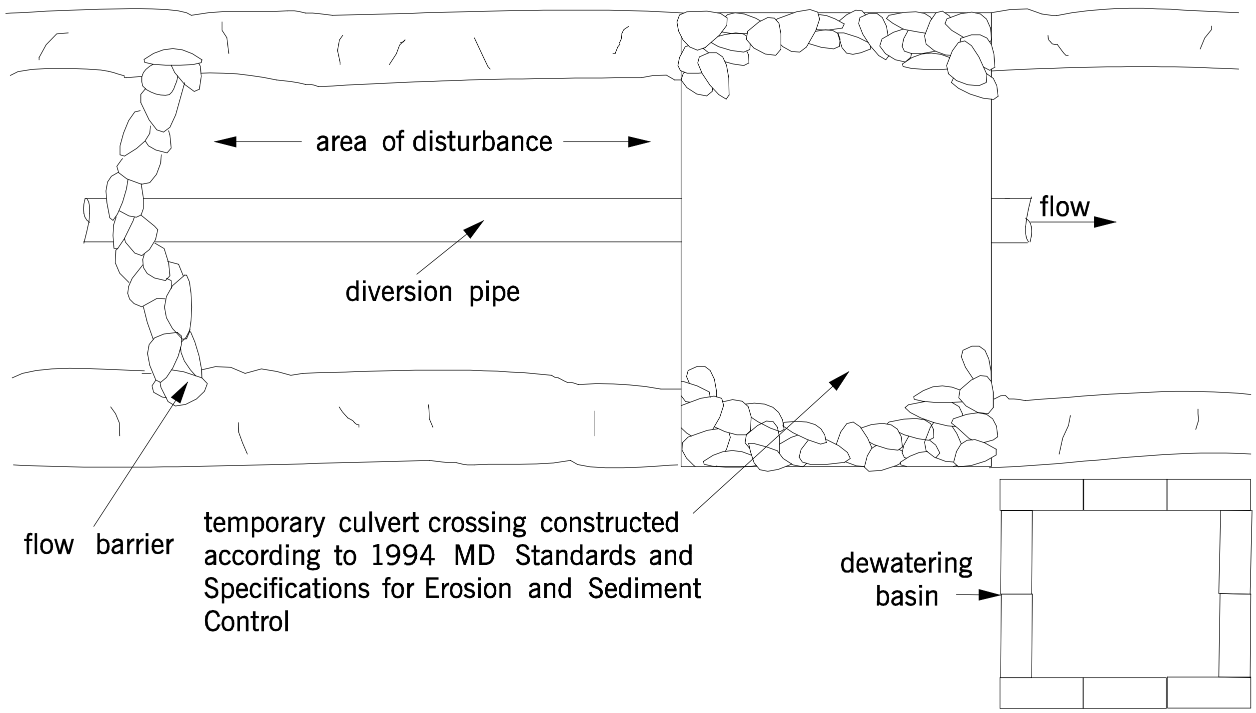
5. Velocity dissipation measures should be provided at the outfall to prevent aggravated erosion of the stream channel. If riprap is utilized, it should be sized according to MGWC 2.1: Riprap.

6. Sediment control devices should remain in place until all disturbed areas have been stabilized in accordance with an approved sediment and erosion control plan and the inspecting authority approves their removal.

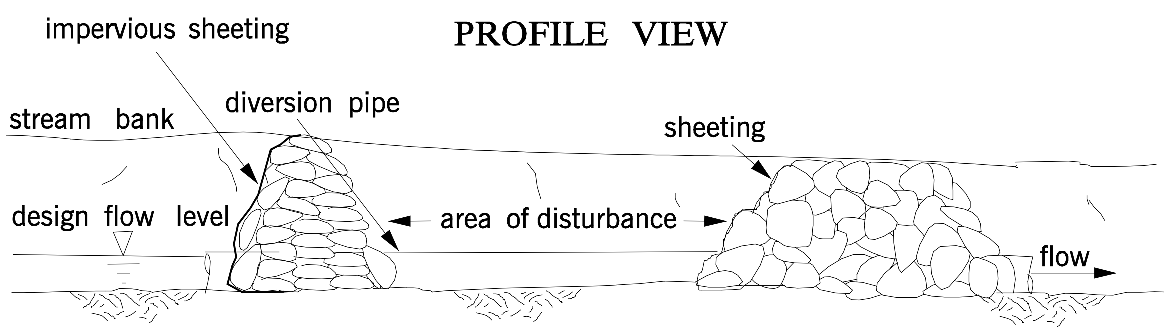
Maryland's Guidelines To Waterway Construction

DETAIL 1.3: CULVERT PIPE W/ACCESS ROAD

PLAN VIEW



PROFILE VIEW



MGWC 1.4: DIVERSION PIPE

Temporary measure for dewatering in-channel construction sites

DESCRIPTION

The work should consist of installing flow diversion pipes in combination with sandbag or stone diversions when construction activities occur within the stream channel.

EFFECTIVE USES & LIMITATIONS

Diversion pipes with an insufficient flow capacity can cause the channel diversion to fail thereby resulting in severe erosion of the disturbed channel section under construction. Therefore, in-channel construction activities should occur only during periods of low flow.

MATERIAL SPECIFICATIONS

Materials for stream diversions should meet the following requirements:

- *Riprap*: Stone should be washed and have a minimum diameter of 6 inches (15 centimeters).
- *Sandbags*: Sandbags should consist of materials which are resistant to ultra-violet radiation, tearing, and puncture and should be woven tightly enough to prevent leakage of fill material (i.e., sand, fine gravel, etc.).
- *Sheeting*: Sheeting should consist of polyethylene or other material which is impervious and resistant to puncture and tearing.

INSTALLATION GUIDELINES

All erosion and sediment control devices including mandatory dewatering basins should be installed as the first order of business according to a plan approved by the WMA or local authority. Installation should proceed from upstream to downstream during low flow conditions. If necessary, silt fence or straw bales should be installed around the perimeter of the work area.

Diversion pipes with sandbag or stone barriers should be completed as follows (refer to Detail 1.4):

1. Sandbag/stone barriers should be sized and installed as detailed in MGWC 1.5: Sandbag/Stone Diversion. The materials should be sized to withstand baseflow velocities.

2. All excavated material should be deposited and stabilized in an approved area outside the 100-year floodplain unless otherwise authorized by the WMA.

3. Sediment-laden water from the construction area should be pumped to a dewatering basin.

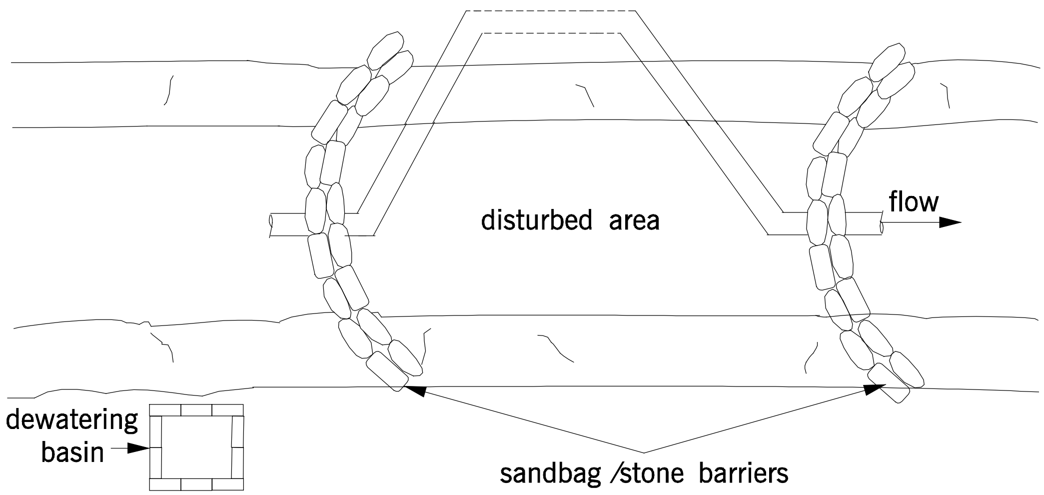
4. The diversion pipe should have a minimum capacity sufficient to convey the 2-year flow for projects with a duration of two weeks or greater. For projects of shorter duration, the capacity of the pipe can be reduced accordingly.

5. If necessary, silt fence or straw bales should be installed around the perimeter of the work area.

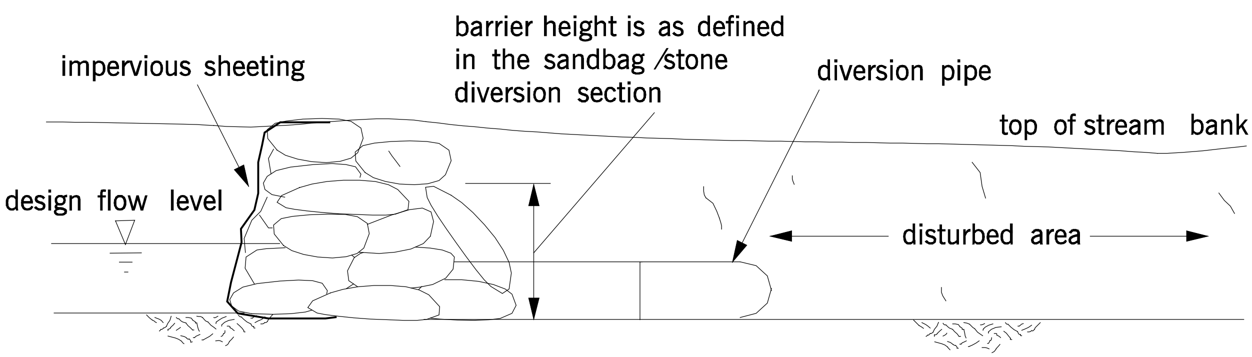
6. Sediment control devices are to remain in place until all disturbed areas are stabilized and the inspecting authority approves their removal.

DETAIL 1.4: DIVERSION PIPE

PLAN VIEW



LONGITUDINAL SECTION VIEW



MGWC 1.5: SANDBAG/STONE CHANNEL DIVERSION

Temporary measure for dewatering in-channel construction sites

DESCRIPTION

The work should consist of installing sandbag or stone flow diversions for the purpose of erosion control when construction activities occur within the stream channel.

EFFECTIVE USES & LIMITATIONS

Diversions are used to isolate work areas from flow during the construction of in-stream projects. Diversions which have an insufficient flow capacity can fail and severely erode the disturbed channel section under construction. Therefore, in-channel construction activities should occur only during periods of low rainfall. This temporary measure may not be practical in large channels.

MATERIAL SPECIFICATIONS

Materials for sandbag and stone stream diversions should meet the following requirements:

- *Riprap*: Riprap should be washed and have a minimum diameter of 6 inches (0.15 meters).
- *Sandbags*: Sandbags should consist of materials which are resistant to ultra-violet radiation, tearing, and puncture and should be woven tightly enough to prevent leakage of the fill material (i.e., sand, fine gravel, etc.).
- *Sheeting*: Sheeting should consist of polyethylene or other materials which are impervious and resistant to puncture and tearing.

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. Installation should proceed from upstream to downstream during periods of low flow. If necessary, silt fence or straw bales should be installed around the perimeter of the work area.

Sandbag/stone diversions can be used independently or as components of other stream diversion techniques. Installation of this measure should proceed as follows (refer to Detail 1.5):

1. The diversion structure should be installed from upstream to downstream.

2. The height of the sandbag/stone diversion should be a function of the duration of the project in the stream reach. For projects with a duration less than 2 weeks, the height of the diversion should be one half the streambank height, measured from the channel bed, plus 1 foot (0.3 meters) or bankfull height, whichever is greater. For projects of longer duration, the top of the sandbag or stone diversion should correspond to bankfull height. For diversion structures utilizing sandbags, the stream bed should be hand prepared prior to placement of the base layer of sandbags in order to ensure a water tight fit. Additionally, it may be necessary to prepare the bank in a similar fashion.

3. All excavated material should be deposited and stabilized in an approved area outside the 100-year floodplain unless otherwise authorized by the WMA.

4. Sediment-laden water from the construction area should be pumped to a dewatering basin.

5. Sheeting on the diversion should be positioned such that the upstream portion covers the downstream portion with at least a 18-inch (0.45 meters) overlap.

6. Sandbag or stone diversions should not obstruct more than 45% of the stream width. Additionally, bank stabilization measures should be placed in the constricted section if accelerated erosion and bank scour are observed during the construction time or if project time is expected to last more than 2 weeks.

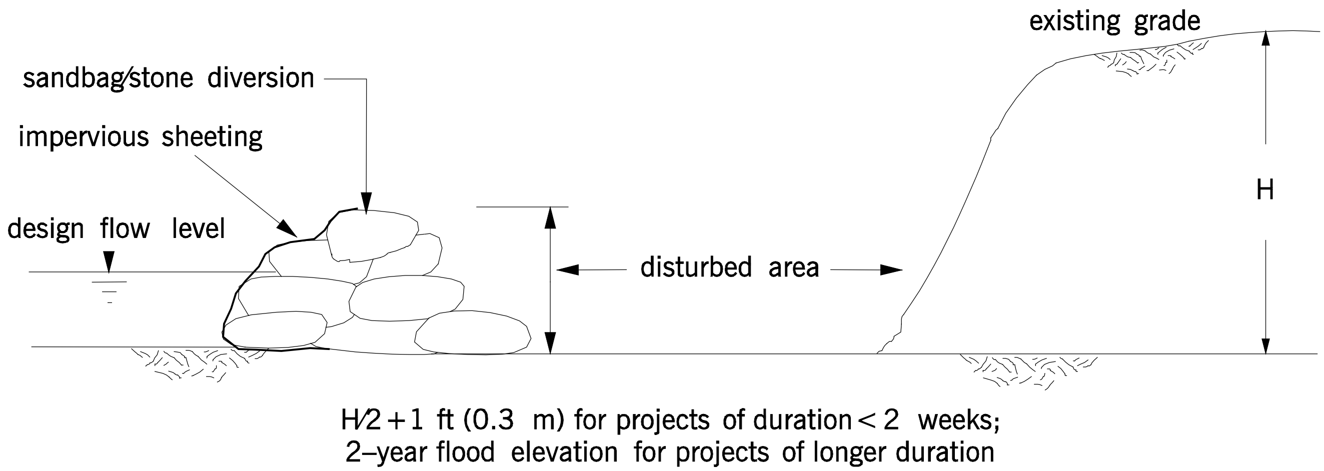
7. Prior to removal of these temporary structures, any accumulated sediment should be removed, deposited and stabilized in an approved area outside the 100-year floodplain unless authorized by the WMA.

8. Sediment control devices are to remain in place until all disturbed areas are stabilized in accordance with an approved sediment and erosion control plan and the inspecting authority approves their removal.

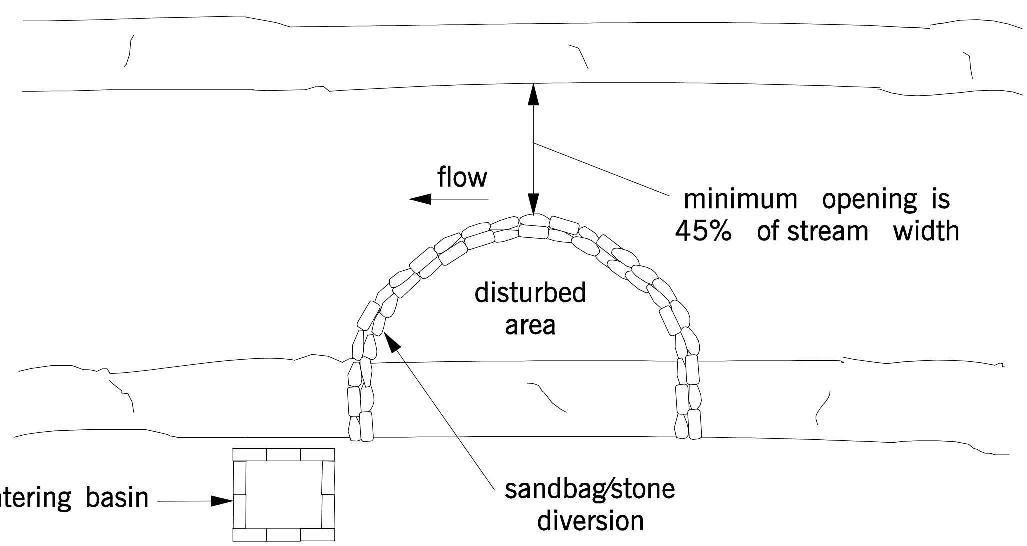
Maryland's Guidelines To Waterway Construction

DETAIL 1.5: SANDBAG/STONE DIVERSION

TRANSVERSE SECTION VIEW



PLAN VIEW



MGWC 1.6: FABRIC-BASED CHANNEL DIVERSION

Temporary measure for dewatering in-channel construction sites

DESCRIPTION

The work should consist of installing fabric-based diversion channels for the purpose of erosion control when construction activities occur within the stream channel.

EFFECTIVE USES & LIMITATIONS

Diversions are used to divert flow during construction of in-stream projects. Diversions which have an insufficient flow capacity can fail and severely erode the disturbed channel section under construction. Therefore, in-channel construction activities should occur only during periods of low rainfall.

MATERIAL SPECIFICATIONS

Materials for fabric-based channel diversions should meet the following requirements:

- *Riprap*: Class I riprap should be used with fabric-based channel diversions.
- *Filter Cloth*: Filter cloth should be a woven or non-woven fabric consisting only of continuous chain polymeric filaments or yarns of polyester. The fabric should be inert to commonly encountered chemicals, hydro-carbons, and mildew and should be rot resistant.
- *Anchor Pins*: Hold down pins should have a minimum length of 18 inches (0.45 meters), and accompanying washers should have a minimum diameter of 1 inch (2.5 centimeters).
- *Sandbags*: Sandbags should consist of materials which are resistant to ultra-violet radiation, tearing, and puncture and should be woven tightly enough to prevent leakage of fill material (i.e., sand, fine gravel, etc.).
- *Sheeting*: Sheeting should consist of polyethylene or other material which is impervious and resistant to puncture and tearing.

INSTALLATION GUIDELINES

All erosion and sediment control devices, including mandatory dewatering basins, should be installed as the first order of business according to a plan approved by the WMA or local authority. Installation should proceed from upstream to downstream during periods of low flow.

Construction of fabric-based channel diversions involves channel excavation, placement of geotextile fabric, and installation of flow diverters for both the main channel and all tributaries contributing flow to the work area (refer to Detail 1.6).

Channel Excavation

1. All disturbances resulting from construction of the channel should be contained by appropriate sediment control measures.

2. Excavation of the channel should begin at the downstream end and proceed upstream. The channel should have a minimum capacity sufficient to convey the stream's base flow for projects with duration of 2 weeks or less. For projects of longer duration, channels should have a capacity sufficient to convey bankfull flow. All excavated materials should be stockpiled outside of the 100 year flood plain and temporarily stabilized to

prevent re-entry into the stream channel.

3. The process of excavation and stabilization with fabric should be a continuous and uninterrupted operation. All materials should be on-site prior to channel construction.

4. The downstream and upstream connection to the natural channel should be constructed under dry conditions. The stream should be contained by sandbags along the opposing bank during the process of cutting the diversion channel into the natural stream channel. Excavation and stabilization should be a continuous and uninterrupted operation.

5. All debris such as rocks, sticks, etc. should be removed and the channel surfaces made smooth so that the fabric will rest flush with the channel at all sides and bottom.

Stabilization with Geotextile Fabric

1. The fabric should have a minimum width such that it is keyed in and anchored at the top of stream bank.

2. Fabric should be placed so that it rests flush with the channel at all points of contact.

3. Fabric should be placed such that one piece will line the entire channel. If this is not possible, fabric should be placed so that transverse overlapping occurs in accordance with the detail. Longitudinal overlaps should not be allowed. Upstream sections should overlap downstream sections. Overlap width should equal 2 feet (0.6 meters) minimum.

4. The fabric should be keyed into 2 by 2-foot (0.6 by 0.6-meter) trenches located at the upstream edge and at 50-foot (15.25-meter) intervals with the overlap placed nearest to each 50 feet increment. The key-in should be from top of channel to top of channel. Class I riprap should be carefully placed into the trench with zero drop height.

5. The fabric sections should be secured with hold down pins and washers. Overlaps should be pinned along transverse and longitudinal axes with spacing equal to 3 feet (0.9 meters) maximum.

6. Sediment from surrounding areas of disturbance should not be allowed to enter the diversion channel.

Alternate Methods of Placing the Fabric

1. The above design may be modified to allow sewing of the geotextile fabric. Sewing of the geotextile fabric, rather than overlapping, should eliminate the requirement for transverse placement of the fabric. Either transverse or longitudinal placement should work equally well.

2. The spacing of the pins could be either larger or smaller depending on the anticipated velocities and thickness and type of geotextile fabric.

3. The entire bottom of the channel could be riprapped if high velocities are anticipated. When the area is riprapped, it is not required that the geotextile fabric underneath the riprap be pinned.

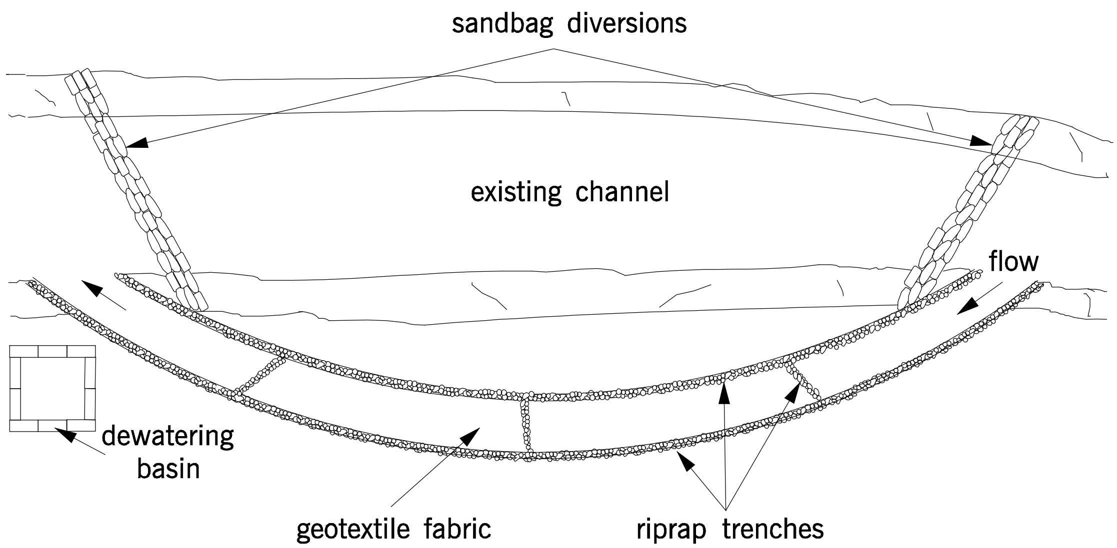
Removal of Diversion

1. Water should not be allowed through the natural stream until all construction is completed.

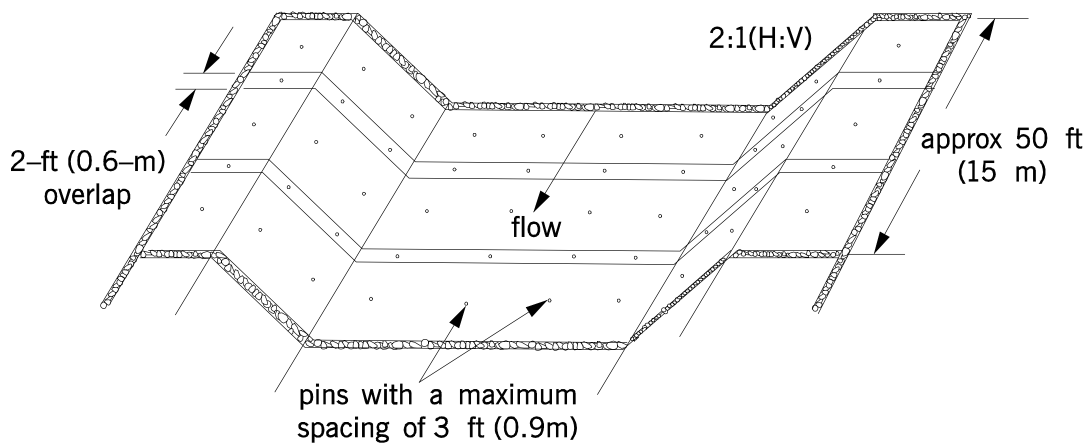
2. After redirecting the flow through the natural channel, all fabric should be removed from the temporary diversion. The diversion should then be backfilled and stabilized. Points of tie-in to the natural channel should be protected with riprap according to the riprap guidelines.

DETAIL 1.6: FABRIC–BASED DIVERSION

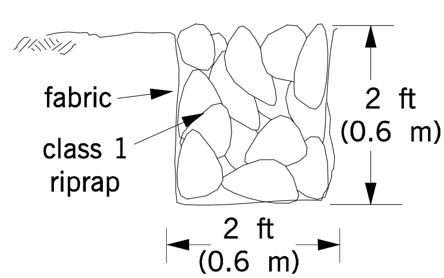
PLAN VIEW



SECTION VIEW



TRENCHING DETAIL



SECTION 2

SLOPE PROTECTION & STABILIZATION TECHNIQUES

MGWC 2.1: RIPRAP

Rigid engineering technique for bank stabilization

DESCRIPTION

Riprap is used to protect and stabilize embankment soils from the erosive forces of flowing water and piping forces resulting from groundwater seepage. A well-engineered riprap system should consist of the following:

- a filter layer of gravel or cloth designed to prevent soil movement into or through the riprap layer while allowing water to drain from the embankment, and
- a stone layer of appropriate gradation and thickness to resist the shearing forces of channelized water.

EFFECTIVE USES & LIMITATIONS

When properly designed and installed, riprap is an effective method where soil conditions, water turbulence and velocity, expected vegetative cover, and groundwater conditions are such that the soil may erode under the design flow conditions. Some common areas of riprap applicability are:

- diversion channel banks and/or bottoms,
- roadside ditches,
- drop structure outlets, and
- laterally expanding banks threatening infrastructure or personal property.

Additionally, properly graded riprap forms a flexible, self-healing cover which can be easily repaired in localized areas by the timely replacement of stone. Uniform-grade riprap can also be used with a geotextile filter cloth.

Filter cloth should only be utilized when the bank material is noncohesive such as sand or gravel.

MATERIAL SPECIFICATIONS

- *Filters:* Material and design specifications for granular filters are found in Table 3.1a.

Table 3.1a: Granular Filter Material Grading Specifications

% less than	U.S. Standard sieve size
100	2 ½ in (64 mm)
85-100	1 in (25 mm)
60-100	½ in (13 mm)
35-70	No. 10
20-50	No. 40
3-20	No. 200

The thickness of the filter should not be less than 6 inches (15 cm). Generally, filters that are one-half the thickness of the riprap layer are satisfactory.

Synthetic filter cloth may be used cautiously based on the *1994 MD Standards and Specifications for Soil Erosion and Sediment Control*.

- *Riprap:* The maximum diameter or weight of stone for riprap should be based upon the design flow velocity using Figure 3.1. This chart is based on a maximum slope of 2H:1V. The stone gradations for Classes I - III are found in Table 3.1b.

Table 3.1b: Stone Gradations for Riprap Stone Classes

Class	Size	% Total Weight < Given Size
I	150 lb (70 kg)	100
	2 lb (1 kg)	10 max
II	700 lb (320 kg)	100
	20 lb (10 kg)	10 max
III	2000 lb (910 kg)	100
	40 lb (20 kg)	10 max

Uniform-grade riprap should incorporate angular rock to promote interlocking.

Approximate Cost ($1999):
$78 per linear ft

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. Once a slope stabilization project is initiated, preparation and placement of the riprap should immediately follow the initial disturbance to minimize the chances for further slope degradation. The recommended construction procedure for riprap is as follows beginning with initial slope preparations (refer to Detail 2.1):

1. The contractor should install all sediment and erosion control devices as the first order of business.

2. Excavation should be made in reasonably close conformity with the existing stream slope and bed.

3. All fill in the subgrade should be compacted to a density approximating that of the surrounding undisturbed material.

4. Provisions must be made to anchor the riprap at the stream bed so as to provide protection against undermining. If this cannot be accomplished by creating a toe trench, an alternative method of protection must receive prior written approval from the WMA or local authority.

5. The filter layer or blanket should be placed immediately after slope preparation.
   - The stone for granular filters should be spread in a uniform layer to the specified depth. Where more than one layer is employed, they should be spread such that there is minimal mixing.
   - When cloth filters are used, special care should be taken not to damage the fabric during riprap placement.

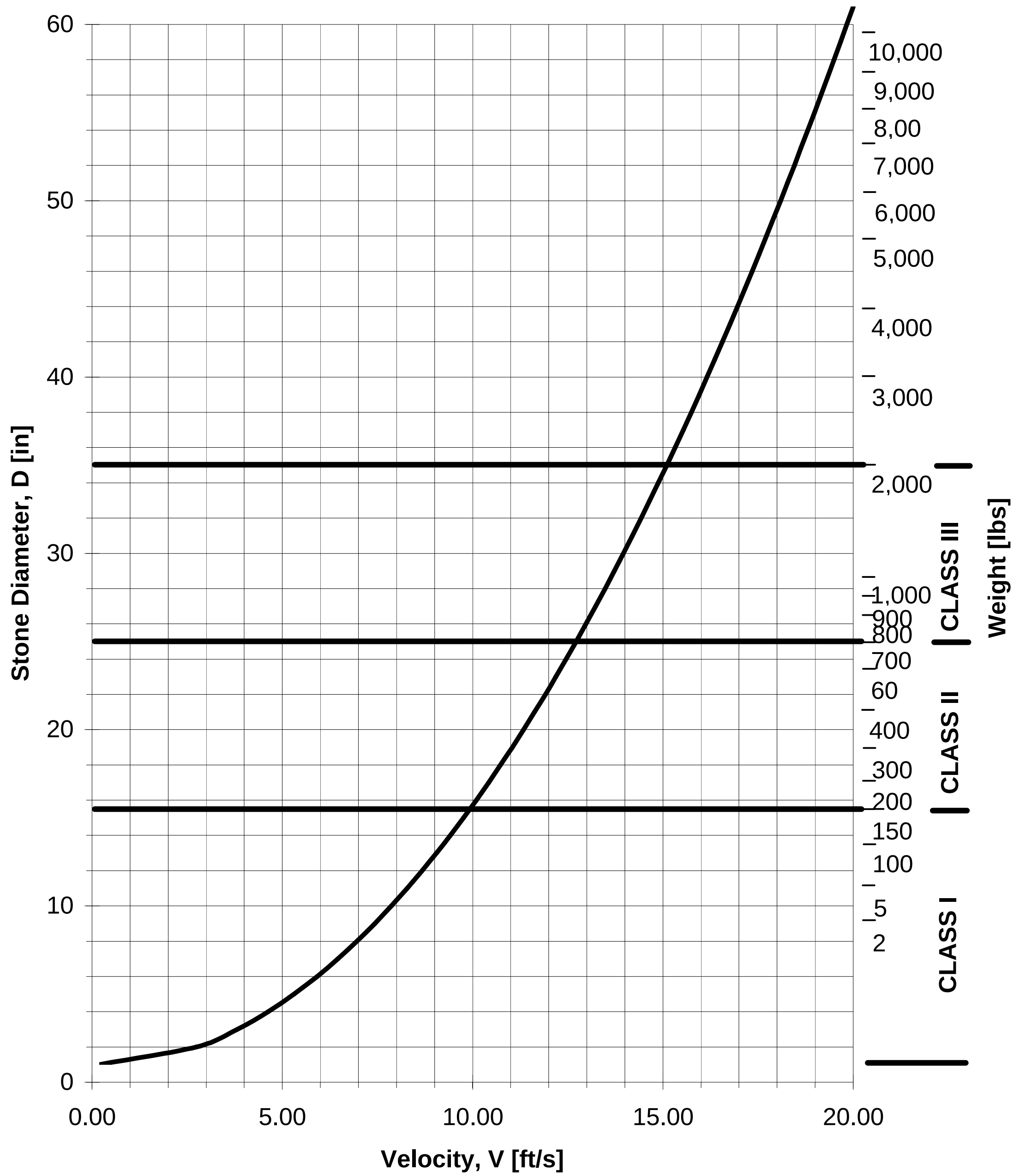
6. Riprap placement should begin with the toe. The larger stones, as specified by the design gradation, should be placed in the toe and along the perimeter of the slope and channel protection. The riprap should be placed with suitable equipment in such a manner as to produce a reasonably graded mass of stones with zero drop height. The placing of stones that cause extensive segregation is not allowed. Where appropriate, a low flow channel shall be constructed through the riprap.

7. Any excavation voids existing along the edges of the completed slope and channel protection should be backfilled and compacted.

8. All disturbed areas should be permanently stabilized in accordance with an approved sediment and erosion control plan.

***Note**: The use of rock vanes (MGWC 3.3: Rock Vanes) should be considered to redirect high-velocity flows at the toe.*

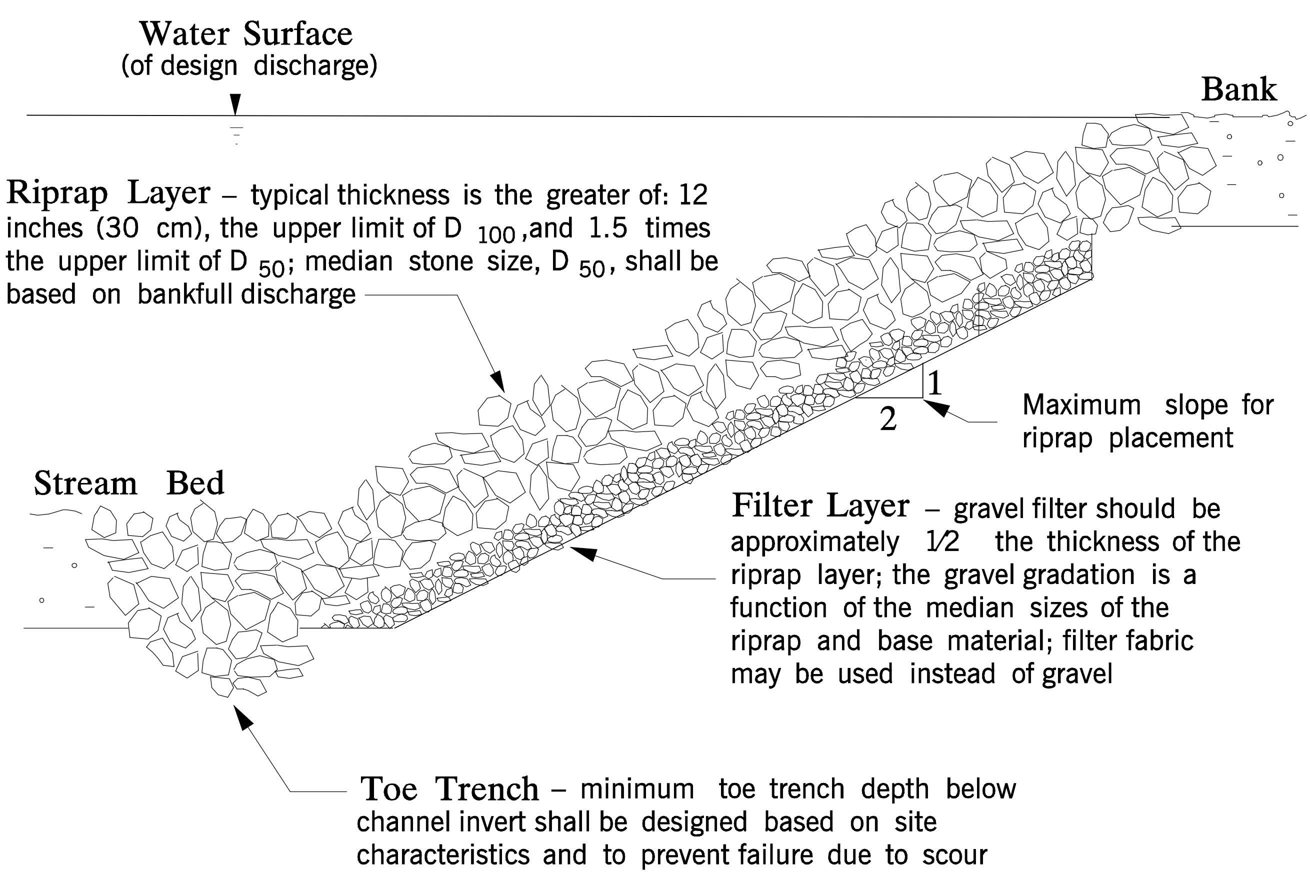
FIGURE 2.1: RIPRAP DIAMETER AS A FUNCTION OF STREAM VELOCITY (BASED ON ISHBASH EQUATION)



Maryland's Guidelines To Waterway Construction

DETAIL 2.1: RIPRAP

SECTION VIEW



MGWC 2.2: IMBRICATED RIPRAP

Rigid engineering technique for bank stabilization

DESCRIPTION

Imbricated riprap is used to protect and stabilize embankment soils from the erosive forces of flowing water and piping forces resulting from groundwater seepage. A well-engineered imbricated riprap revetment should consist of the following:

- a filter layer of gravel or cloth designed to prevent soil movement into or through the riprap layer while allowing water to drain from the embankment, and
- a stone wall of appropriate size and positioning to resist the shearing forces of channelized water and the lateral earth pressures of the enveloped bank.

EFFECTIVE USES & LIMITATIONS

When properly designed and installed, imbricated riprap revetments resist lateral earth pressures to some extent and can be an effective method of bank armoring where soil conditions, water turbulence and velocity, expected vegetative cover, and groundwater conditions are such that the soil may erode under the design flow conditions and threaten infrastructure or personal property.

Filter cloth should only be utilized when the bank material is a noncohesive material such as sand or gravel.

MATERIAL SPECIFICATIONS

Materials for imbricated riprap construction and installation should meet the following requirements:

- *Filters*: Synthetic filter fabric may be used cautiously based on the *1994 MD Standards and Specifications for Soil Erosion and Sediment Control*. Whenever possible, however, granular filters with a minimum thickness of 6 inches (15 cm) should be used with a gradation as found in Table 2.2.

Table 2.2: Granular Filter Material Grading Specifications

Percent Less Than	U.S. Standard Sieve Size
100	2 1/2 in (64 mm)
85 - 100	1 in (25 mm)
60 - 100	1/2 in (13 mm)
35 - 70	No. 10
20 - 50	No. 40
3 - 20	No. 200

- *Toe Riprap*: The maximum diameter or weight of stone for toe riprap should be based upon the bankfull stream channel velocity as detailed in the MGWC 2.1: Riprap and Figure 2.1.

- *Imbricated Stones*: Imbricated riprap should be angular and blocky in shape such that they are stackable and should be sufficiently large to resist displacement by both the design storm event and the site-specific lateral earth stresses. Therefore, the length of the longest axis of each stone should be the greater of 1/3 the height of the proposed wall and the size necessary to resist the design stream flow according to MGWC 2.1: Riprap. A typical minimum axis length is 24 inches (0.6 meters).

MGWC 2.2: IMBRICATED RIPRAP

Approximate Cost ($1999):
$90 per linear ft

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. The recommended construction procedure for imbricated riprap is as follows (refer to Detail 2.2):

1. The stream should be diverted according to a WMA recommended procedure (see *Section 1*, *Temporary Instream Construction Measures, Maryland's Guidelines to Waterway Construction*), and the construction area should be dewatered.

2. All excavation should be made in reasonably close conformity with the existing stream slope and bed. The slope of the cut face should be in the range of 1H:6V to 2H:6V. Loose material at the toe of the embankment should be excavated until a stable foundation is reached, usually within 2 to 3 feet (0.6 to 0.9 meters) of the surface. The subgrade should be smooth, firm, and free from protruding objects or voids that would effect the proper positioning of the first layer of stones.

3. A graded granular filter or filter fabric should be placed on the face of the cut slope to prevent the migration of fine materials through the revetment. If filter fabric is used, it should be carefully and loosely placed on the prepared slope and secured. Adjacent strips should overlap a minimum of 8 inches (0.20 meters). If the filter fabric is torn or damaged, it should be repaired or replaced.

4. The rock layers should be neatly stacked with staggered joints so that each stone rests firmly on two stones in the tier below. Additionally, smaller stones should be used to fill voids so that each rock rests solidly on the previous rock layer with minimal opportunity for movement. Upon completion of the first layer of stone, the toe trench should be filled with Class III riprap sized according to MGWC 2.1: Riprap or additional imbricated stone. Two footer stones should be used where high potential for channel incision exists. The height of the imbricated revetment is dictated by the size of the stone used, and the height should not exceed 3 times the length of the longest axis and should not be greater than 10 feet (3 meters).

5. Placement of the granular backfill should occur concurrently with the stone placement. The backfill slope angle should be 2H:1V or flatter but should be greater than 0 degrees to facilitate drainage. Once all of the backfill is in place, it should be covered with a filter layer and a layer of topsoil sufficient to support a native vegetative cover.

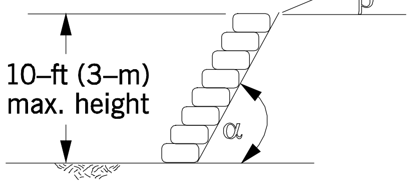
6. The disturbed sections of the channel, including the slopes and stream bed, should be stabilized with methods approved by the WMA.

Note: The use of rock vanes (MGWC 3.3: Rock Vanes) should be considered to dissipate excessive toe velocities.

Maryland's Guidelines To Waterway Construction

DETAIL 2.2: IMBRICATED RIPRAP

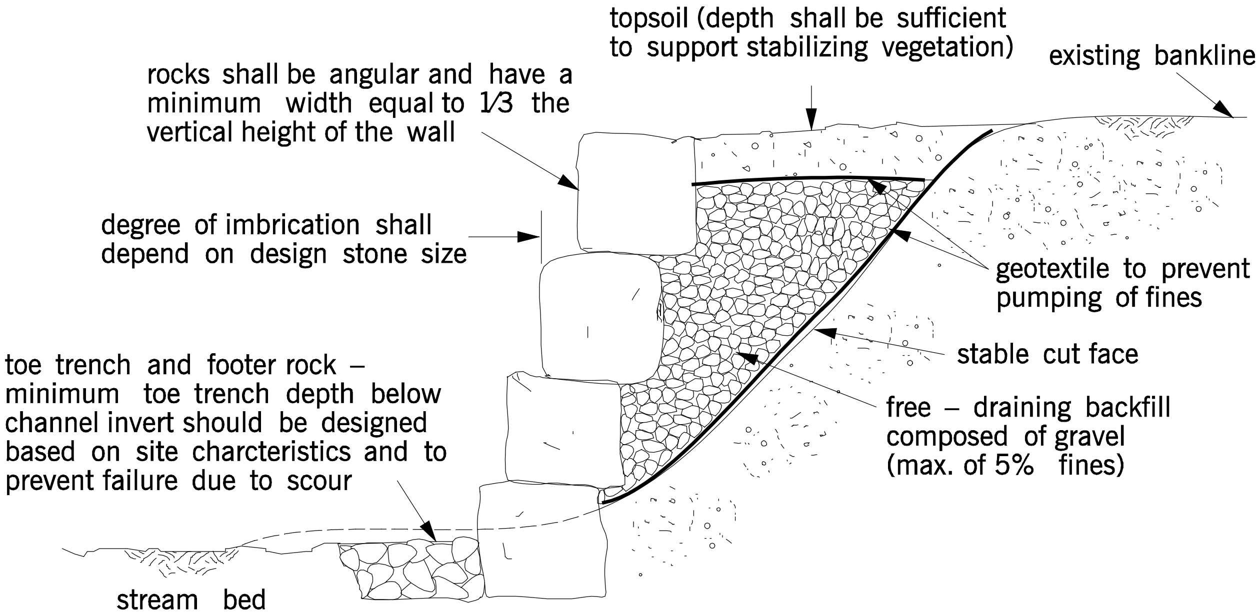
DEFINITION SKETCH



β = backfill slope angle (2H:1V or flatter but greater than 0°)

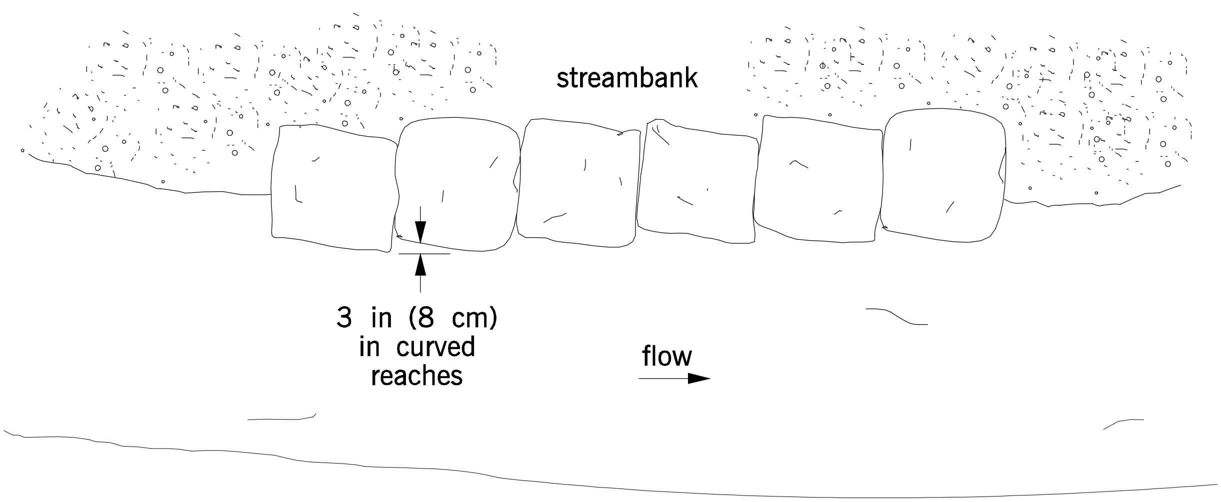
α = inclination of wall from horizontal (1H:6V to 2H:6V)

SECTION VIEW



PLAN VIEW

Construction Note: stone blocks shall be rotated into the bank during placement such that the upstream blocks overlap the downstream blocks by a minimum of 3 inches (8 cm)



MGWC 2.3: GABIONS

Rigid engineering technique for bank stabilization

DESCRIPTION

The work should consist of protecting streambanks against erosive currents with stone-filled wire baskets.

EFFECTIVE USES & LIMITATIONS

Gabion revetments should be used cautiously in high velocity streams (i.e. Rosgen stream types A1-A6, refer to Table 3). Additionally, the use of gabion baskets should be limited to areas outside of the base flow channel.

MATERIAL SPECIFICATIONS

Materials for gabion basket construction and installation should meet the following requirements:

- *Filter Fabric*: synthetic filter cloth may be used cautiously based on *the 1994 MD Standards and Specifications for Soil Erosion and Sediment Control*.
- *Stones*: acceptable stone diameters should be a function of the basket thickness as given below.
- *Gabion Basket*: wire used to form gabion basket should be PVC coated to prevent corrosion

Table 2.3: Suggested Stone Diameters for Design Basket Thickness

Basket Thickness	Stone Diameter
6 in (150 mm)	3-5 in (80-130 mm)
9 in (225 mm)	4-7 in (100-180 mm)
12 in (300 mm)	4-7 in (100-180 mm)
18 in (460 mm)	4-7 in (100-180 mm)
36 in (910 mm)	4-12 in (100-300 mm)

Approximate Cost ($1999):
$90 per linear foot

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA. Refer to *Maryland's 1994 Standards and Specifications for Soil Erosion and Sediment Control*. The recommended construction procedure for gabions is as follows (refer to Detail 2.3):

1. The stream should be diverted according to a WMA recommended measure, and the construction area should be dewatered during placement of the gabion revetment's foundation (See *Section 1: Temporary Instream Construction Measures, Maryland's Guidelines to Waterway Construction*).

2. Excavation, including cutoff walls and a stable foundation, should be made in reasonably close conformity with the existing stream slope such that the placed baskets prevent undermining from water flow and overturning from lateral earth pressure. The foundation should accommodate the placement of at least one layer of gabion baskets below the channel invert elevation. The subgrade should be smooth, firm, and free from protruding

objects or voids that would effect the proper positioning of the wire baskets or damage the filter cloth.

3. Filter fabric should be carefully and loosely placed on the prepared subgrade and secured. Adjacent strips should overlap a minimum of 8 inches (0.20 meters). To avoid damaging the filter cloth, care should be exercised in placing, stretching, and holding the empty basket units in good alignment. If the filter fabric is torn or damaged, it should be repaired or replaced.

4. Placement of the wire basket units should begin with the cutoff walls. The empty wire baskets should be set on the prepared subgrade and filter fabric, and the vertical ends should be bound together with wire ties at a spacing that is adequate to permit stretching of the units for installation purposes. Stakes, pins, or other acceptable methods should be used to insure a good alignment of the empty wire basket units. Tiebacks may be required to guard against rotational overturning of the streambank.

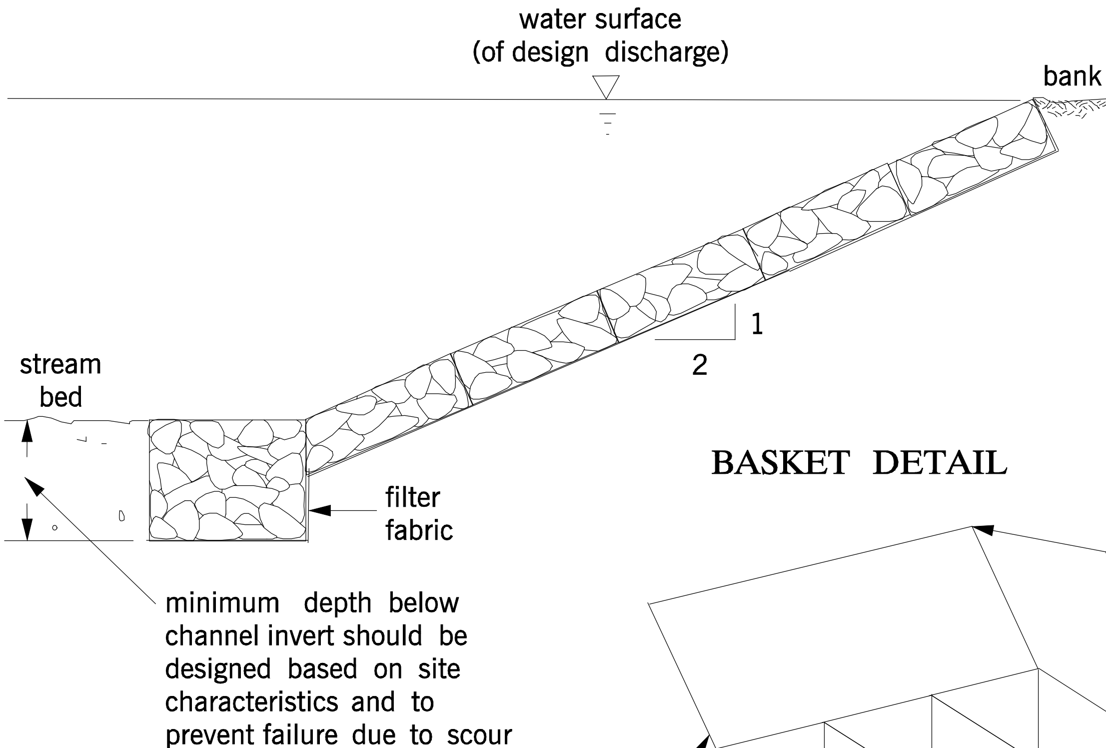
5. The empty baskets should be filled carefully with stone placed by hand or machine, in a minimum of two courses, to assure good alignment with a minimum of voids between stones and to avoid bulging of the mesh. The maximum height from which the stone may be dropped into the wire mesh should be 3 feet (1 meter). Care should be taken in placing the top layer of stone to assure a uniform surface thus avoiding any bulging of the lid mesh. After a basket unit has been filled, its lid should be bent over until it meets the end of the unit. The lid should then be secured to the sides and ends with wire ties. When a complete basket unit cannot be installed on slopes or channels because of space limitations, the basket unit should be cut to fit in a manner approved by the WMA.

6. All excavation voids existing along the edges of the completed gabions should be backfilled and permanently stabilized in accordance with an approved sediment and erosion control plan.

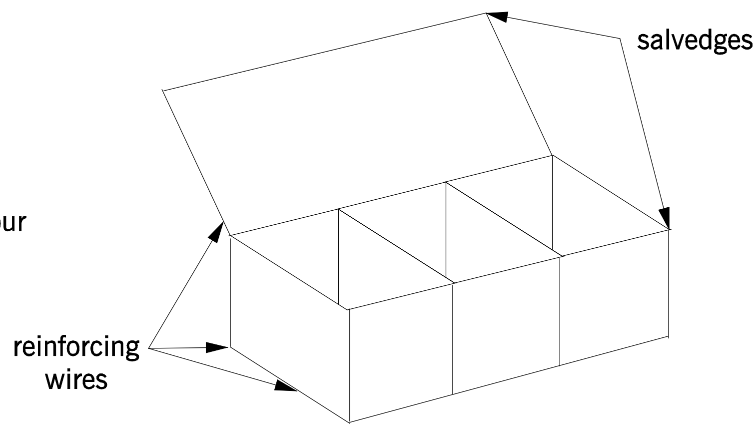
Maryland's Guidelines To Waterway Construction

DETAIL 2.3: GABIONS

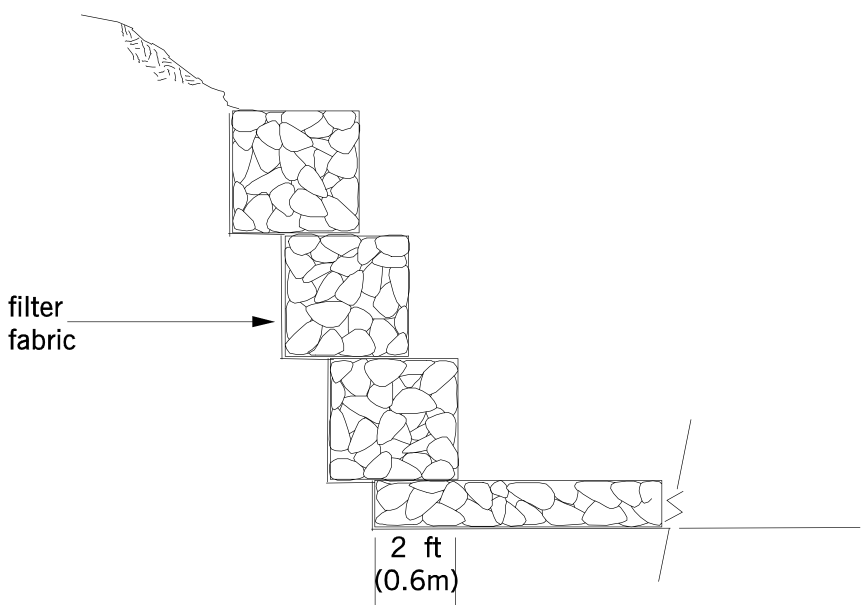
SECTION VIEW



BASKET DETAIL



ALTERNATE SECTION



MGWC 2.4: LIVE STAKES

Rigid engineering technique for bank stabilization

DESCRIPTION

The work should consist of inserting live, woody, rootable plant cuttings into streambanks and encouraging their growth. When properly utilized, the binding root mass of the mature shrubs and/or trees will ultimately stabilize and reinforce the soil.

EFFECTIVE USES & LIMITATIONS

Live staking is an economical method when local supplies of woody cuttings are readily available since the implementation of this measure requires minimal labor. When utilized effectively, live stakes can:

- act to trap soil particles in sediment laden water resulting from the erosion of adjacent land;
- slow water velocities, trap sediment, and control erosion when organized in clustered arrays along the sides of gullies;
- repair small earth slips and slumps which are frequently wet;
- help control shallow mass movement when placed in rows across slopes; and
- promote bank stabilization, especially when used in conjunction with one of the following Rosgen stream types: B3, B4, B5, B6, C1, C2, C3, C4, C5, C6, DA, E3, E4, E5, and E6.

Live staking is a *preventative* measure and should be employed before severe erosion problems occur. Additionally, in order to be effective, live stakes should be:

- planted only on streams with low to moderate flow fluctuations,
- established in the original bank soil on moderate slopes of 4:1(h:v) or less,
- planted where appropriate lighting exists, and
- used jointly with other restoration techniques especially on slopes with high erosion rates and incidents of mass wasting

MATERIAL SPECIFICATIONS

When choosing and preparing woody material for live stakes, the following guidelines should be followed:

- Live stakes should be cut from fresh, green, healthy, dormant parent plants which are adapted to the site conditions whenever possible. Commonly used woody plants for this measure include willow, poplar, and alder since they are versatile and have high growth rates with shrubby habits, fibrous root systems, and high transpiration rates, especially when in leaf. A partial listing of woody plants recommended by the United States Department of Agriculture's Soil Conservation Service is presented in Table 2.4.

- Live stakes should have a diameter between 0.75 and 1.5 inches (2 to 4 centimeters) and should be long enough to reach below the groundwater table so that a strong root system can quickly develop. At least 1 foot (0.3 meters) should be exposed to sunlight. Live woody posts with diameters up to 10 inches (0.25 meters) and lengths ranging from 4 to 6 feet (1.2 to 1.8 meters) may also be used at the discretion of the project manager.

- Live stakes should be kept covered and moist at all times and should be placed in cold storage if more than a few hours elapse between the cutting and replanting times

MGWC 2.4: LIVE STAKES

Approximate Cost ($1999):
$1 to $4 per stake

INSTALLATION GUIDELINES

Live stake installation should proceed as follows (refer to Detail 2.4):

1. Live stake rooting areas should be soaked in barrels of water for 24 to 48 hours just prior to installation.

2. While keeping the bark of the live stakes intact, the side branches should be cleanly removed, the basal ends angled for easy insertion, and the tops cut square.

3. The cuttings should be implanted with the angled basal end down and buds oriented up at a minimum angle of 10 degrees to the horizontal so that rooting will not be restricted. All stakes should be positioned above the normal baseflow level. Project planners may need to study an aptly chosen vegetated reference reach for further guidance when installing live stakes.

   - In soft soils, the stakes can be inserted perpendicularly into the slope using a dead blow hammer; in hard soils, however, a steel rod should be employed to create a pilot hole before the stakes are planted.
   - Twenty percent of the live stake, and a minimum of two lateral buds, should be exposed above the slope so that green, leafy shoots will readily grow.
   - Split or otherwise damaged stakes should be discarded.

4. After the stakes have been inserted into the ground, soil should be tamped firmly around their bases to encourage root growth.

5. Successive stakes should be arranged in a triangular configuration and spaced a distance of 2 to 3 feet (0.6 to 0.9 meters) apart, allowing for a typical density of 2 to 4 cuttings per square yard (0.8 square meters). Willow posts require additional room for growth and propagation and should be planted at 3 to 5-foot (1 to 1.5-meter) intervals. When inserted in arrays, the stakes should be spaced 12 to 18 inches (30 to 46 centimeters) apart to form chevron-like rows that point downstream.

6. Unstable slope toes should be reinforced against scouring and undercutting using live fascines or rock fill to give the live stakes the best opportunity to root and grow.

MGWC 2.4: LIVE STAKES

Table 2.4: Soil bioengineering plant species (Adapted From USDA-SCS, 1992)

Common Name/ Scientific Name	Location	Availability	Habitat Value	Size/Form	Root Type	Rooting Ability from Cuttings
Eastern baccharis *baccharis halimifolia*	S, SE	common	very poor	small-med. shrub	fibrous	fair-good
Silky dogwood *cornus amomum*	N, SE	very common	very good	small shrub	shallow/ fibrous	very good
Gray dogwood *cornus racemosa*	NE	common	very good	med.-small shrub	shallow	good
Roundleaf dogwood* *cornus rugosa*	NE	common	very good	med.-small shrub	shallow/ fibrous	fair-good
Red osier dogwood *cornus sericea ssp. stolonifera*	N, NE, W	very common	very good	med.-small shrub	shallow	very good
Hawthorn *crataegus sp.*	SE	uncommon	good	small dense tree	top root	fair
Chinese privet* *ligustrum sinense*	S, SE	common	fair-good	small-med. shrub	shallow/ fibrous	good
Black twinberry* *lonicera involuerata*	E	common	poor-fair	small shrub	shallow	good
Common ninebark *physocarpus opulifolius*	NE	common	good	med.-high shrub	shallow/ lateral	fair-good
Eastern cottonwood *populus deltoides*	MW, E	very common	good	large tree	shallow	very good
Black locust *robinia pseudoacacia*	NE	common	very poor	tree	shallow	good
Allegheny blackberry *rubus allegheniensis*	NE	very common	very good	small shrub	fibrous	good
Red raspberry *rubus strigosus*	N, NE, W	very common	very good	small shrub	fibrous	good
Sandbar willow *ssp. interior*	N, SE	common	good	large shrub	shallow to deep	fair-good
Peachleaf willow* *salix amygdaloides*	N, S	common	good	very large shrub	shallow to deep	very good
Prairie willow *salix humilis*	N, NE	very common	good	medium shrub	fibrous	good

* This species is not native to Maryland. Use of non-native plantings may result in reduced natural biodiversity.

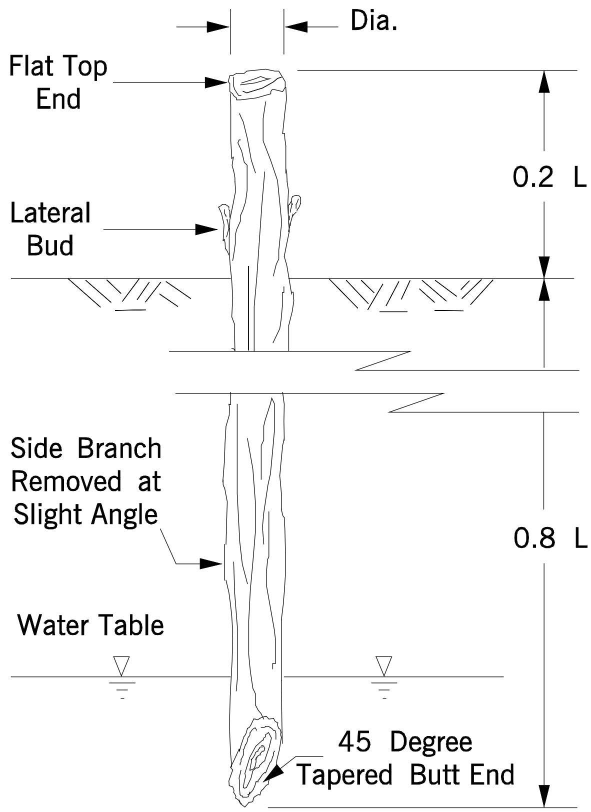
Table 2.4 (continued): Soil bioengineering plant species (Adapted From USDA-SCS, 1992)

Common Name/ Scientific Name	**Location**	**Availability**	**Habitat Value**	**Size/Form**	**Root Type**	**Rooting Ability from Cuttings**
Shining willow *salix lucida*	N, NE	very common	good	med.-large shrub	fibrous	very good
Black willow *salix nigra*	N, SE	very common	good	large shrub-small tree	shallow to deep	excellent
Streamco* *salix purpurea*	N, S, E, W	very common	very good	medium shrub	shallow	very good
Scoulers willow* *salix scouleriana*	NE	very common	good	large shrub-small tree	shallow	very good
Bankers willow* *salix x cotteti*	N, S, E, W	uncommon	good	small shrub	shallow	very good
Red willow *salix discolor*	N, NE	very common	good	large shrub	shallow	very good
American elderberry *sambucus canadensis*	NE, SE	very common	very good	medium shrub	fibrous	good
Scarlet elder* *ssp. pubens*	NE	common	very good	medium shrub	deep laterals	fair-good
Meadowsweet spirea *spiraea alba*	N, E	common	good	small dense tree	dense/ shallow lateral	fair-good
Hardhack spirea *spiraea tomentosa*	NE	common	good	small shrub	dense/ shallow	fair
Snowberry *symphoricarpos albus*	N, NW, E	common	good	small shrub	shallow/ fibrous	good
Hubbiebush viburnum *viburnum alnifolium*	NE	fairly common	good	large shrub	shallow/ fibrous	good
Arrowwood viburnum *viburnum dentatum*	E	common	good	medium shrub	shallow/ fibrous	good
Nannyberry viburnum *viburnum lentago*	S, SE	fairly common	good	large shrub	shallow	fair-good

* This species is not native to Maryland. Use of non-native plantings may result in reduced natural biodiversity.

Maryland's Guidelines To Waterway Construction

DETAIL 2.4: LIVE STAKES



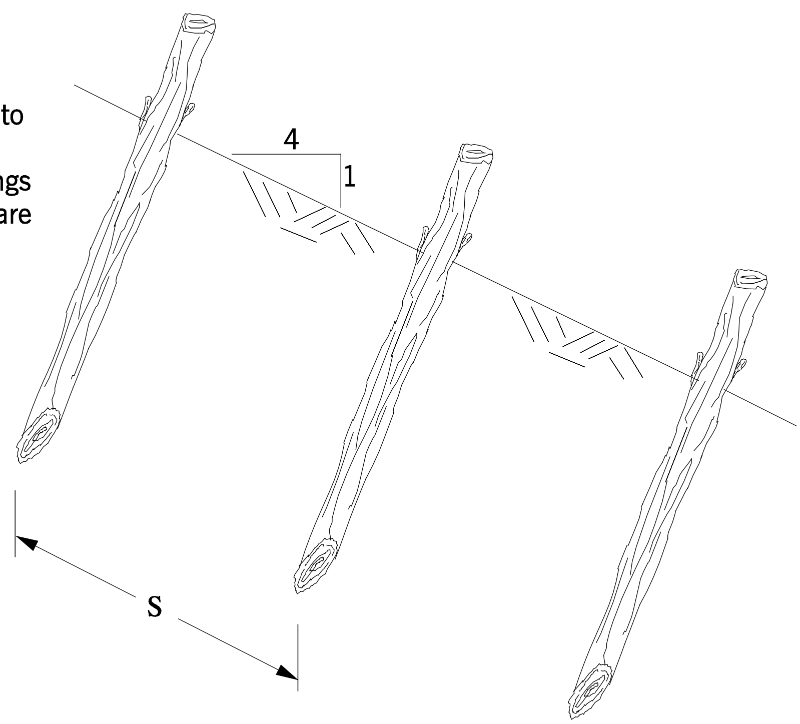
Adapted From USDA–SCS (1994)

DETAIL

Live stout stakes should be long enough to reach below the groundwater table. (Generally, a length of 2 to 3 feet, or 0.6 to 0.9 meters, is sufficient.) Additionally, the stakes should have a diameter in the range of 0.75 to 1.5 inches (2 to 4 centimeters).

SECTION VIEW

Live stout stakes shall be spaced 2 to 3 feet (0.6 to 0.9 meters) apart to give a density of 2 to 4 cuttings per square yard (0.8 square meters).



MGWC 2.5: LIVE FASCINES

Woody vegetative system for bank stabilization

DESCRIPTION

Establishment of live fascines, also known as wattles, consists of the following:

- preparation of sausage-shaped bundles of live, woody plant cuttings,
- anchoring of these bundles in shallow ditches in a slope or streambank with live and/or inert stout stakes, and
- partial burial of the fascines to promote growth.

EFFECTIVE USES & LIMITATIONS

As with other bioengineering measures, live fascines are an economical method when materials are locally available. Additionally, wattling is often an effective measure when employed to:

- reduce runoff energy, and hence surface erosion, by braking a slope into a series of shorter slopes,
- protect other bioengineering measures from washout and undercutting,
- replace brush layers on suitable cut slopes (since they are easier to install),
- protect streambanks from washout and seepage, particularly at toes where water levels fluctuate only moderately, and
- stabilize or protect streambanks for the following Rosgen stream types: B4, B5, B6, C1, C2, C3, C4, C5, C6, DA, E3, E4, E5, and E6.

Supplementary or alternative mitigating measures may be required for the following situations:

- streambanks with heavy surface drainage,
- areas of flashy flows,
- slopes subject to shallow mass movements (since fascines have a modest rooting depth), and
- the outsides of meander bends (high velocity areas of the channel).

MATERIAL SPECIFICATIONS

Willow, alder, and dogwood cuttings are well suited for use in live fascines. Fascine bundles can range from 5 to 30 feet (1.5 to 9 meters) in length, depending upon handling and transportation limitations, with diameters ranging from 4 to 10 inches (10 to 25 cm). Untreated twine or wire used to tie the bundles should be at least 2 millimeters thick. If inert (dead) stakes are employed to secure the bundles, they should be made from 2 by 4-inch (5 by 10-cm) lumber cut on the diagonal with lengths of 2.5 feet (0.8 meters) for cut slopes and 3 feet (0.9 meters) for fill slopes.

Approximate Cost ($1999):
$5.50-$22 per linear ft

INSTALLATION GUIDELINES

Live fascine construction should occur during the dormancy period, usually late fall to early spring, with bundle preparation proceeding as follows (refer to Detail 2.5):

- the growing tips of all branches should be oriented downstream in the same direction, and

- bundles should be tied every 12 to 18 inches (30 to 45 cm) along their lengths.

The initial row of bundles should be positioned at the height of the normal summer water level such that one half to two thirds of the bundle is submerged. These toe bundles should be protected from washout by positioning them on brush layers extending 20 to 31 inches (50 to 80 cm) into the stream. Project planners may need to study an aptly chosen vegetated reference reach for further guidance when installing live fascines.

All bundles should be anchored in trenches dug to a depth at least one-half the bundle diameter. Inert stakes should be driven every 12 to 39 inches (30 to 100 cm) through and below the lengths of the fascines with extra stakes used at bundle overlaps. The length of overlap should be approximately 1 to 3 feet (0.3 to 0.9 meter). Live stakes can be employed on the down slope side of the fascine rows or through the bundles with the tops of the stakes extending 2 to 3 inches (5 to 8 cm) above the bundle tops. Soil should be tamped into and along the sides of the bundles, leaving the top 2 inches (5 cm) exposed to promote growth.

Additional fascine rows should be installed up the slope at predetermined intervals. If the slope is dry a majority of the time, bundles should be arranged parallel to the contour according to Table 2.5a.

Table 2.5a: Fascine Spacing on Dry Slope

Slope Steepness	Contour Distance
1:1 to 1.5:1	3-4 ft (0.9-1.2 m)
1.5:1 to 2:1	4-5 ft (1.2-1.5 m)
2:1 to 2.5:1	5-6 ft (1.5-1.8 m)
2.5:1 to 3:1	6-8 ft (1.8-2.4 m)
3.5:1 to 4:1	8-9 ft (2.4-2.7 m)
4.5:1 to 5:1	9-10 ft (2.7-3.0 m)

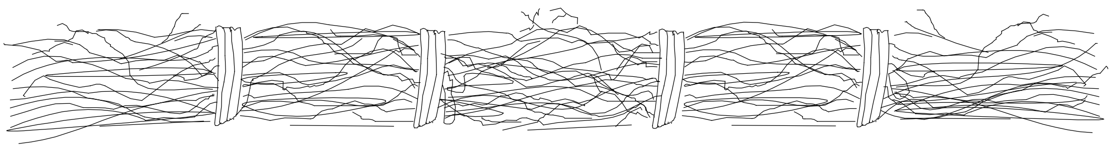
Conversely, if the slope is excessively wet, bundles should be installed at an angle to the contour to expedite slope drainage as dictated in Table 2.5b.

Table 2.5b: Fascine Spacing on Wet Slope

Slope Steepness	Contour Distance
1:1 to 1.5:1	2-3 ft (0.6-0.9 m)
1.5:1 to 2:1	3-5 ft (0.9-1.5 m)
2:1 to 2.5:1	3-5 ft (0.9-1.5 m)
2.5:1 to 3:1	4-5 ft (1.2-1.5 m)
3.5:1 to 4:1	5-7 ft (1.5-2.1 m)
4.5:1 to 5:1	6-8 ft (1.8-2.4 m)

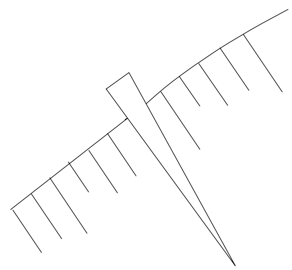
Straw or mulching material should be spread between fascine rows on slopes flatter than 1.5:1, and jute or coir fabric should be used on slopes greater than 1.5:1 to control erosion until the fascine rows and supporting vegetation become established.

DETAIL 2.5: LIVE FASCINES

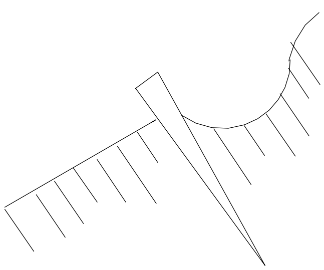


Preliminary Step – prepare fascine bundles as follows: cigar–shaped bundles of live, rootable brush and branches with butts alternating, 4 to 10–inch (10 to 25–cm) diameters, tied 12 to 18 inches (30 to 45 cm) on center

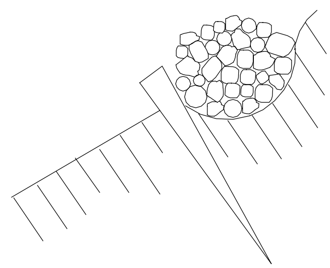
Construction Note: installation begins at the bottom of the slope and proceeds from Step 1 through Step 5
Adapted from Leiser (1983)



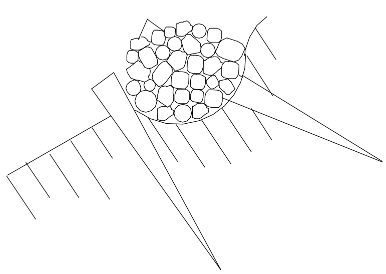
Step 1 – insert stakes on contour



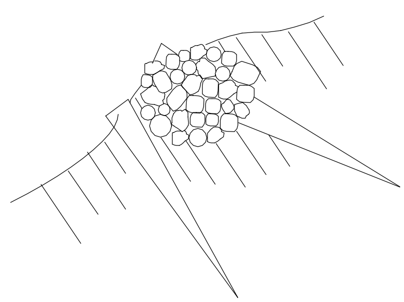
Step 2 – dig trench (1⁄2 bundle diameter in depth) above the stakes



Step 3 – place bundles in trench



Step 4 – add additional stakes through and below bundles



Step 5 – tamp soil into and along sides of bundle leaving the top 2 inches (5 cm) exposed to promote growth

MGWC 2.6: NATURAL FIBER ROLLS

Natural fiber and vegetative system for bank stabilization

DESCRIPTION

Natural fiber rolls are commonly made from coir fiber and netting. They are used to provide channel and shoreline stabilization in areas of low shear stress by acting as a medium for plant propagation.

EFFECTIVE USES & LIMITATIONS

Natural fiber rolls are used to stabilize slopes and improve aesthetics in areas of low shear stress by encouraging the growth of vegetation. Coir fiber used in these rolls has a high tensile strength, is biodegradable, and has excellent moisture retention and sediment trapping properties to encourage plant growth. Natural fiber rolls are easily installed with wooden stakes, can be readily molded to fit the bank line, and over time blend naturally into the aquatic environment. Once vegetation becomes established in these rolls, slope stability is increased by fibrous root systems which consolidate the surrounding soil, and leaves and stalks of herbaceous plant species which lessen energy of moving water and elastically deform in flood flows, thereby covering the bank and protecting it from erosion without blocking the channel.

Natural fiber rolls can also be used as toe protection in ponds and lakes where flow velocities are low and moderate toe stabilization is required.

Natural fiber rolls should be avoided in channels which are actively incising and in reaches with large debris loads and/or potential for significant ice build up. Additionally, the following Rosgen stream types should be avoided when considering the use of fiber rolls: A1, A5, B1, C1, D3-D6, DA, F1, G1, G4, and G5.

MATERIAL SPECIFICATIONS

- *Fiber logs*: Natural fiber logs composed of biodegradable materials such as coir fiber are commercially available in 16 or 18-inch (0.40 or 0.45-meter) diameter rolls.
- *Plantings*: Vegetative plantings should be chosen according to their adaptability to site-specific conditions and objectives by a plant specialist.
- *Live stakes:* Live stakes should be cut from fresh, green, healthy dormant parent plants which are adapted to the site conditions whenever possible.

Approximate Cost ($1999):
$61 per running foot (installed)

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. Refer to the *1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control.* The recommended construction procedure for natural fiber logs should proceed as follows (refer to Detail 2.6):

1. Natural fiber rolls should be installed so that they rest against the bottom of the waterway in ponds or lakes. In streams and rivers, the first row of fiber logs should be placed above any necessary toe stabilization measures. Natural fiber logs should not be used as the primary toe stabilization measure in streams or rivers.

2. Plants should be plugged in an alternating pattern along the top of the fiber log in gaps between the coir fiber netting. Appropriate species and a spacing ranging from 6 to 12 inches (0.15 to 0.3 meters) should be selected by a plant specialist according to site characteristics such as soil properties, anticipated post-construction bank slope, water chemistry, amount of available sunlight, and expected duration of inundation during high stream flows. If water levels are too low for the fiber logs to be submerged ½ to 2/3 of their diameter, plants should be plugged inside the soil/log interface where they will receive adequate moisture.

3. Dead or live stakes should be used to anchor the fiber logs in place. Stakes should be notched approximately 5 inches (13 centimeters) from their tops and pounded partially into the ground on either side of the bundle at a spacing of 3 to 4 feet (0.9 to 1.2 meters). Twine should be tied from the notch in one stake to the notch in the stake directly opposite. The stakes should then be driven so that the twine is secured against the top of the roll. Ideally, the top of the stake should be flush with the top of the roll.

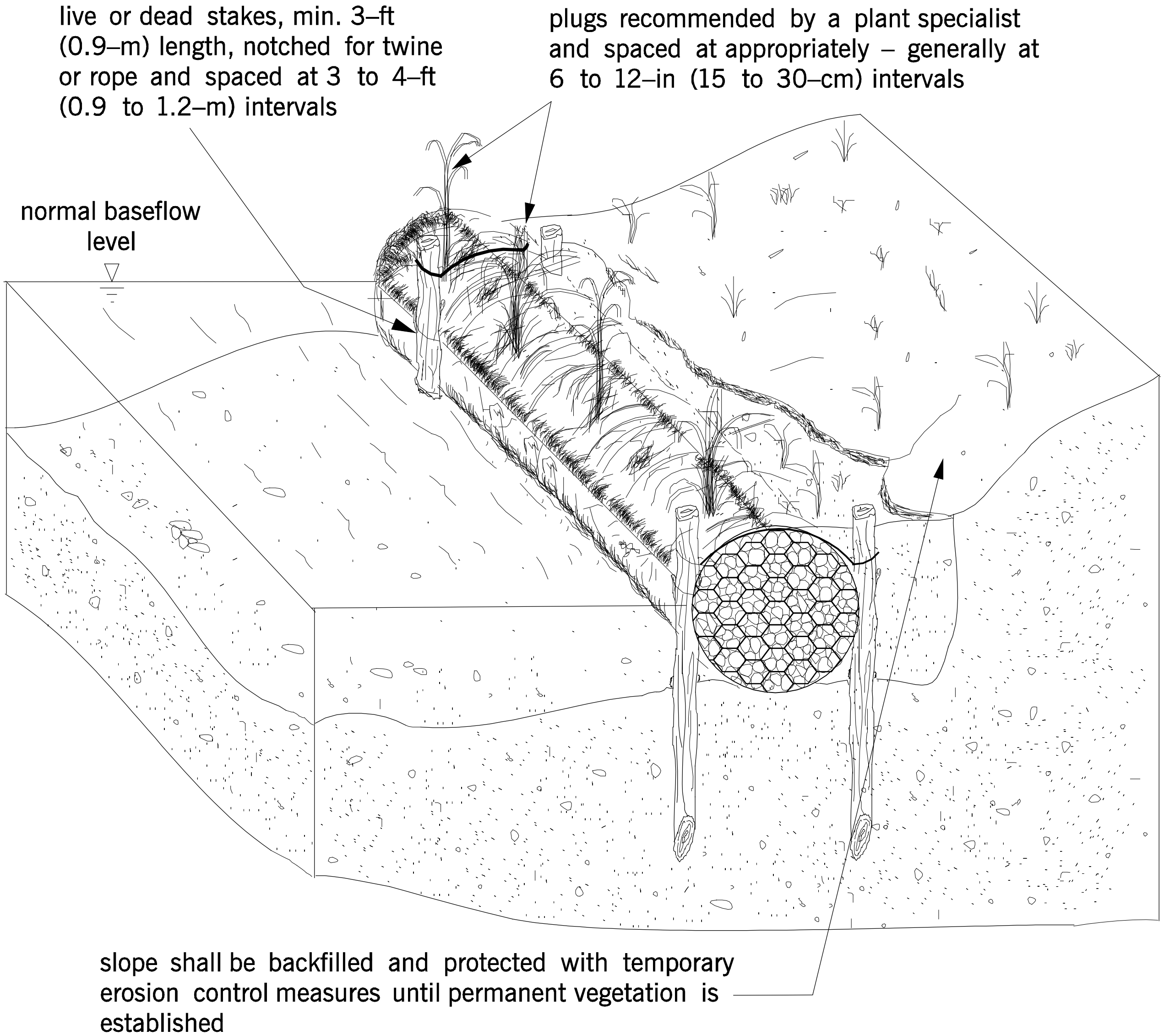
4. The ends of adjacent logs should be laced together with twine by making a number of passes in the end netting between the logs and pulling the twine taut. Where a fiber roll does not abut another fiber roll, the end should be bent inward and buried in the bank to prevent water from intruding behind the roll and dislodging it.

5. Successive rows of fiber rolls should be offset 3 to 8 inches (8 to 20 centimeters). Additionally, to ensure that roots extend into the soil, plants should be plugged into the sides of the fiber log near the soil. The need to backfill/contour the soil behind the fiber logs and between successive lifts will depend on the specific aesthetic and physical requirements of the project. The re-contoured soil should be seeded and/or plugged with appropriate vegetative species and covered with an erosion control blanket to prevent slope erosion.

DETAIL 2.6: NATURAL FIBER ROLLS

DETAIL

Adapted From Goldsmith and Bestmann (1992)



MGWC 2.7: BRUSH LAYERING

Woody vegetative system for bank stabilization

DESCRIPTION

Brush layers are live branch cuttings interspersed between layers of compacted soil in the face of a cut or fill slope to provide stability and act as horizontal slope drains. Brush layers can be used in conjunction with wooden stakes to repair small localized slumps or holes in streambanks (*live gully repair*).

EFFECTIVE USES & LIMITATIONS

Live brush layers effectively:

- provide long-term durability and erosion control, especially when used on Rosgen stream types B3, B4, B5, B6, C1, C2, C3, C4, C5, C6, DA, E3, E4, E5, and E6;
- trap debris and slow surface waters thereby reducing erosion;
- encourage plant propagation and the invasion of natural vegetation;
- act as lateral drains to dry excessively wet sites;
- reinforce newly constructed fill slopes; and
- replace brush mattresses and live fascines on sites with deep-seated mass stability problems.

When constructed for live gully repair, brush layers:

- provide an immediate surface barrier by redirecting water away from the washed-out area,
- reinforce the backfill and protect the restored area against future scour and washout, and
- furnish cover for wildlife.

To improve their effectiveness, brush layers can be used in combination with rock toe protection and other restoration measures. Additionally, brush layering is an effective technique when the following limitations are observed:

- brush layering is usually more effective on fill slopes than cut slopes because branch length is not restricted by the depth to which benches can be dug,
- cut brush layering should be limited to slopes of 2H:1V or less, and
- live gully repair should be used only to repair relatively small slumps and holes.

MATERIAL SPECIFICATIONS

Live branches should be cut from fresh, green, healthy, dormant parent plants which are adapted to the site conditions whenever possible.

- Live branches should be 0.5 to 2.5 inches (1.3 to 6 centimeters) in diameter and should be long enough so that 1/2 to 2/3 of the branch is in contact with the soil at the back of the terrace, bench, or gully while projecting slightly from the slope face.
- Commonly used woody plants for this measure include willow, poplar, and alder since they are versatile and have high growth rates with shrubby habits, fibrous root systems, and high transpiration rates especially when in leaf.

- A partial listing of woody plants recommended by the United States Department of Agriculture's Soil Conservation Service is presented in MGWC 2.4:Live Stakes.
- Live branch cuttings should be kept covered and moist at all times and should be placed in cold storage if more than a few hours elapse between the cutting and construction times.

Live or inert stakes used for live gully repair should be sufficiently long to reach 3 feet (0.9 meters) into competent soil at the base of the slump or hole and soaked for 24 to 48 hours prior to installation.

Approximate Cost ($1999):
Cut: $9 to $14.50 per linear ft
Fill: $13 to $28 per linear ft

INSTALLATION GUIDELINES

Brush layer installation should occur during periods of low flow beginning at the rivers edge or low point of the targeted gully. If construction begins at the river's edge, a stable toe with an granular filter designed according to MGWC 2.1: Riprap must first be constructed below the normal baseflow level according to riprap sizing and installation guidelines (refer to Detail 2.7).

- Live cuttings should be placed on prepared earth lifts for fill brush layering or excavated terraces for cut brush layering.

    1. Fill brush layers should be positioned on prepared earth lifts 7 to 17 feet (2 to 5 meters) in width, and cut brush layers should be arranged on trenches with a minimum width of 3 to 7 feet (1 to 2 meters).
    2. The brush rows should be angled away from the contour on excessively wet sites, and the angle of the branches from the horizontal should range from 10 to 20 degrees; steeper for wetter soils and flatter for dry soils.
    3. Branches should be arranged in a crisscross fashion in 4 to 12-inch (10 to 30-cm) thick layers with their cut ends touching the back of the slope or gully. Live gully repair requires that the branch cuttings be arranged around wooden stakes. The wooden stakes should be spaced 1 to 1.5 feet (0.3 to 0.45 meters) apart and driven a minimum of 2 to 3 feet (0.6 to 0.9 meters) into competent ground. A maximum of 25% of the brush layer should protrude from the slope face.

- Moist backfill should be lightly compacted on top of each layer of branches to eliminate air voids and provide an adequate soil/branch interface to initiate growth. Each layer of backfill should have a thickness of 6 to 12 inches (0.15 to 0.30 meters).
- Subsequent rows of brush layers should be spaced as follows, though frequently wet and unstable slopes may require closer spacing:

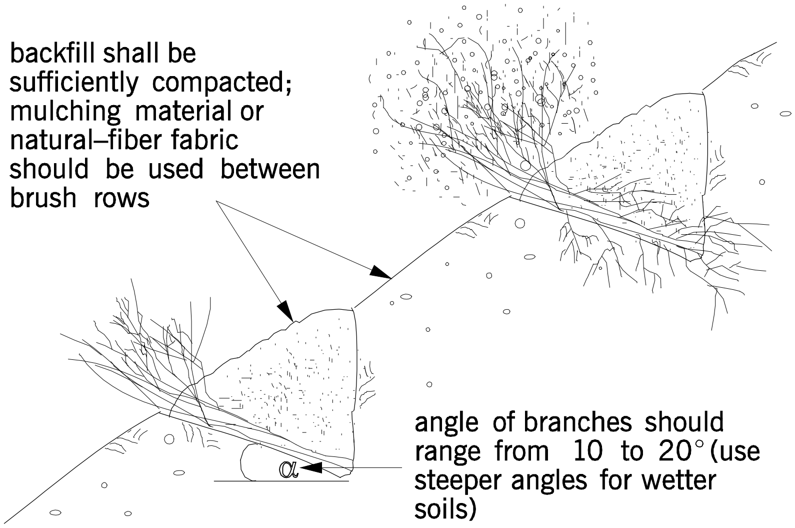
Table 2.7: Suggested Spacing for Brush Layers

Slope Steepness	Contour Spacing
1.5:1 to 2:1	4-5 ft (1.2-1.5 m)
2:1 to 2.5:1	5-6 ft (1.5-1.8 m)
2.5:1 to 3:1	6-8 ft (1.8-2.4 m)
3:1 to 4:1	7-10 ft (2.1-3.0 m)

- The completed installation should match the existing slope profile. Long straw or mulching material should be used between brush layer rows on slopes of 3H:1V or flatter to impede surface erosion until native vegetation invades the area. On steeper slopes, jute or coir fabric should be used.

Maryland's Guidelines To Waterway Construction

DETAIL 2.7(a): BRUSH LAYERING

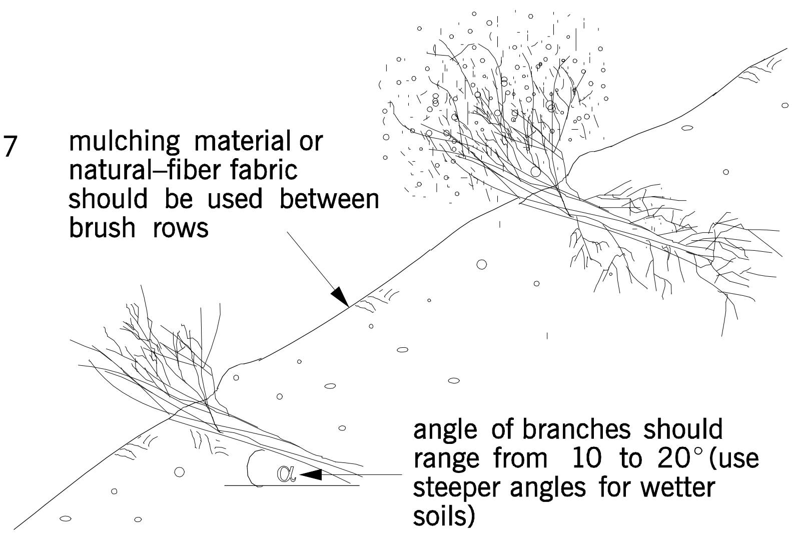


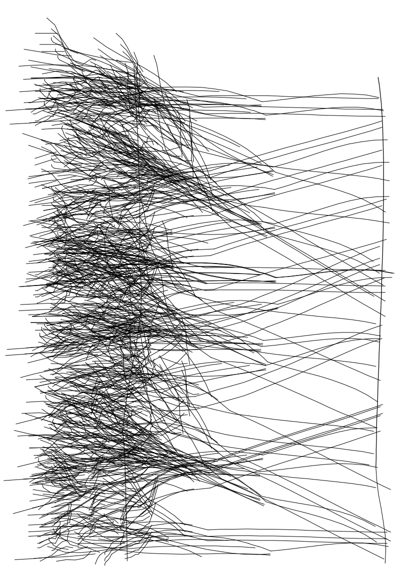
SECTION VIEW: FILL

In Fill Sections: brush layers shall be placed on prepared earth lifts 7 to 17ft (2 to 5m) wide and angled away from the contour on excessively wet sites; the distance between successive brush layers is a function of slope angle (see installation specifications)

SECTION VIEW: CUT

In Cut Sections: brush layers shall be placed on trenches 3 to 7 ft (1 to 2m) wide and angled away from the contour on excessively wet sites; the distance between successive brush layers is a function of slope angle (see installation specifications)





PLAN VIEW: CUT & FILL

live branches should have diameters between 0.5 to 2.5 inches (1.5 to 6.0cm); branch cuttings shall be arranged in a crisscross fashion in 4 to 12–inch (10 to 30–cm) thick layers with the growing tips oriented towards the slope face; a maximum of 25% of the branch length shall protrude from the slope surface

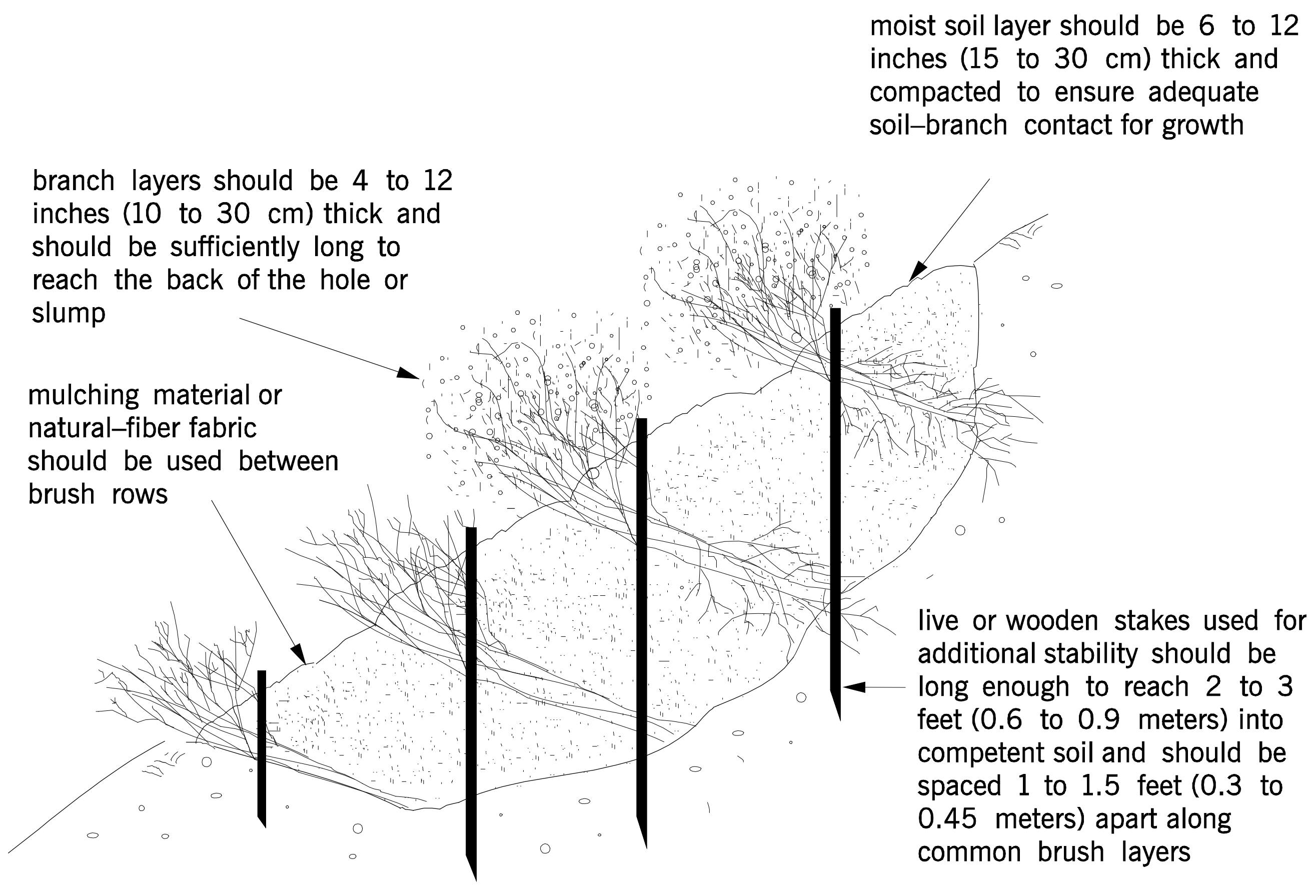
Construction Notes: installation should occur during periods of low flow and should proceed up the slope; a stable rock toe should be constructed below the normal baseflow level (see riprap guidelines)

Adapted From Gray & Sotir (1996)

DETAIL 2.7(b): BRUSH LAYERING

Adapted From Gray & Sotir (1996)

SECTION VIEW



MGWC 2.8: BRUSH MATTRESSES

Woody vegetative system for bank stabilization

DESCRIPTION

Brush mattresses are formed from live branches which are wired together to create an erosion resistant mat. This mat is then secured to the bank by live and/or dead stakes and partially covered with fill soil to initiate growth of the cuttings.

EFFECTIVE USES & LIMITATIONS

Brush mattresses provide bank protection soon after establishment. They are generally resistant to wave and current action and function to:

- capture sediment and rebuild streambanks;
- facilitate the colonization of native riparian vegetation; and
- provide long-term durability and erosion control, especially when used on Rosgen stream types B3, B4, B5, B6, C1, C2, C3, C4, C5, C6, DA, E3, E4, E5, and E6.

Brush mattresses should be limited to use on:

- sites having only low to moderate water level fluctuations and slope gradients not exceeding 2H:1V,
- streams with low to moderate suspended sediment loads since high loads may precipitate the burial of these bioengineering systems and complicate future planting efforts at the site, and
- native fill soils which contain enough fine material to allow the live branches to root and grow readily; key trenches backfilled with topsoil may be required on rocky slopes.

Additionally, this measure should be initiated in conjunction with a revegetation strategy since brush mattresses make it more difficult to propagate vegetative plantings once the mats become established.

MATERIAL SPECIFICATIONS

When choosing and preparing woody material for brush mattresses, the following guidelines should be followed:

- Live branches should be cut from fresh, green, healthy, dormant parent plants which are adapted to the site conditions whenever possible with the following guidelines:

    1. Woody branches up to 2.5 inches (6 centimeters) in diameter and 5 to 10 feet (1 to 3 meters) in length can be used for brush mattresses.
    2. Commonly used woody plants for this measure include willow, poplar, and alder since they are versatile and have high growth rates with shrubby habits, fibrous root systems, and high transpiration rates, especially when in leaf.
    3. A partial listing of woody plants recommended by the United States Department of Agriculture's Soil Conservation Service is presented in MGWC 2.4: Live Stakes.

- Live branch cuttings should be kept covered and moist at all times and should be placed in cold storage if more than a few hours elapse before installation.

MGWC 2.8: BRUSH MATTRESSES

Approximate Cost ($1999):
$33.50 per square ft

INSTALLATION GUIDELINES

Brush mattresses should be installed as follows (refer to Detail 2.8):

1. Live branches should be oriented in crisscross layers perpendicularly to the flow of water in slight manmade depressions along the embankment. The butt ends should alternate to provide a uniform mat thickness of at least 12 inches (0.3 meters) and a minimum percentage of air voids.

   - Approximately 20 to 50 branches should be used per running meter provided their lengths are the same as the slope length.
   - If the branches are not long enough to cover the entire slope from the toe to the top of slope, multiple layers should be utilized with the branches in the lower layers overlapping those in the upper layers by at least 1 foot (30 centimeters).

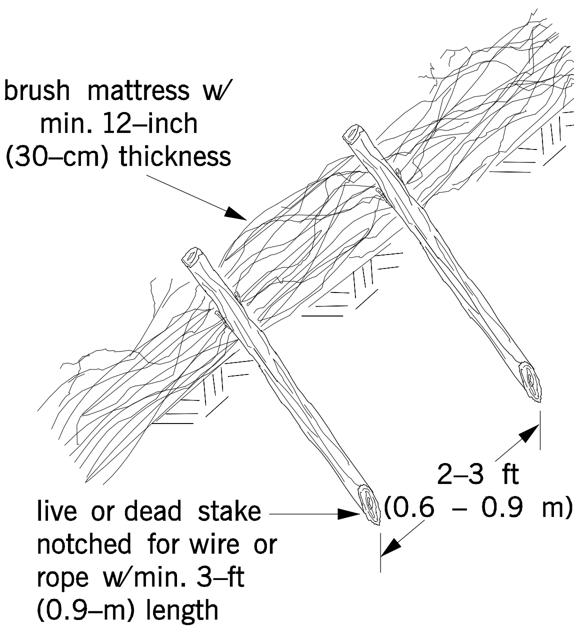
2. Once in position, the mattresses should be bound with wire and secured with 3-foot (0.9-meter) wooden stakes spaced at 2 to 3-foot (0.60 to 0.90-meter) intervals The wire should be tied to notches in the stakes before they are driven into the ground; this allows for tension to develop in the wire when the stakes are driven, thereby pulling the mattress firmly to ground.

3. Upon being bound and secured to the embankment, the mattresses should be covered with alternating layers of soil and water until only a portion of the top layer of branches is exposed, but all butt ends must be covered. The use of alternating applications of soil and water helps to insure a proper soil-branch interface to initiate growth.

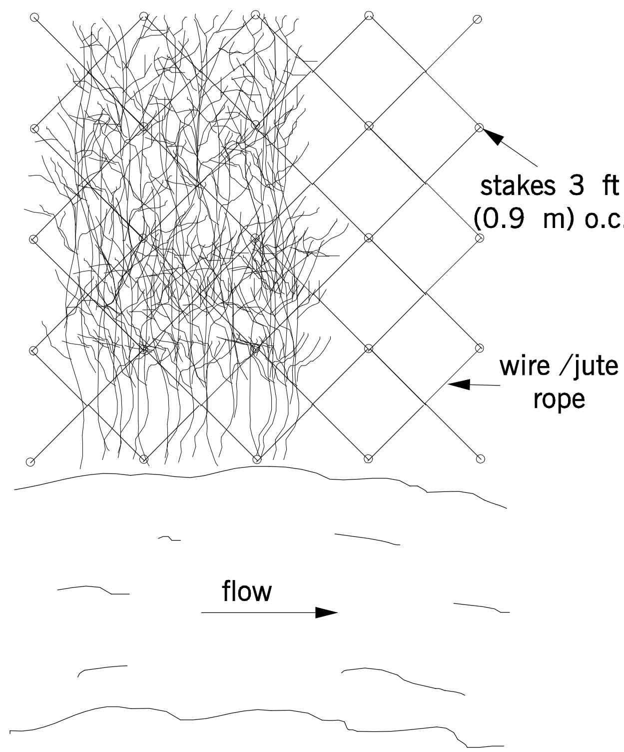
4. Finally, the toe of the embankment should be reinforced against undercutting with a rock toe and vegetative measure such as a live fascine. (Refer to MGWC 2.1: Riprap and Figure 2.1.)

Maryland's Guidelines To Waterway Construction

DETAIL 2.8: BRUSH MATTRESSES

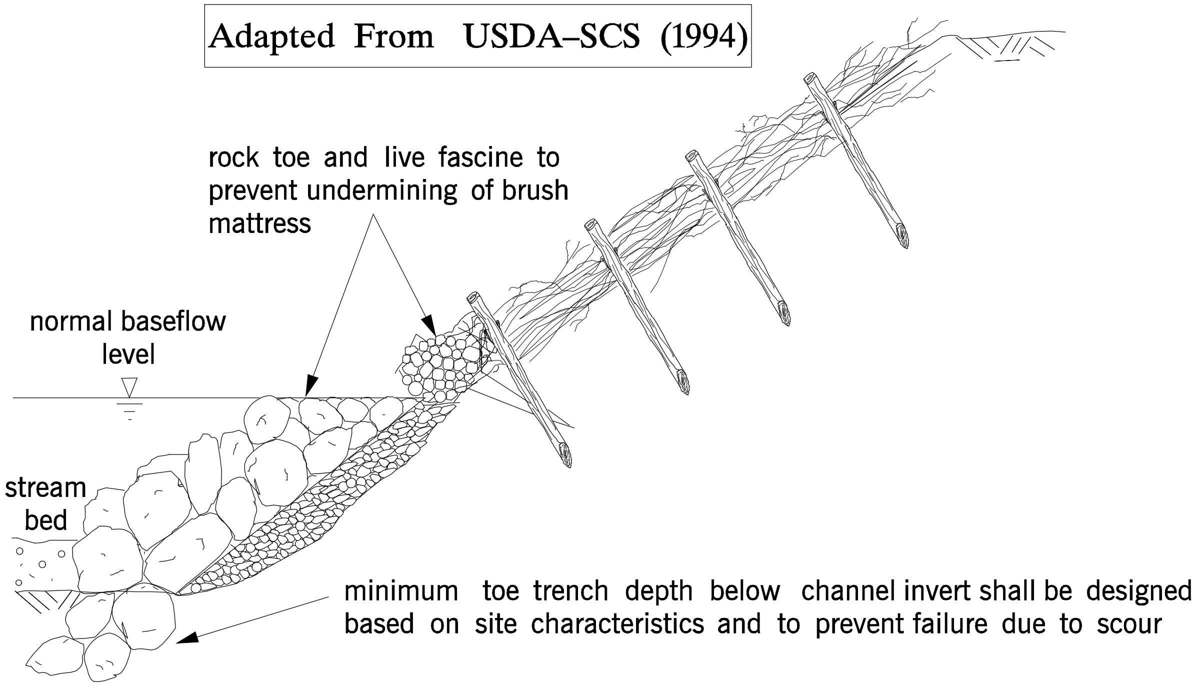


DETAIL



PLAN VIEW

Adapted From USDA–SCS (1994)



SECTION VIEW

MGWC 2.9: LIVE CRIB WALL

Woody vegetative system for bank stabilization

DESCRIPTION

Live crib walls are hollow, box-like frameworks of untreated logs or timbers filled with riprap and alternating layers of suitable backfill and live branch layers and are used for slope, streambank, and shoreline protection.

EFFECTIVE USES & LIMITATIONS

Live crib walls are constructed to protect the toes and banks of eroding stream reaches against scour and undermining, particularly at the outsides of meander bends where strong river currents are present. The log frameworks provide immediate protection from erosion while the live branch cuttings contribute long-term durability and ultimately replace the decaying logs. Additionally, live crib walls are effective in areas where encroachment into the stream channel should be avoided.

When considering these structures as a stream restoration technique, the following limitations should be considered:

- Live crib walls should not be used where the channel bed is severely eroded or where undercutting is likely to occur (e.g. where the terrain is rocky or where narrow channels are bounded by high banks).
- Live crib walls are not intended to resist large lateral earth stresses, therefore their heights should be limited accordingly (as noted in the installation specifications).
- Live crib walls promote siltation and retain large amounts of bed material; therefore they require continual monitoring for adverse streamflow patterns.
- Live crib walls can be an effective restoration measure when used on the following Rosgen stream types: B3, B4, B5, B6, C1, C2, C3, C4, C5, C6, DA, E3, E4, E5, and E6.

MATERIAL SPECIFICATIONS

When choosing and preparing logs and woody cuttings for live crib walls, the following guidelines should be followed:

- Crib frameworks should be constructed from stripped logs or untreated lumber 4 to 6 inches (10 to 15 centimeters) in diameter.
- Live branches should be cut from fresh, green, healthy parent plants which are adapted to the site conditions whenever possible.

  1. Live branches should be 0.5 to 2.5 inches (1.3 to 6 centimeters) in diameter and should be long enough to reach the soil at the back of the wooden crib structure while projecting slightly from the crib face.
  2. Commonly used woody plants for this measure include willow, poplar, and alder since they are versatile and have high growth rates with shrubby habits, fibrous root systems, and high transpiration rates especially when in leaf.
  3. A partial listing of woody plants recommended by the United States Department of Agriculture's Soil Conservation Service is presented in MGWC 2.4: Live Stakes.
  4. Live branch cuttings should be kept covered and moist at all times and should be placed in cold storage if more than a few hours elapse before installation.

- Gravel and stones for the filter and riprap layers should be sized according to MGWC 2.1: Riprap.

- Fill soil should be native to the site, when possible, and should contain enough fine material to allow for the live branches to root and grow readily.

Approximate Cost ($1999):
$11 to $28 per square foot of the front face

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. **L**ive crib walls should be installed as follows (refer to Details 2.9a):

1. The location of the crib wall revetment should vary depending upon flow conditions and the reach's degree of curvature (refer to Detail 2.9b).

2. Stream flow should be diverted away from the site according to a plan approved by the WMA or local authority. (See *Section 1, Temporary Instream Construction Measures, Maryland Guidelines to Waterway Consruction*).

3. Loose material at the toe of the embankment should be excavated until a stable foundation is reached, usually within 2 to 3 feet (0.6 to 0.9 meters) of the surface. The crib foundation and structure should be inclined into the slope at a minimum angle (measured from the horizontal) ranging from 10H:1V to 6H:1V to increase the structure's stability.

4. The first course of logs or timbers should be positioned at the front and back of the excavated foundation approximately 3 to 6 feet (0.9 to 1.8 meters) apart and parallel to the slope contour. Successive courses of logs or timbers should be situated at right angles on top of the previous course such that they overhang the front and back of the previous course by 3 to 6 inches (7.6 to 15 centimeters). Once in position, each course should be secured to the previous course with nails or reinforcing bars and backfilled with granular filter material and stone riprap (up to the normal baseflow level).

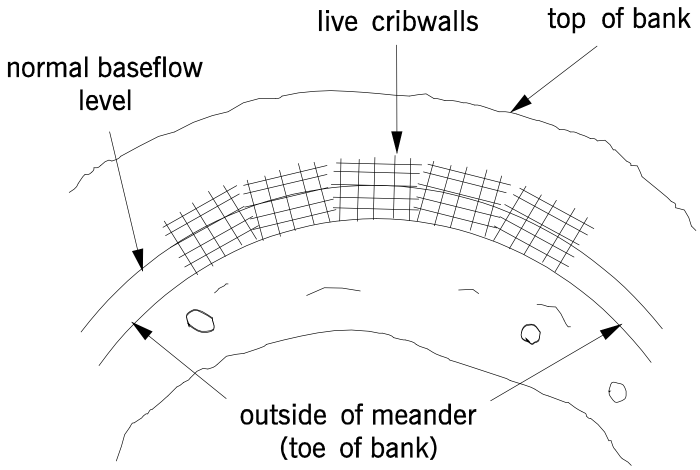
5. Live branch cuttings should be placed on top of the courses having logs or timbers running parallel to the contour (above the normal baseflow level).

    - The growing tips of the branches should be oriented toward the front face such that a maximum of 25 percent of their lengths project from the framework.
    - Each layer of branches should be followed with a layer of compacted soil to ensure an adequate soil-branch interface to stimulate growth.
    - Cribbing heights should range from 50 to 70% of the bank height. It has also been recommended that live crib walls should be designed to a maximum height of 6 feet (1.8 meters), including the foundation, or 13 feet (4 meters) in height for structural stability reasons.

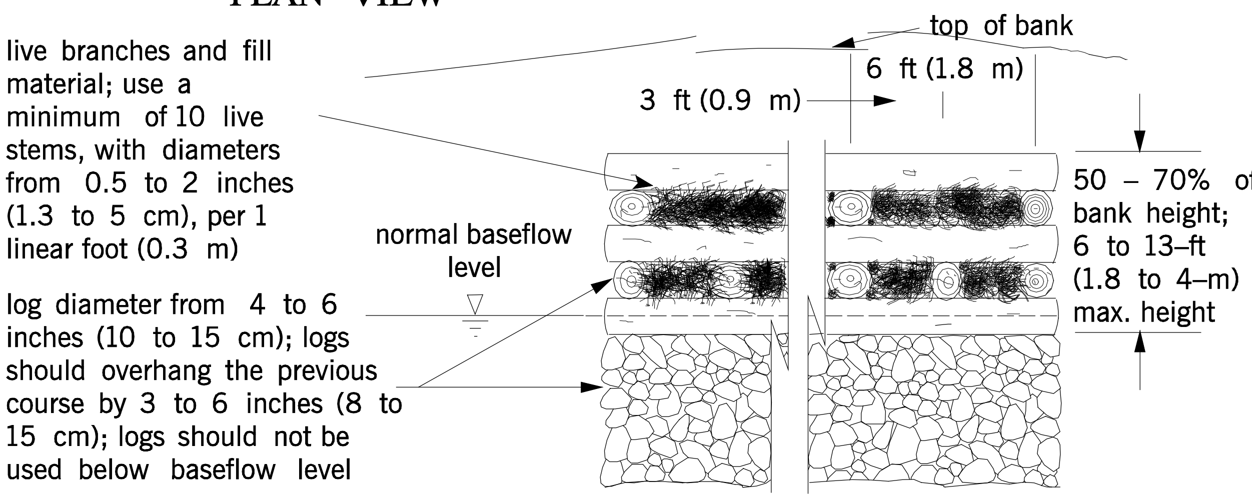
Note: *Live crib walls can also be constructed in a stair-step fashion with each successive course of timbers set back 6 to 9 inches (15 to 23 centimeters) from the previously installed course.*

DETAIL 2.9(a): LIVE CRIB WALL

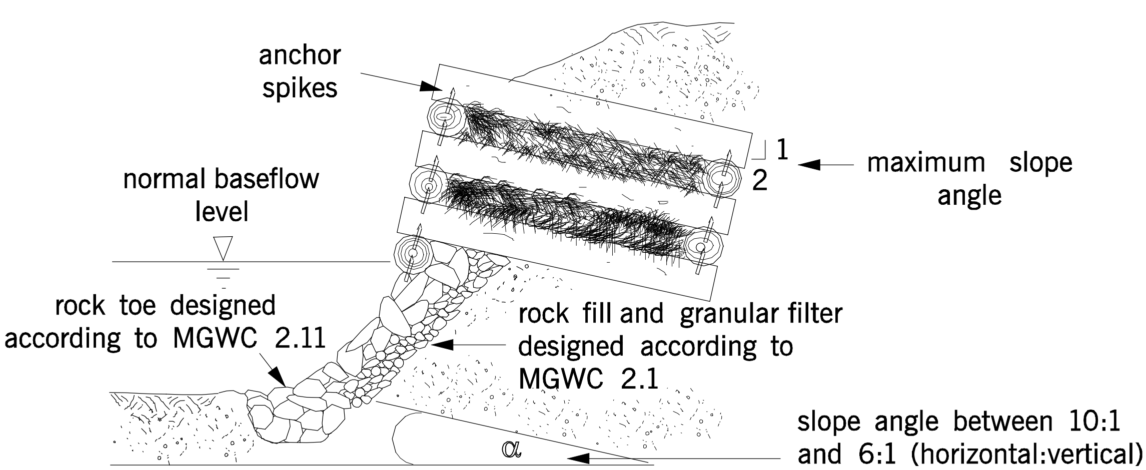
Adapted From USDA–SCS (1994)



PLAN VIEW



FRONT VIEW



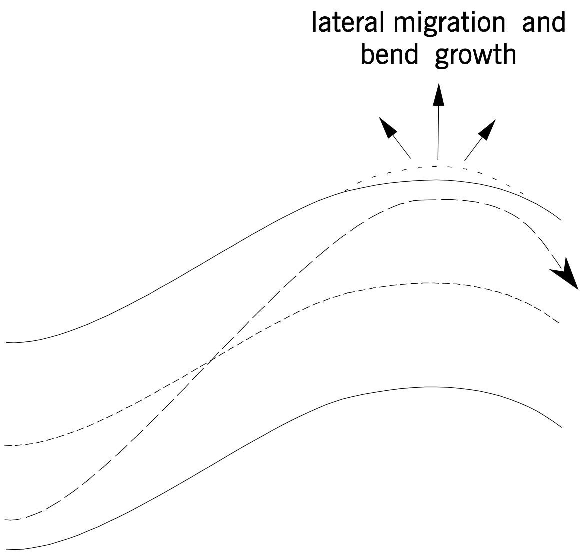
SECTION VIEW

DETAIL 2.9(b): CRIB WALL PLACEMENT

Adapted From Chang (1988)

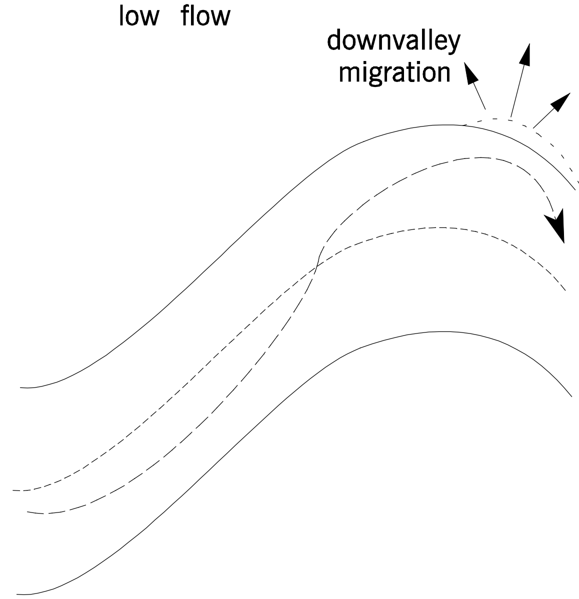
thalweg — channel centerline — erosional area

Case 1: mild bend/ low flow



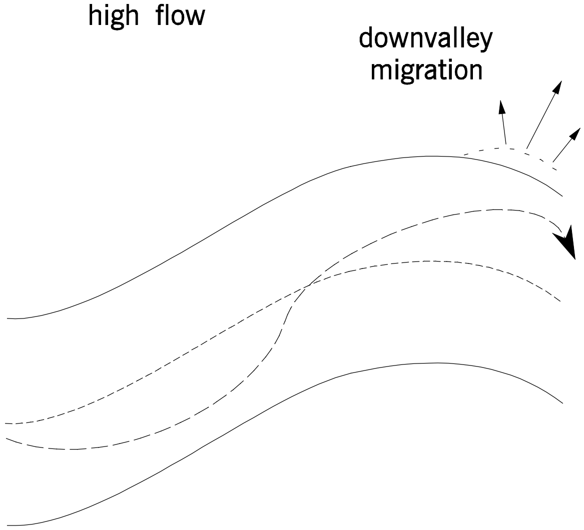
place cribwalls on concave bank centering around apex of curve

Case 3: sharp bend/ low flow



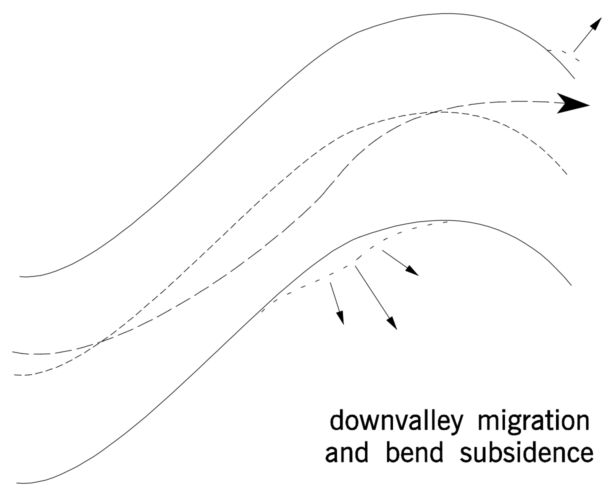
place cribwalls on concave bank at apex of curve and continue into crossover reach of bend exit

Case 2: mild bend/ high flow



place cribwalls on concave bank at apex of curve and continue into crossover reach of bend exit

Case 4: sharp bend/ high flow



place cribwalls on concave bank at apex of curve and continue into crossover reach of bend exit; place cribwalls on convex bank in the crossover reach of bend entrance

MGWC 2.10: ROOT WADS

Woody vegetative system with simple structures for limited bank stabilization and aquatic habitat enhancement

DESCRIPTION

Root wads are used for limited bank stabilization and can be cost-effective when native materials are available. Additionally, root wads enhance fish rearing habitat by creating scour pools and overhead cover.

EFFECTIVE USES & LIMITATIONS

The following limitations should be considered before incorporating root wads into stream restoration plans:

- The adoption of this measure as a stream restoration technique is rather recent, and therefore its performance is currently being assessed and documented.
- Root wads should not be used in stream sections where the bed is severely eroded or where undercutting is likely to occur such as where the terrain is rocky or where narrow channels are bounded by high banks. Additionally, they should be avoided in braided streams and in reaches with sandy/silty soils.
- Flows greater than bankfull discharge may cause local scour around the top of the structure and may even initiate total bank collapse in severe instances. Therefore, root wad revetments require systematic monitoring, especially after high flows, for evidence of local erosion and organic decay of the structure.
- Vanes can be used in combination with root wads to reduce bank erosion.
- Root wads can be an effective restoration measure when used on the following Rosgen stream types: B3, B4, B5, B6, C1, C2, C3, C4, C5, C6, DA, E3, E4, E5, and E6.

MATERIAL SPECIFICATIONS

When choosing natural materials for root wad revetments, the following guidelines, compiled from stream restoration projects in Maryland, should be observed:

- Intact stumps should be taken from fresh, green, healthy parent trees, preferably hardwood, with a minimum base diameter of 12 inches (30 centimeters). The size of the ball and fan should be determined by the stream size and availability of parent trees. The length of the rootwad should be at least 20 feet (6 meters) in most

- Footer and brace logs should have a diameter equivalent to that of the root wad.
- Fill soil should be native to the site, when possible, and should contain enough fine material to allow for rapid revegetation of the disturbed bank.
- Boulders used to anchor root wads and associated footer and brace logs should be of adequate size; a minimum diameter of 2 feet (61 centimeters) has been recommended.

Approximate Cost ($1999):
$168-$1,121per root wad

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. The construction of a root wad revetment should proceed as follows (refer to Detail 2.10a):

MGWC 2.10: ROOT WADS

1. The location of the revetment should vary depending upon flow conditions and the reach's degree of curvature (refer to Detail 2.10b).

2. Stream flow should be diverted away from the site and sediment control devices installed according to a plan approved by the WMA or local authority. (See *Section 1*, *Temporary Instream Construction Measures, Maryland's Guidelines to Waterway Construction*.)

3. Work should proceed from the upstream section to the downstream end of the reach or meander beginning with excavation of a toe trench to a depth of one-half to two-thirds the diameter of the footer logs. Trenches should also be excavated for root wad placement. Appropriately sized root balls should be set at approximately 1/3 the bankfull height in order to provide toe protection.

4. Placement of the root wad components should be as follows:

   - Footer logs should be positioned in the trench below the stream invert such that each upstream log is shingled over its downstream neighbor.
   - In cut sections, root wads should be positioned in trenches such that the root mass of the trunk sits level with the cut end of the stump. The root mass should be oriented perpendicularly to the direction of flow. An angle of 30 to 60 degrees to the channel center line is usually adequate. Subsequent root wads should be spaced such that the bank is shielded from flows deflected by adjacent upstream root wads.

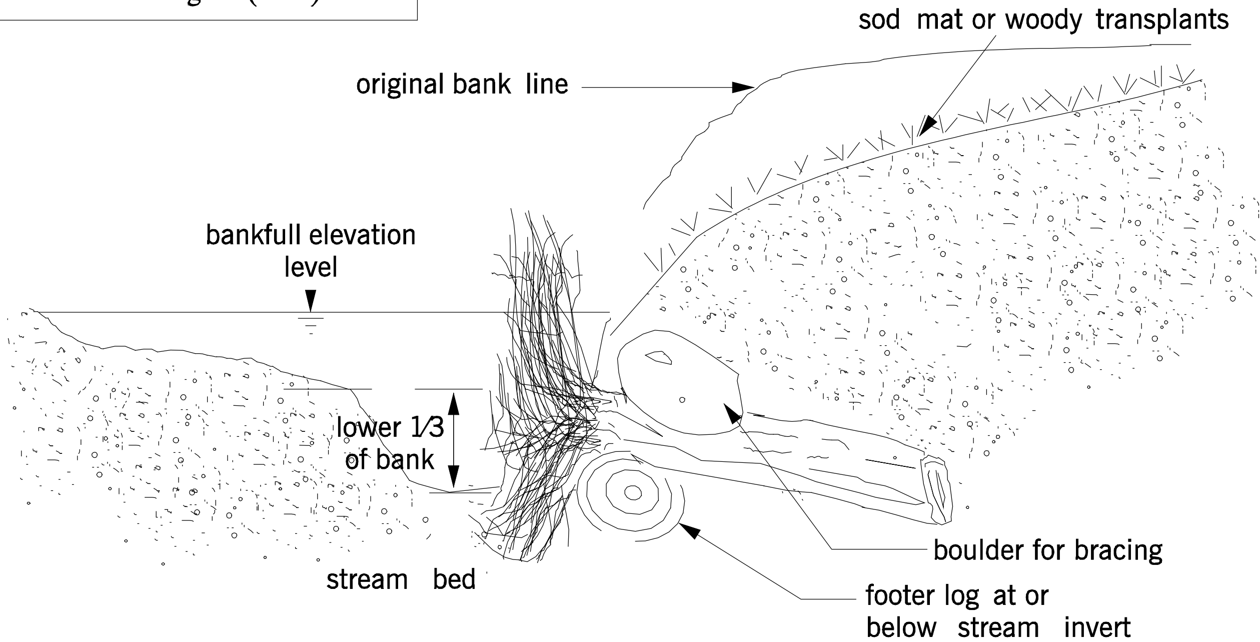
5. The root wad revetment should be backfilled to the specified grade, and fill material should be tightly packed in the joints, connections, and gaps to firmly secure all components. Larger material should be used to plug holes and gaps to keep fill from falling into the channel. The backfilled area should be sloped and protected with 1 to 2 feet of sod mat or temporary erosion control measures and should be seeded, mulched, and planted with woody transplants or live woody cuttings according to an approved revegetation plan within 72 hours of the revetment's completion. Stone may be necessary on flashy streams.

Maryland's Guidelines To Waterway Construction

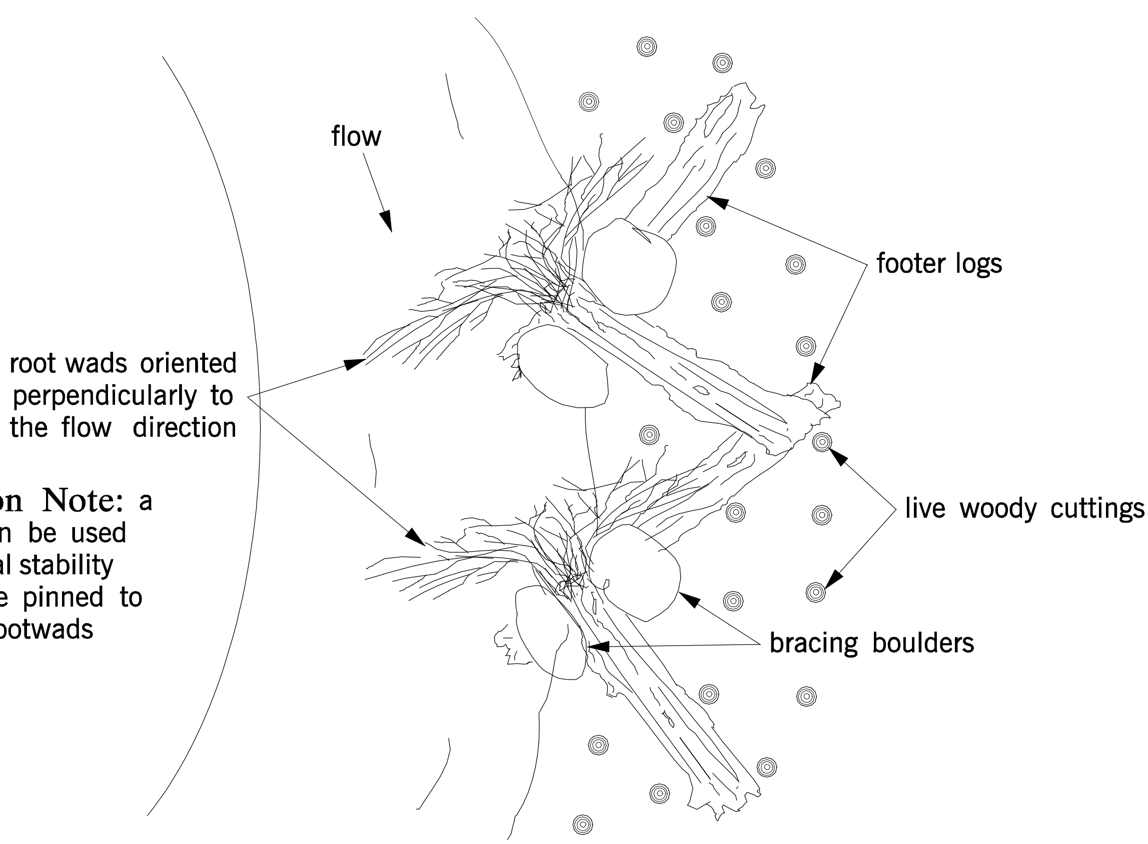
DETAIL 2.10(a): ROOT WAD REVETMENT

Section & Plan Views Adapted From Rosgen (1999)

SECTION VIEW



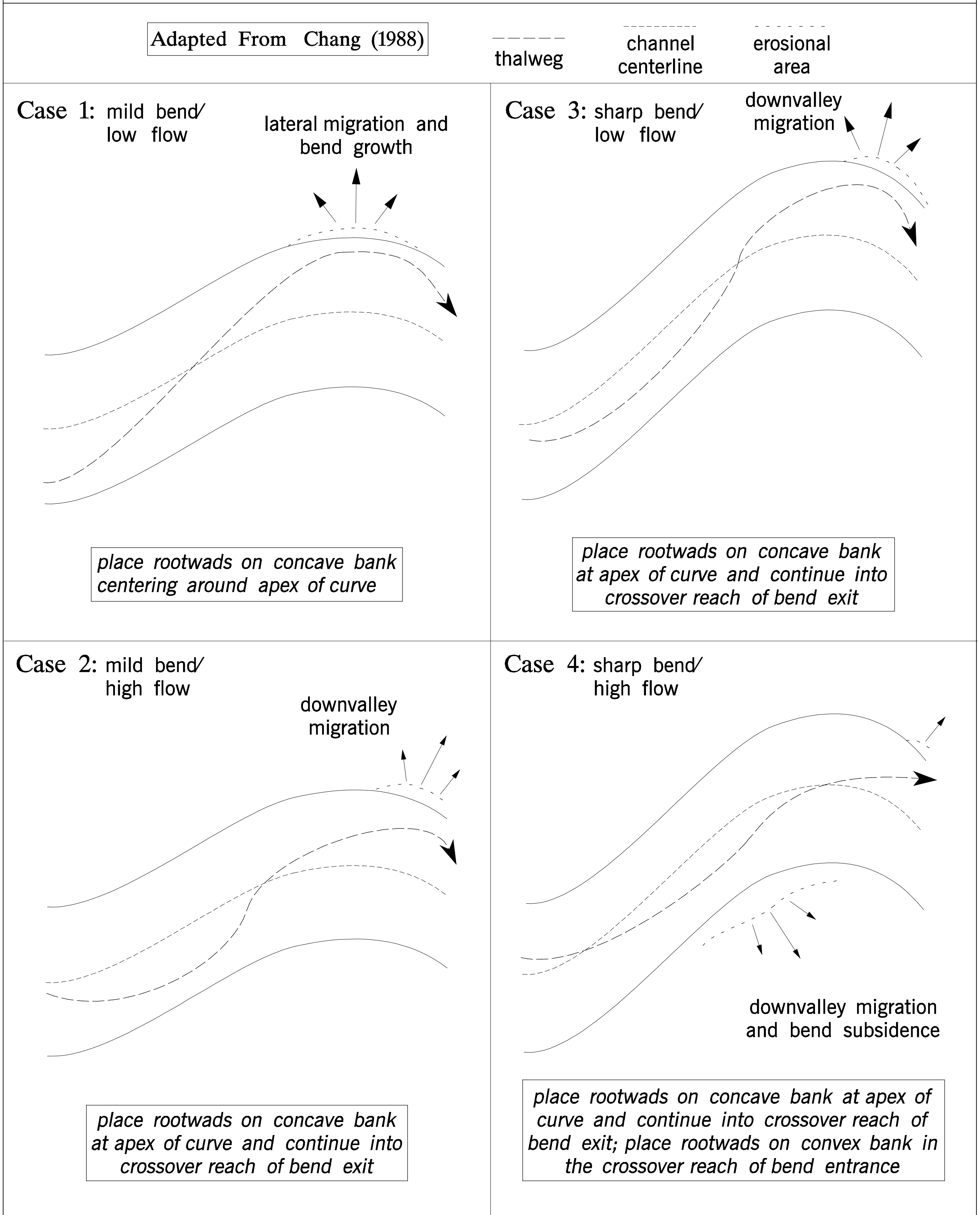
PLAN VIEW



Construction Note: a brace log can be used for additional stability and should be pinned to adjacent rootwads

Maryland's Guidelines To Waterway Construction

DETAIL 2.10(b): ROOT WAD PLACEMENT



MGWC 2.11: TOE PROTECTION

Lower bank protection and enhancement measures

DESCRIPTION

The work should consist of reinforcing bank toes with vegetation, bioengineering methods, or rigid engineering techniques to ensure the dynamic or rigid stability of the stream corridor.

EFFECTIVE USES & LIMITATIONS

Refer to the Detail 2.11 for the applicability of alternative measures as a function of shear stress. Toe protection should not be used on actively incising streams unless measures have been taken to promote vertical stability

Vegetation: The use of vegetation for toe enhancement should be limited to low gradient, vertically stable and non-incising channels where proper growing conditions exist, as defined by a plant specialist. The suitability of vegetation as a toe stabilization measure may be indicated by the presence of established plant communities in a reference reach with similar channel gradients, flow rates and flashiness, bed and bank material characteristics, and type and density of woody riparian vegetation.

Bioengineering measures: Bioengineering measures may be used in low to moderate gradient streams where existing bank material supports the growth of woody vegetation. Supplementary or alternative mitigating measures may be required in urbanized streams with flashy flows, on banks with heavy surface drainage, on the outsides of meander bends and other high-velocity areas of the channel, and on slopes subject to shallow mass movements

Rigid structures: Rigid toe protection is most effectively utilized in actively incising stream channels, in areas of flow concentration such as in the vicinity of hydraulic structures, and in areas where the primary flow directly impinges on the stream banks.

Note: It has been noted that these structures may increase velocity gradient and boundary stress at the toe region which may lead to stream incision and instability. To reduce near-bank stress, the use of a vane or other structure in conjunction with toe protection measures should be considered.

MATERIAL SPECIFICATIONS

Plant species including woody varieties should be chosen by a plant specialist according to location within the riparian bank zone and adaptability to site-specific conditions and objectives. Refer to MGWC 2.4:Live Stakes for material and Detail 2.11 for placement and usage. The use of non-native plantings may result in reduced natural biodiversity.

Rock toe protection should be composed of angular stones sized to resist the near-bed channel velocities resulting from the design storm event according to MGWC 2.1: Riprap. The minimum toe trench depth should be sufficient to resist scour or at a minimum of 1.5 times the maximum riprap diameter.

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. The proposed construction sequence for toe protection measures are as follows:

<u>MGWC 2.11: TOE PROTECTION</u>

1. The stream should be redirected by an approved temporary stream diversion (See *Section 1: Temporary Instream Construction Measures, Maryland's Guidelines to Waterway Construction*), the construction area should be dewatered, and any disturbed banks should be stabilized.

2. The appropriateness of toe stabilization measures should be based primarily upon the magnitude of the imposed shear stress at the reach of interest among other considerations as shown in Detail 2.11. Installation will vary according to material used.

Vegetated Toe Protection Measures

- *Vegetation:* Refer to MGWC 2.6: Natural Fiber Rolls
- *Live Fascines*: Refer to MGWC 2.5: Live Fascines
- *Crib Walls*: Refer to MGWC 2.9: Live Crib Walls

Rigid Toe Protection Measures

- *Riprap*: a rock toe designed to withstand the near-bed velocities of the design storm event can be used to increase the effectiveness of toe protection measures in moderate to high shear stress areas. Rocks should be sized and filter layers designed according to MGWC 2.1: Riprap and Figure 2.1.
- *Imbricated Riprap*: Refer to MGWC 2.2: Imbricated Riprap
- *Gabion*: Refer to MGWC 2.3: Gabion

3. The use of rock vanes (MGWC 3.3: Rock Vanes) should be considered to break up high velocities at the toe of any embankment where bank stabilization measures are to be employed. Additionally, grade control structures such as weirs and step pool sequences should be used to enhance channel bed stability in reaches that are actively incising or may be subjected to upstream migrating instabilities.

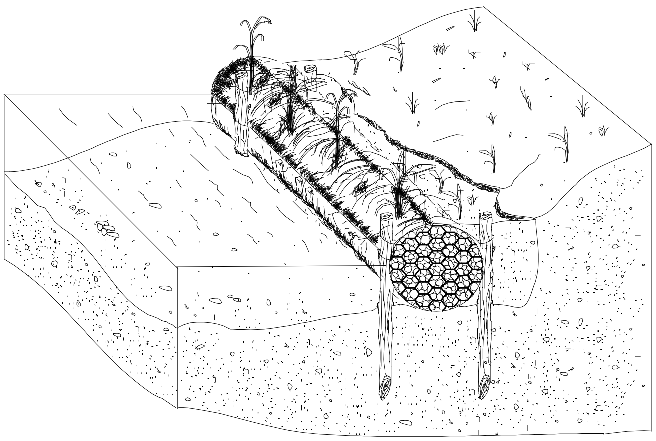
4. Once construction is completed, the diversion should be removed from upstream to downstream. Sediment control devices, including perimeter erosion controls, are to remain in place until all disturbed areas are stabilized in accordance with an approved sediment and erosion control plan and the inspection authority approves their removal.

Maryland's Guidelines To Waterway Construction

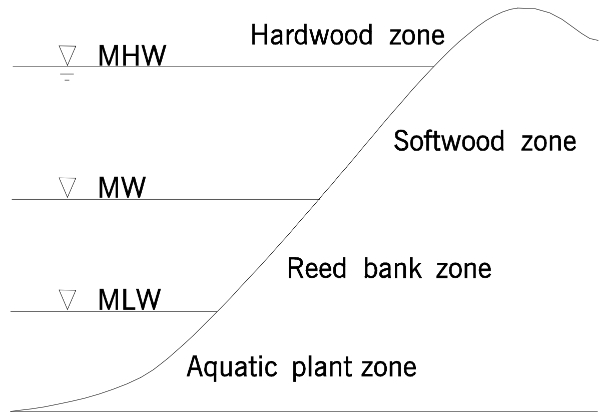
DETAIL 2.11(a): TOE PROTECTION

AREAS OF LOW SHEAR STRESS

MGWC 2.6: natural fiber roll

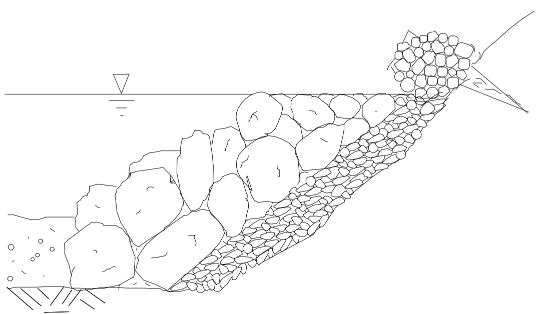


MGWC 3.11: bank vegetation

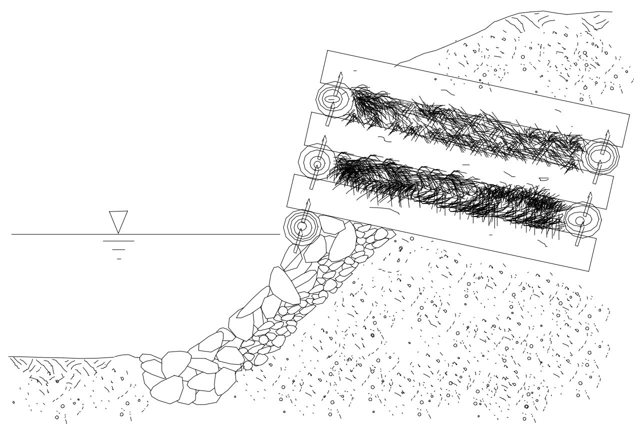


AREAS OF MODERATE SHEAR STRESS

MGWC 2.1/2.5: fascine w/rock toe

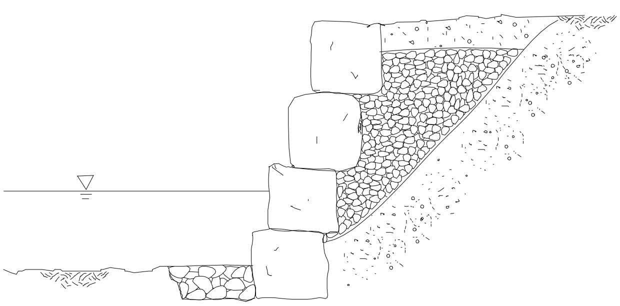


MGWC 2.1/2.9: crib wall w/rock toe

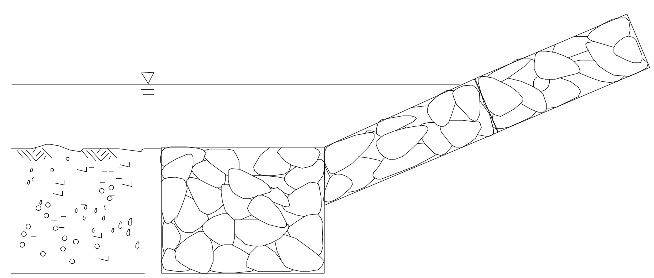


AREAS OF HIGH SHEAR STRESS

MGWC 2.2: imbricated riprap



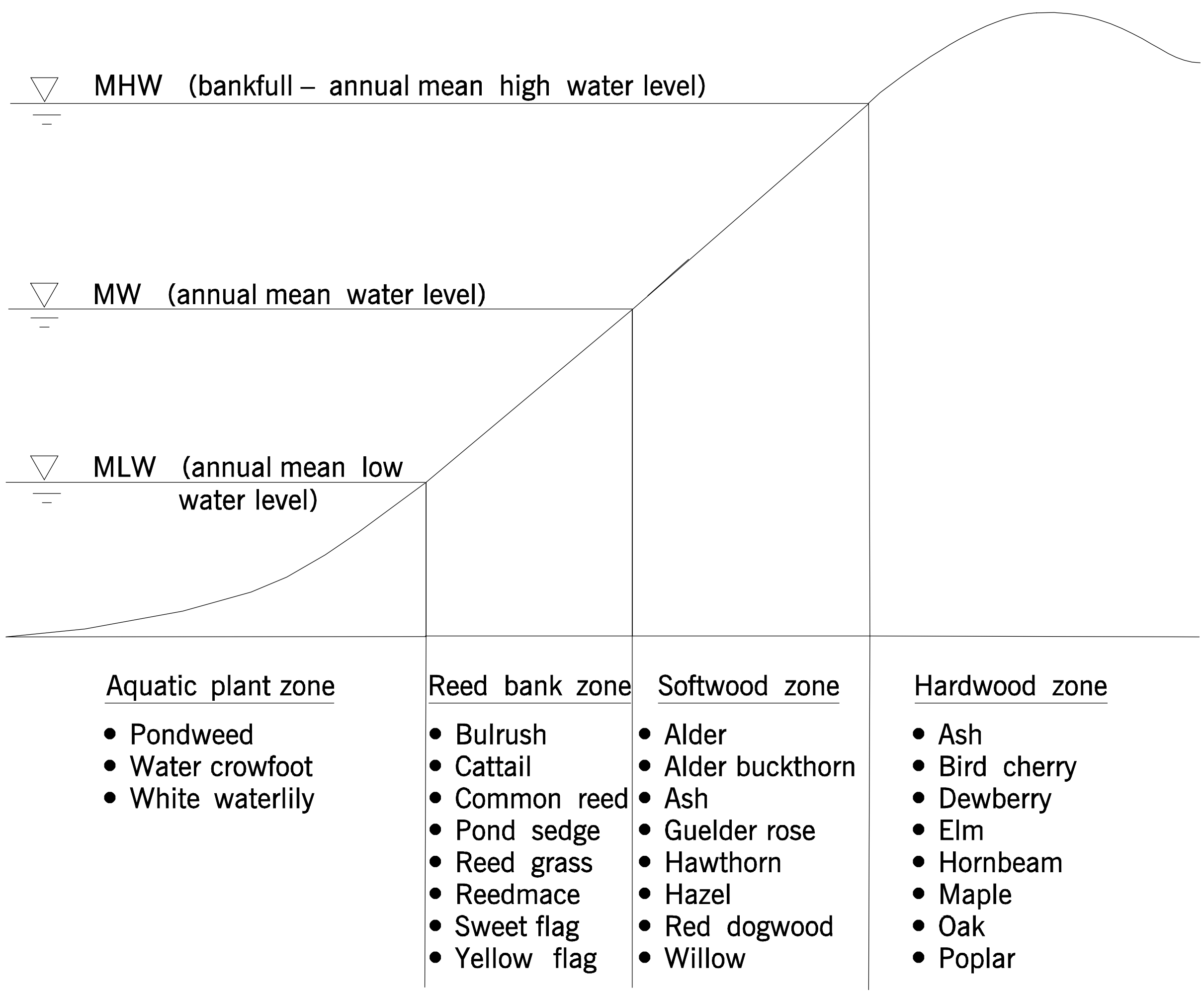
MGWC 2.3: gabion revetment



DETAIL 2.11(b): TOE PROTECTION

Adapted From Seibert (1968)

RIPARIAN VEGETATION ACCORDING TO BANK ZONE



SECTION 3

CHANNEL STABILIZATION & REHABILITATION TECHNIQUES

PAGE

MGWC 3.1: BOULDER PLACEMENT

Improvement/creation of aquatic habitat

DESCRIPTION

The work should consist of placing boulders in stream channels to encourage riffles and pools and to provide habitat and spawning areas for aquatic life.

EFFECTIVE USES & LIMITATIONS

When properly utilized, boulder placements create small scour pools and eddies which can be used as rearing areas for salmonids and other fish. Additionally, they are sometimes used to restore meanders and pools in channelized reaches and to protect eroding streambanks by deflecting flow. Boulder placements are most effective when used in the following conditions:

- moderately wide, shallow, high velocity streams with gravel or cobble beds;
- stream reaches with pool densities less than 20 percent; and
- Rosgen stream types B3 and B4.

Boulder placements should be avoided in the following areas:

- channels which do not have sufficient particle size ranges to develop armor layers such as streams with fine, noncohesive bed material such as sand or small gravel that will scour deeply and rapidly, thereby undermining and burying boulder groups,
- channels with highly erodible embankment soils or soils with an extreme excess of one texture or size range unless measures are taken to adequately reinforce the banks;
- low-velocity streams with a mean velocity of less than about 2 feet (0.6 meters) per second, since sufficient scour pools cannot be developed;
- newly formed stream curvatures since boulder clusters can alter natural patterns of stream meander resulting in erosion and scour problems;
- and overwide streams or streams with large bedload.

MATERIAL SPECIFICATIONS

Boulders should be chosen based upon stream size, flow characteristics, bed stability, desired habitat effects such size and position of resultant scour pools and eddies, and the capacity of available heavy equipment. Boulder diameters of 2 to 5 feet (0.6 to 1.5 meters) and volumes of 35 to 70 cubic feet (1 to 2 cubic meters) have been suggested for this restoration practice. It is recommended, however, that boulders be sized according to guidelines developed for riprap placement found in MGWC 2.1: Riprap and that footers be provided. However, boulders should not be more than 25 to 30% of bankfull depth after partial embedment. Blocky, angular rock should be used in place of round rock when feasible.

Boulder diameters should be no more than 1/8 the width of the stream. If a larger size is to be used, bank stabilization measures should be considered.

Approximate Cost ($1999):
$583 per ten boulders

MGWC 3.1: BOULDER PLACEMENT

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. Boulder placement should proceed as follows (refer to Detail 3.1):

1) Complete the work during periods of low flow to ensure proper location within the stream channel and to facilitate the movement of heavy equipment.

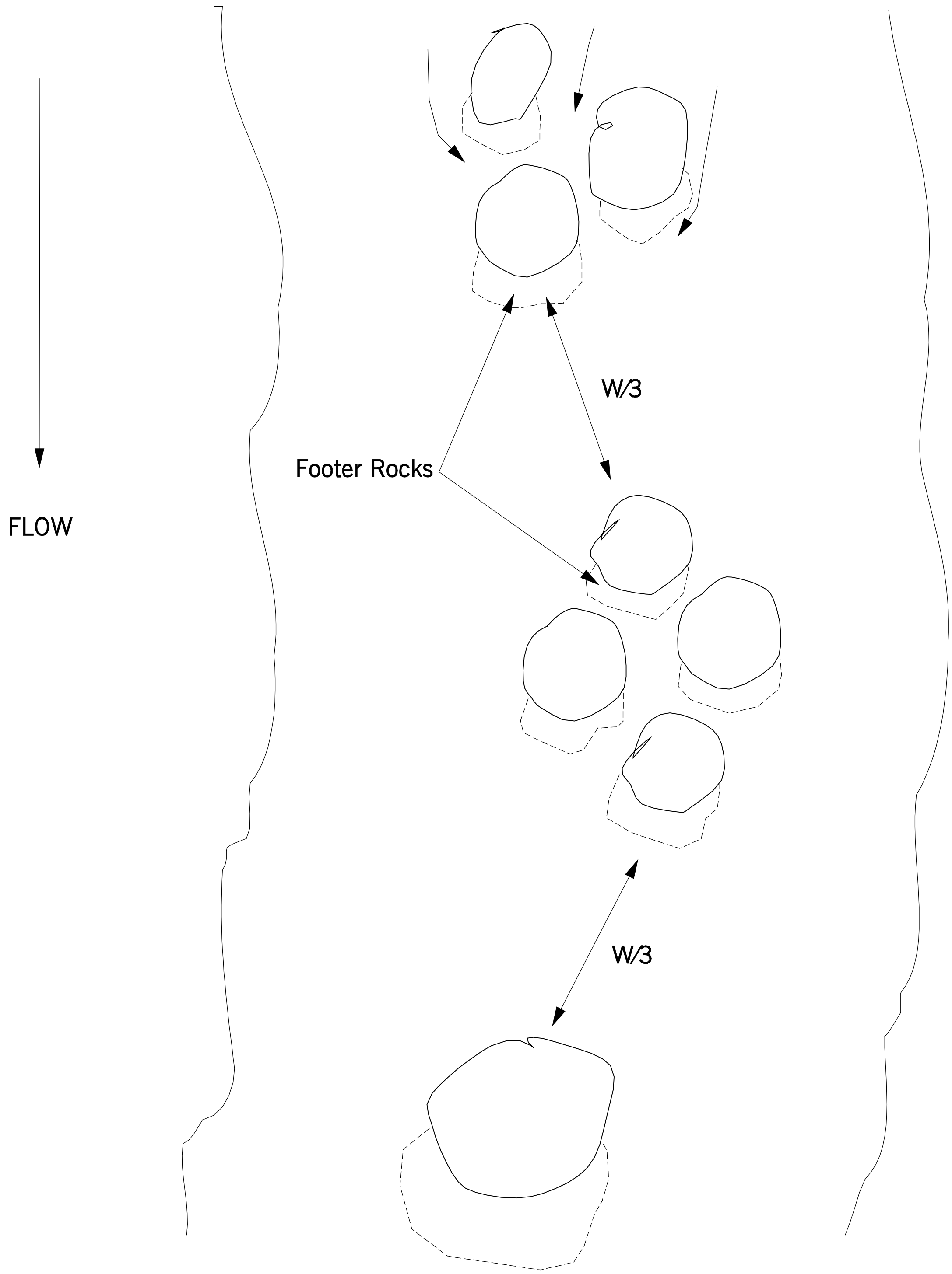
2) Boulders shall be placed on top of footer rocks(s) so that the boulder is offset in the upstream direction.

3) Place clusters comprised of 3 to 5 boulders arranged in a triangular configuration in the downstream half of long riffles, sufficiently far from the associated pool, and embed them in the stream bed to increase the cluster's stability. The substrate in which boulders are placed should be competent enough to resist undercutting.

4) Space multiple boulder clusters constructed in the same stream section a minimum of 1/3 of a stream width apart. Avoid an overabundance of newly placed boulders since this can inhibit the natural process of sediment flushing.

Maryland's Guidelines To Waterway Construction

DETAIL 3.1: BOULDER PLACEMENT



MGWC 3.2: LOG VANES

Rigid engineering techniques for bank stability and creation of flow diversity

DESCRIPTION

The work should consist of installing log vanes to direct normal flows away from unstable stream banks and to improve/create aquatic habitat by enhancing flow diversity through the formation of scour pools.

EFFECTIVE USES & LIMITATIONS

Log vanes are single-arm structures which are partially embedded in the streambed such that they are submerged even during low flows. When properly positioned, log vanes induce secondary circulation of the flow thereby promoting the development of scour pools. Log vanes can also be paired and positioned in a channel reach to initiate meander development or migration.

Additionally, the following limitations apply to log vanes:

- Vanes should be used carefully in vertically unstable streams unless measures have been taken to promote stream stability so that it may retain a constant planform and dimension without signs of migration or incision
- Vanes are ineffective in bedrock channels since minimal bed scouring occurs. Conversely, log vanes should be used carefully in streams with fine sand, silt, or otherwise unstable substrate since significant undercutting can destroy these measures.
- Vanes should not be used in stream reaches which exceed a 3% gradient.
- Vanes should not be used in streams with large sediment or debris loads.
- Vanes are best suited to Rosgen types B2-B5 and C2-C4.
- Banks opposite these structures should be monitored for excessive erosion.

MATERIAL SPECIFICATIONS

Materials for vanes should meet the following requirements:

Logs: Single logs should be at least 8 to 10 inches (20 to 25 centimeters) in diameter. Smaller logs should be bolted securely together.

Approximate Cost ($1999):
$406 per single wing vane

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. Recommended construction requirements for log vanes are as follows (refer to Detail 3.2):

1. The stream should be diverted according to an approved practice, and the construction area should be dewatered.

2. Combinations of log vanes should be installed according to a plan approved by the WMA. When placed to initiate meander development, vanes should be spaced 5 to 7 stream bankfull widths apart and arranged on

alternating banks. Vanes used for habitat creation should be spaced 1 or more channel widths apart depending upon the pattern of scour pools in natural reference reaches. Additionally, the following primary design criteria need to be satisfied: shape and orientation, height, and length.

- *Shape and orientation*. Vanes should be angled 20 to 30 degrees from the upstream bank.
- *Height*. The bank-end of the vane should be at the bankfull elevation and the tip of the vane should be partially embedded in the streambed such that it is submerged even during low flows. The vane should be placed at a vertical angle of 3% to 7%.
- *Length*. Vanes should span a maximum of 1/3 of the channel width, depending on the channel size. Channels less than 20 feet may require a vane to extend 1/2 of the channel width. The larger the channel, the shorter the vane should be relative to the channel width.

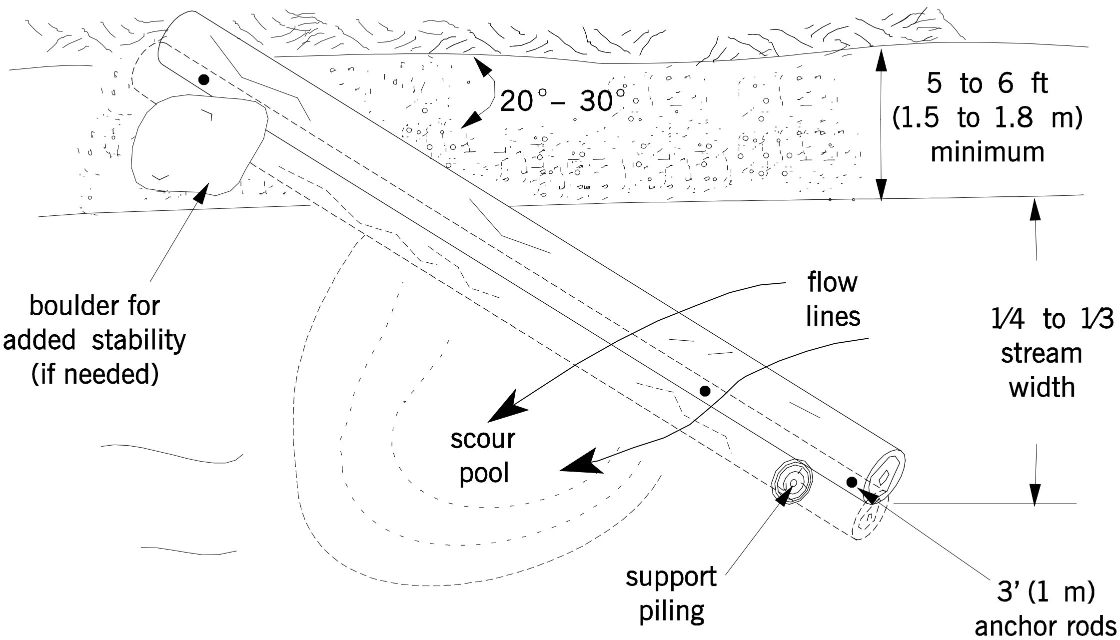
1. When installing vanes, the bank end of the structure should be firmly anchored a minimum of 5 to 6 feet (1.5 to 1.8 meters) into the slope. When two or more smaller logs are used in place of one larger log, they should be anchored to each other with 3-foot (0.9-meter) rods of 1/2 to 5/8-inch (1.3 to 1.6-cm) diameters. The rods should be driven in until a 4-inch (10-centimeter) tail remains, which should be bent in a downstream direction. When necessary, the logs may also be secured with cables. Log structures should be anchored to the stream bed with support pilings with lengths exceeding probable scour depths.

2. Large rocks can be positioned on the downstream face of the vanes to provide further stability. The rocks should be installed in accordance with MGWC 3.1 Boulder Placement.

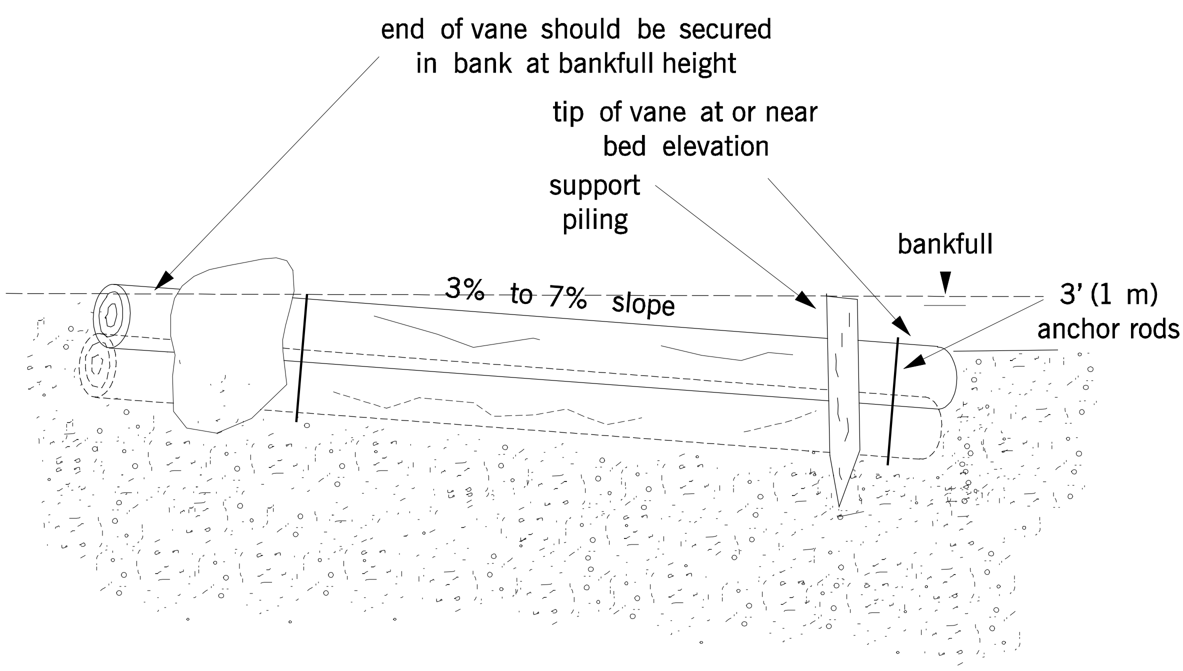
3. All disturbed areas should be permanently stabilized in accordance with an approved sediment and erosion control plan.

DETAIL 3.2(a): LOG VANES

PLAN VIEW: LOG VANE



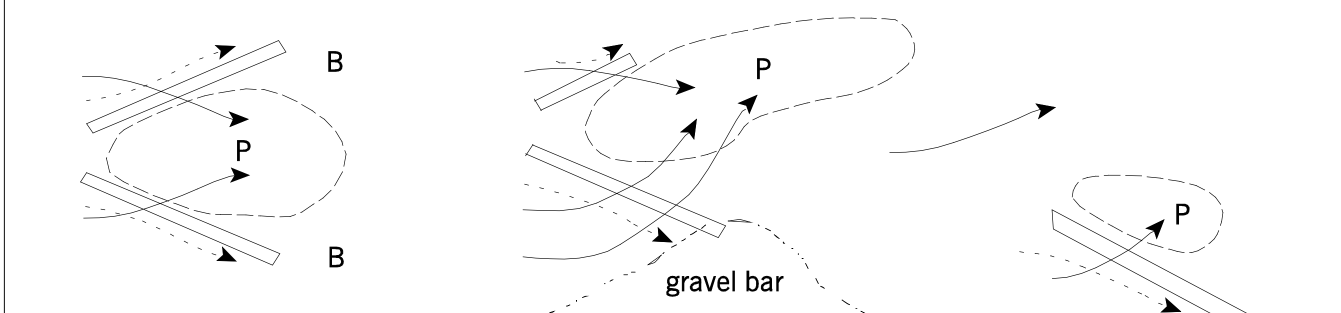
SECTION VIEW: LOG VANE



Maryland's Guidelines To Waterway Construction
DETAIL 3.2(b): ALTERNATIVE VANE PLACEMENT

PLAN VIEW: ALTERNATIVE VANE CONFIGURATIONS

Source: Hey (1995)



Symmetrical Asymmetrical Straight

LEGEND:

P, pool; B, bar; E, bank erosion; ——▷ main/surface flow; - - - ▷ near bed flow; — — ▷ over topping flow

MGWC 3.3: ROCK VANES

Rigid engineering techniques for bank stability and creation of flow diversity

DESCRIPTION

The work should consist of installing rock vanes to direct normal flows away from unstable stream banks and to improve/create aquatic habitat by enhancing flow diversity through the formation of scour pools.

EFFECTIVE USES & LIMITATIONS

Rock vanes are single-arm structures which are partially embedded in the streambed such that they are submerged even during low flows. When properly positioned, rock vanes induce secondary circulation of the flow thereby promoting the development of scour pools. rock vanes can also be paired and positioned in a channel reach to initiate meander development or migration.

Additionally, the following limitations apply to rock vanes:

- Vanes should not be used in unstable streams unless measures have been taken to promote stream stability so that it may retain a constant planform and dimension without signs of migration or incision
- Vanes are ineffective in bedrock channels since minimal bed scouring occurs. Conversely, streams with fine sand, silt, or otherwise unstable substrate should be avoided since significant undercutting can destroy these measures. In these streams, log vanes may be considered.
- Vanes should not be used in stream reaches which exceed a 3% gradient.
- Vanes should not be used in streams with large sediment or debris loads.
- Vanes are best suited to Rosgen types B2-B5 and C2-C4.
- Banks opposite these structures should be monitored for excessive erosion.

MATERIAL SPECIFICATIONS

Materials for vanes should meet the following requirements:

Large Rocks: Large rocks for vane construction should be sized to withstand the design flood according to MGWC 2.1: Riprap and Figure 2.1. In general, rock sizes should have a minimum of 2.5 median diameter or weigh a minimum of 200 pounds. Additionally, large rocks and boulders can be positioned on the downstream side of straight vanes to provide further stability.

Approximate Cost ($1999):
$406 per single wing vane

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. Recommended construction requirements for rock vanes are as follows (refer to Detail 3.3):

1. The stream should be diverted according to an approved practice, and the construction area should be dewatered.

2. Combinations of rock vanes should be installed according to a plan approved by the WMA. When placed to initiate meander development, vanes should be spaced 5 to 7 stream bankfull widths apart and arranged on alternating banks. Vanes used for habitat creation should be spaced 1 or more channel widths apart depending upon the pattern of scour pools in natural reference reaches. Additionally, the following primary design criteria need to be satisfied: shape and orientation, height, and length.

   - *Shape and orientation*. Vanes should be angled 20 to 30 degrees from the upstream bank.

   - *Height*. The bank-end of the vane should be at the bankfull elevation and the tip of vane should be partially embedded in the streambed such that it is submerged even during low flows. The vane arm should be placed at a vertical angle of 3% to 7%.

   - *Length*. Vanes should span a maximum of 1/3 of the channel width, depending on the channel size. The larger the channel, the shorter the vane should be relative to the channel width.

3. When installing vanes, the bank end of the structure should be firmly anchored a minimum of 2-3 rocks into the bank.

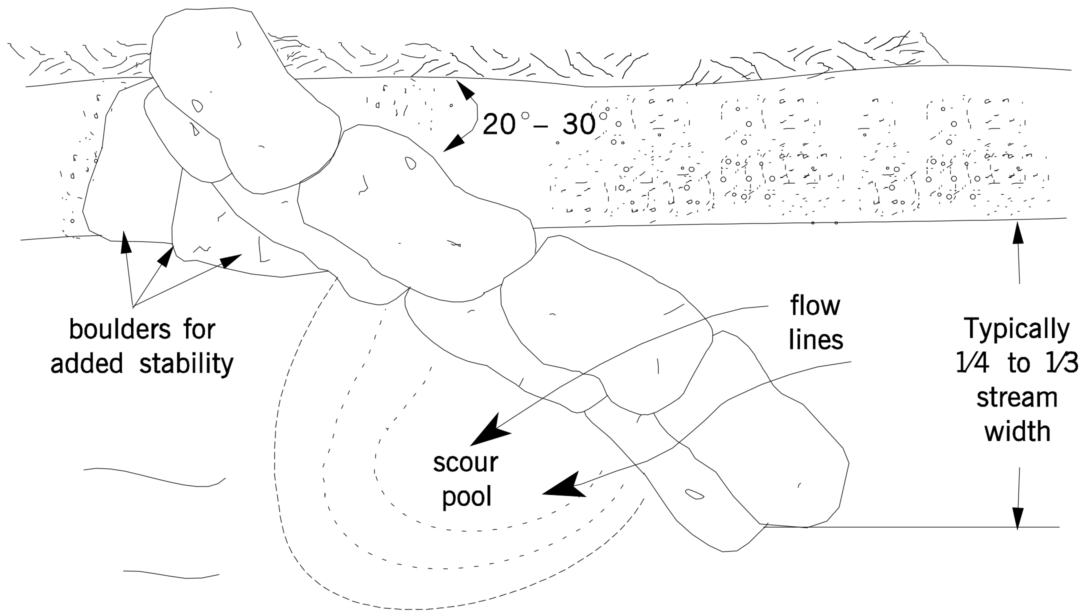
4. All rocks should touch adjacent rocks to form a tight fit. Vane rocks shall be placed on top of footer rocks so that each vane rock rests upon two halves of each footer rock below, and so that the vane rock is offset in the upstream direction. Vane rocks shall be shingled upstream.

5. All disturbed areas should be permanently stabilized in accordance with an approved sediment and erosion control plan.

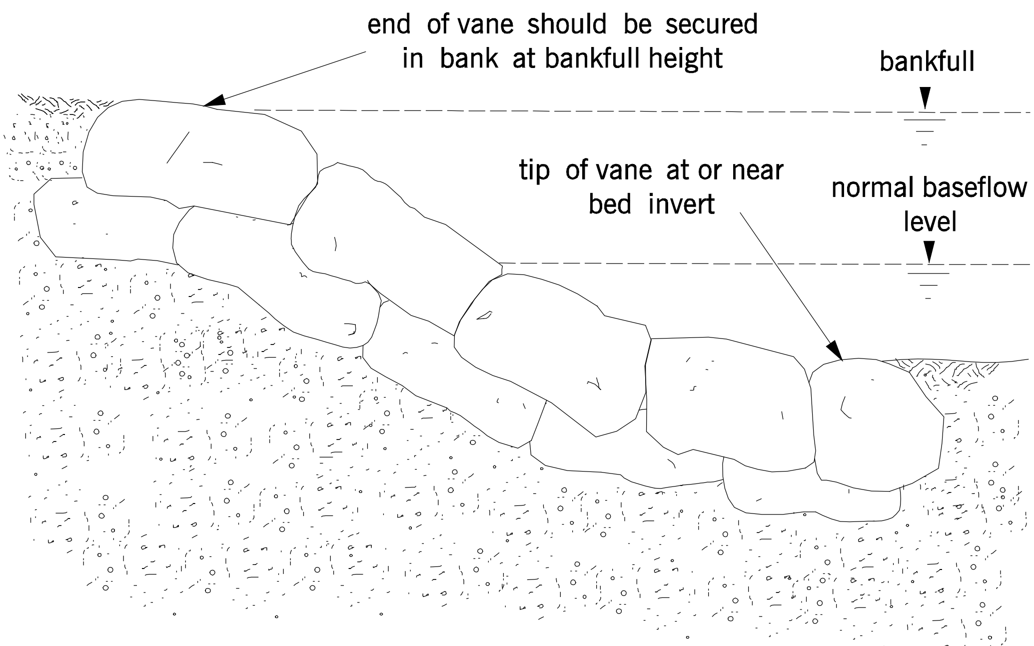
DETAIL 3.3(a): ROCK VANES

Section & Plan Views Adapted From Rosgen (1999)

PLAN VIEW: ROCK VANE



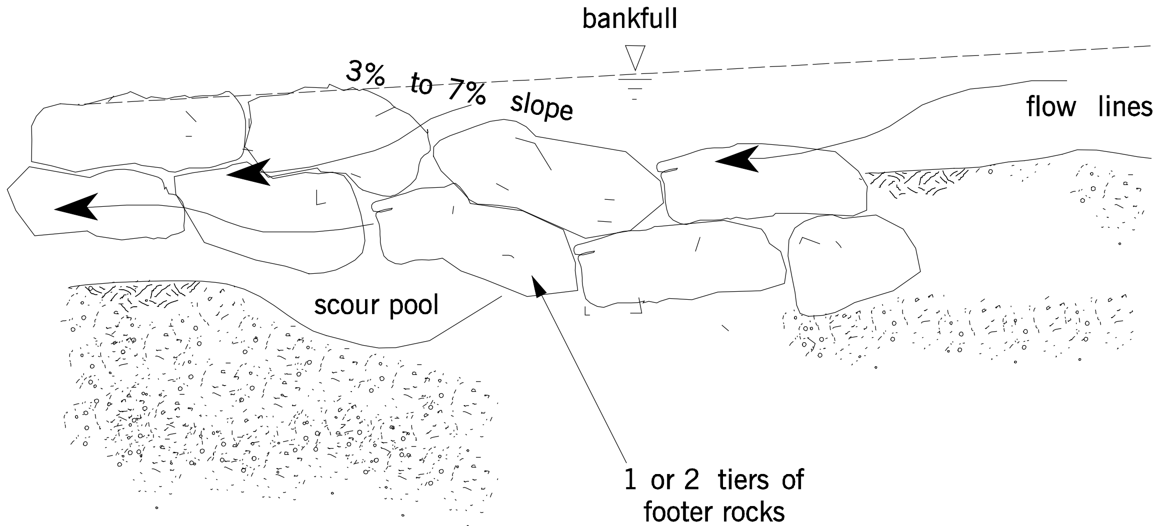
SECTION VIEW: ROCK VANE



DETAIL 3.3(b): ROCK VANES

Section & Plan Views Adapted From Rosgen (1999)

PROFILE VIEW: STRAIGHT VANE



MGWC 3.4: J-HOOK VANES

> *Rigid engineering techniques for bank stability and creation of flow diversity*

DESCRIPTION

The work should consist of installing rock vanes to direct normal flows away from unstable stream banks and to improve/create aquatic habitat by enhancing flow diversity through the formation of scour pools.

EFFECTIVE USES & LIMITATIONS

J-hook vanes are single-arm structures whose tip is placed in a "J" configuration and partially embedded in the streambed such that they are submerged even during low flows. When properly positioned, J-hook vanes induce secondary circulation of the flow thereby promoting the development of scour pools. J-hook vanes can also be paired and positioned in a channel reach to initiate meander development or migration.

Additionally, the following limitations apply to J-hook vanes:

- J-hook vanes should not be used in unstable streams unless measures have been taken to promote stream stability so that it may retain a constant planform and dimension without signs of migration or incision
- J-hook vanes are ineffective in bedrock channels since minimal bed scouring occurs. Conversely, streams with fine sand, silt, or otherwise unstable substrate should be avoided since significant undercutting can destroy these measures.
- J-hook vanes should not be used in stream reaches which exceed a 3% gradient.
- J-hook vanes should not be used in streams with large sediment or debris loads.
- J-hook vanes are best suited to Rosgen types B2-B5 and C2-C4.
- Banks opposite these structures should be monitored for excessive erosion.

MATERIAL SPECIFICATIONS

Materials for vanes should meet the following requirements:

Large Rocks: Large rocks for vane construction should be sized to withstand the design flood according to MGWC 2.1: Riprap and Figure 2.1. In general, rock sizes should have a minimum of 2.5 median diameter or weigh a minimum of 200 pounds. Footer rocks should be long and flat.

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. Recommended construction requirements for J-hook vanes are as follows (refer to Detail 3.4):

1. The stream should be diverted according to an approved practice, and the construction area should be dewatered.

2. Combinations of J-hook vanes should be installed according to a plan approved by the WMA. When placed to initiate meander development, vanes should be spaced 5 to 7 bankfull widths apart and arranged on alternating banks. Vanes used for habitat creation should be spaced 1 or more channel widths apart depending upon the pattern of scour pools in natural reference reaches. Additionally, the following primary design criteria need to be satisfied: shape and orientation, height, and length.

- *Shape and orientation*. Vanes should be angled 20 to 30 degrees from the upstream bank.

- *Height*. The bank-end of the vane should be at the bankfull elevation and the tip of vane should be partially embedded in the streambed such that it is submerged even during low flows. This tip should be placed to form a semi-circular structure at the streambed. The vane arm should be placed at a vertical angle of 3% to 7%.

- *Length*. Vanes should span a maximum of 1/3 of the channel width, depending on the channel size. J-hooks may span up to 60% of the channel width. The larger the channel, the shorter the vane should be relative to the channel width.

3. When installing vanes, the bank end of the structure should be firmly anchored a minimum of 1-2 rocks into the bank.

4. Vane rocks should be placed on top of footer rocks such that each vane rock touches adjacent rocks and rests upon two halves of each footer rock below it, and so that the vane rock is offset in the upstream direction. Vane rocks shall be shingled upstream.

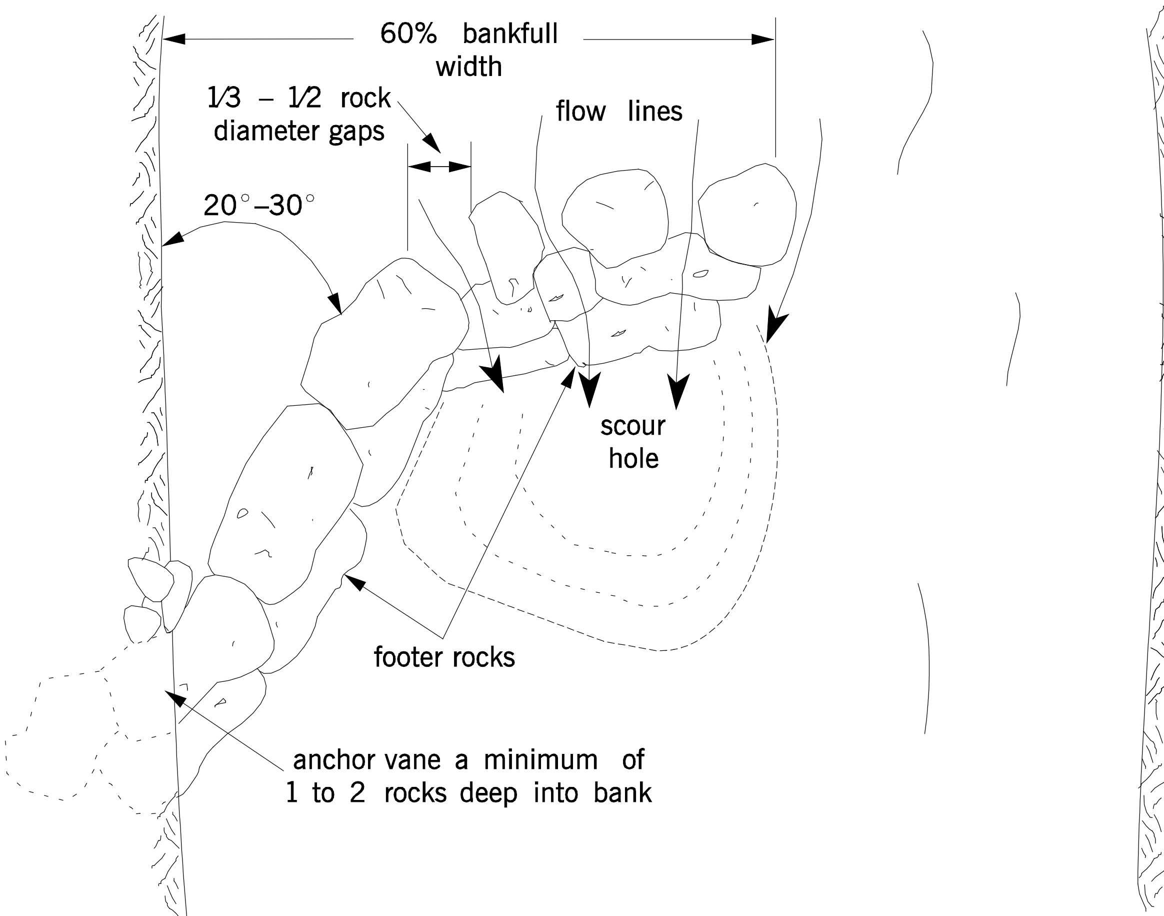
5. All disturbed areas should be permanently stabilized in accordance with an approved sediment and erosion control plan.

Maryland's Guidelines To Waterway Construction

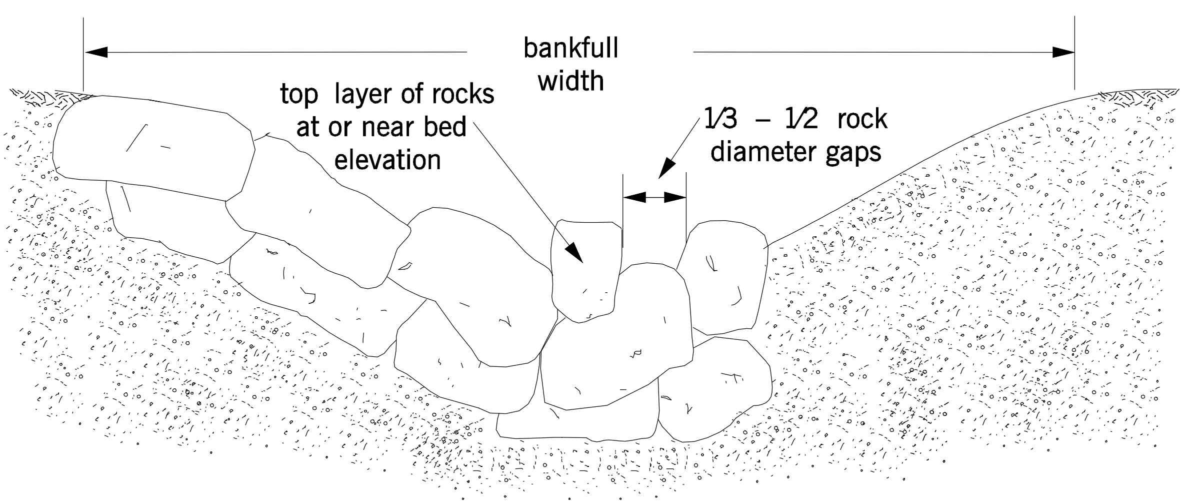
DETAIL 3.4(a): J–HOOK VANES

Section & Plan Views Adapted From Rosgen (1999)

PLAN VIEW: J–HOOK VANE



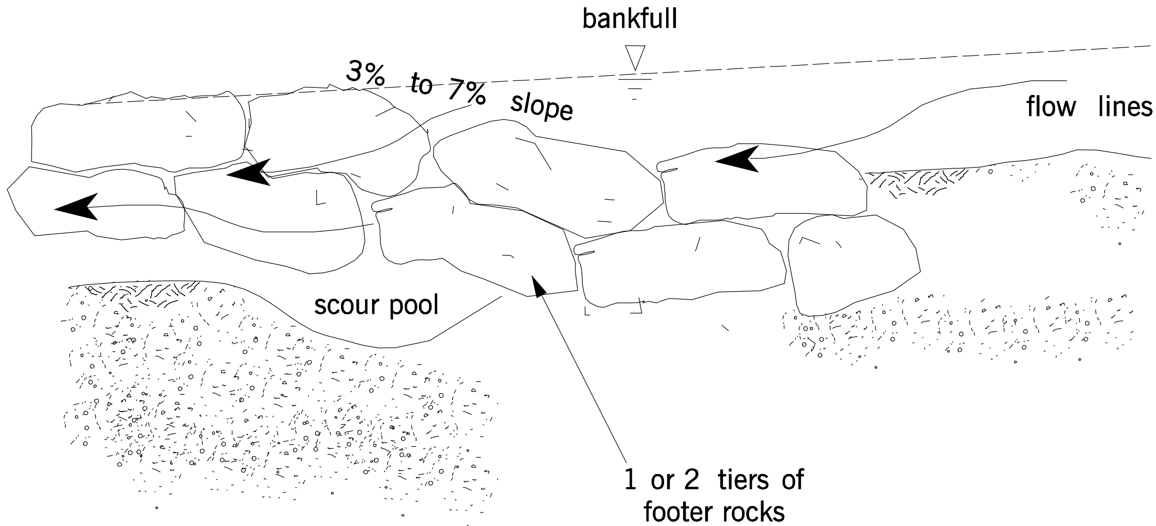
SECTION VIEW: J–HOOK VANE



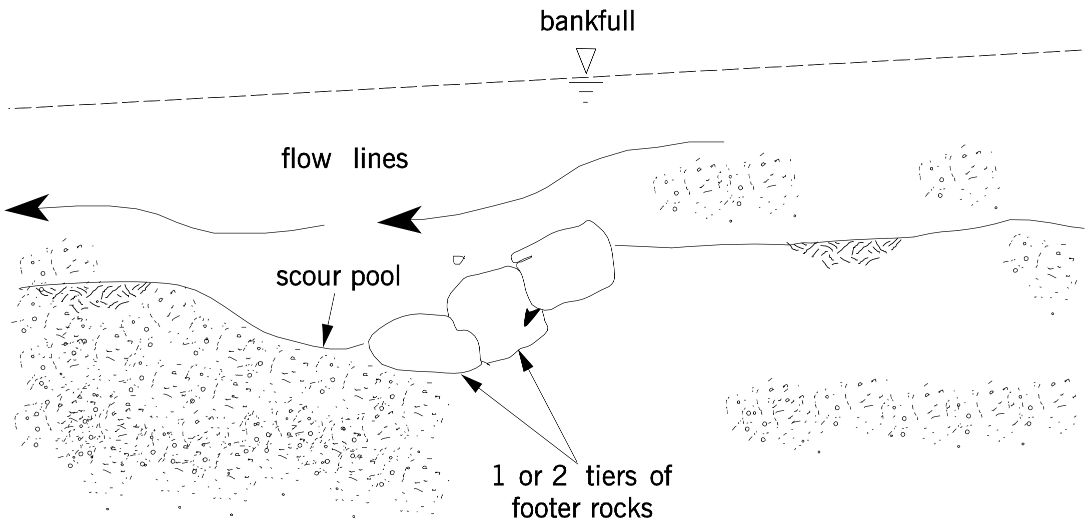
DETAIL 3.4(b): J–HOOK VANES

Section & Plan Views Adapted From Rosgen (1999)

PROFILE VIEW OF VANE ARM



PROFILE VIEW OF J–HOOK



MGWC 3.5: STREAM DEFLECTORS

Rigid engineering techniques for creation of aquatic habitat

DESCRIPTION

The work should consist of installing stream deflectors to provide flow diversity for aquatic habitat.

EFFECTIVE USES & LIMITATIONS

Structures which limit channel width thereby accelerating normal flows through the constricted section are referred to as stream deflectors. Single-wing and triangular deflectors are the two most commonly used types of this measure. Single-wing deflectors consist of a main log or placed rock angled downstream as shown in Detail 3.5. Log wing deflectors consist of a triangular log frame filled with tightly packed rock. When properly constructed either singly or in series in low gradient meandering streams, deflectors divert base flows towards the center of the channel and, under certain conditions, increase the depth and velocity of flow thereby creating scour pools and enhancing fish habitat. Channel constrictors, or paired deflectors on opposite banks, are well suited to shallow stream reaches where the flow needs to be contracted significantly to produce the required velocities to scour the channel bottom. Backwater effects caused by channel constrictors facilitate gravel deposition upstream thereby improving spawning habitat for fish. Stream deflectors should be constructed in the lower half of long riffles to prevent undesired backwater effects from reaching upstream.

Additionally, the following limitations apply to stream deflectors:

- Deflectors should not be used in unstable streams which do not retain a constant planform or are actively incising at a moderate to high rate.
- Deflectors are ineffective in bedrock channels since minimal bed scouring occurs. Conversely, streams with fine sand, silt, or otherwise unstable substrate should be avoided since significant undercutting can destroy these measures.
- Deflectors should not be used in stream reaches which exceed a 3% gradient.
- Deflectors should not be used in streams with large sediment or debris loads.
- Single-wing deflectors are best suited to Rosgen types B2-B5 and C2-C4.
- Banks opposite these structures should be monitored for excessive erosion.

MATERIAL SPECIFICATIONS

Materials for deflectors should meet the following requirements:

Logs: Single logs should be at least 8 to 10 inches (20 to 25 centimeters) in diameter. Smaller logs should be bolted securely together.

Riprap: Riprap for log frame deflectors should be washed and have a minimum diameter of 6 inches (15 centimeters).

Large Rocks: Large rocks can be substituted for frame logs in triangular deflectors provided they are sized to withstand bankfull velocities according to MGWC 2.1: Riprap. Additionally, large rocks and boulders can be positioned on the downstream side of straight and triangular deflectors to provide further stability.

MGWC 3.5: STREAM DEFLECTORS

Approximate Cost ($1999):
$406 per single wing deflector

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. Recommended construction requirements for stream deflectors are as follows (refer to Detail 3.5):

1. The stream should be diverted according to an approved practice, and the construction area should be dewatered.

2. Combinations of log and/or stone deflectors should be installed according to a plan approved by the WMA. When deflectors are used in series for bank protection, they should be spaced one or more stream widths apart (as measured along the bank). When placed to initiate meander development, deflectors should be spaced 5 to 7 stream widths apart and arranged on alternating banks. Additionally, the following primary design criteria need to be satisfied: shape and orientation, height, and length.

   Shape and orientation. Deflectors should be positioned to conform with the natural meander of the stream and should not exceed a downstream angle of 30 to 40 degrees with the stream bank. The greater the flow velocity, the smaller the angle of deflection should be in the specified range. Angles greater than 40 degrees may result in erosion of the opposite bank and expose the structure to more direct forces. In faster flowing streams and rivers, a separation zone can form downstream of the deflector thereby accelerating bank erosion. To avoid this problem with triangular deflectors, the angle of the trailing edge of the deflector can be reduced to allow for the gradual expansion of the flow.

   Height. No more than 6 inches (15 cm) of the deflector should be above the normal flow level.

   Length. The distance from the stream bank to the tip of the deflector should be no more than 1/2 of the channel width, depending on the channel size. The larger the channel, the shorter the deflector should be relative to the channel width. Additionally, straight or angled deflectors may extend a maximum of 3/4 of the channel in grossly over-widened and ponded reaches.

3. When installing single-wing deflectors, all logs should be firmly anchored into the stream bank a minimum of 5 to 6 feet (1.5 to 1.8 meters). Additionally, when two or more smaller logs are used in place of one larger log, they should be anchored to each other with 3-foot (0.9-meter) rods of 1/2 to 5/8-inch (1.3 to 1.6-centimeter) diameters. The rods should be driven in until a 4-inch (10-centimeter) tail remains, which should be bent in a downstream direction. When necessary, the logs may also be secured with cables. The log structures should be anchored to the stream bed with support pilings with lengths exceeding probable scour depths.

4. The first step in constructing a log wing deflector is to trench the main (upstream) log into the bank at a suitable angle in the specified range. The log should be anchored a minimum of 5 to 6 feet (1.5 to 1.8 meters) into the bank and secured to the stream bottom using 3 to 5-foot (1 to 1.5-meter) rebar pins spaced at five-foot (1.5-meter) intervals. Next, the brace, or downstream, log should be trenched into the bank so that it joins the main log at a 90 degree angle, positioned on top of the main log, cut to an exact fit, and pinned with 2-foot (0.6-meter) rebar pins. The main deflector log can overhang the brace log by a few feet to provide extra scouring effect if warranted. The brace log should also be secured to the stream bottom with rebar pins or some other measure. Once the frame is completed, stone should be tightly packed into the frame, and the connection between the logs and stream bank should be reinforced with larger stones for added stability and erosion control. If more than one layer of logs is used, heavy lumber should be sandwiched between the upper and lower main logs to provide a tighter, more secure fit.

MGWC 3.5: STREAM DEFLECTORS

If a wing deflector is to be constructed entirely from stone, rocks sized for bankfull flow according to MGWC 2.1: Riprap should be employed to form the upstream and downstream edges. Keying theses rocks into the bank and channel bed helps to stabilize the structure. Once the upstream and downstream edges are in position, dense, angular rock from 4 to 30 inches (10 to 75 centimeters) in diameter should be shingled against the frame to form the fill.

5. Channel constrictors, made from two deflectors, are designed to reduce the stream width from 25 to 80 percent depending on specific site conditions such as relative bank stability, substrate size, and design flow with associated hydraulic characteristics. At the midpoint of the structure, the constrictor should be roughly the height of the expected high stream flow. To allow for the expansion of flows passing through the constrictor, banks downstream should be reinforced against scour and erosion. If the constrictors are placed in series in straight reaches, they should be spaced according to step-pool configurations (see MGWC 3.9: Step Pools).

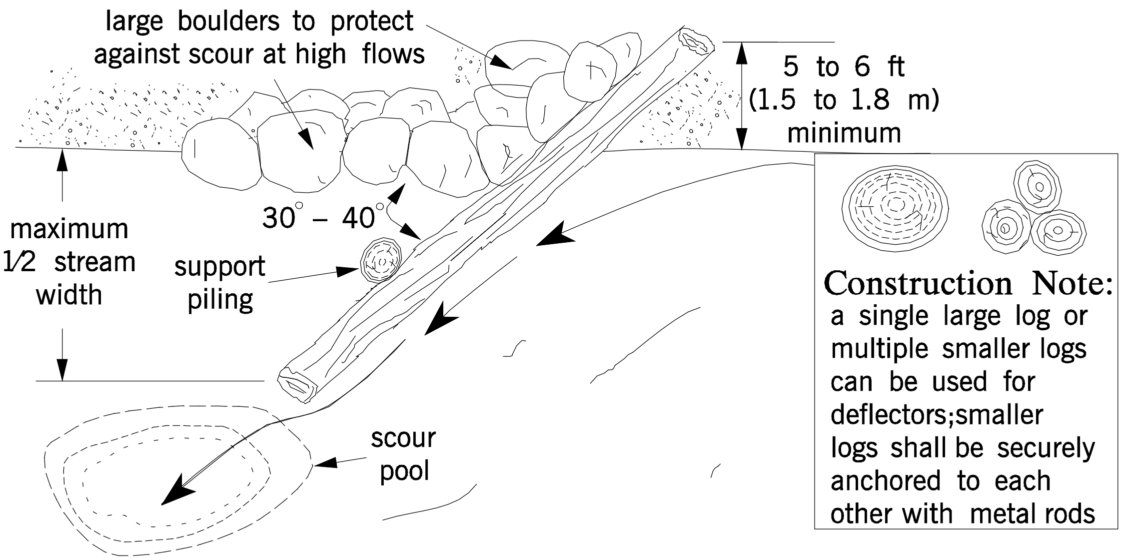
6. If necessary, the bank opposite the deflector should be reinforced against scouring effects with cover logs, riprap, or other measures. Additionally, large stones should be hand-placed on the downstream side of the deflectors to protect against scouring from flood flows since high flows which overtop the deflectors are directed into the bank.

7. All disturbed areas should be permanently stabilized in accordance with an approved sediment and erosion control plan.

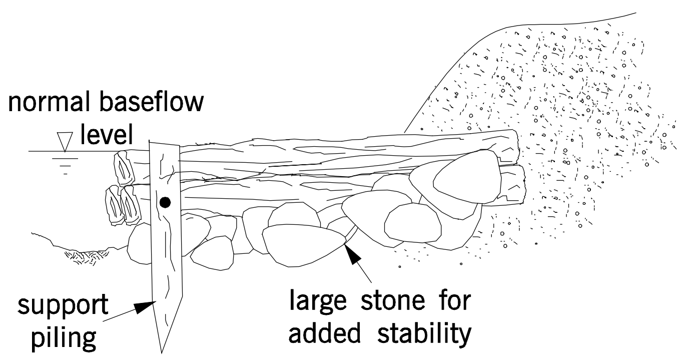
Maryland's Guidelines To Waterway Construction

DETAIL 3.5(a): STREAM DEFLECTORS

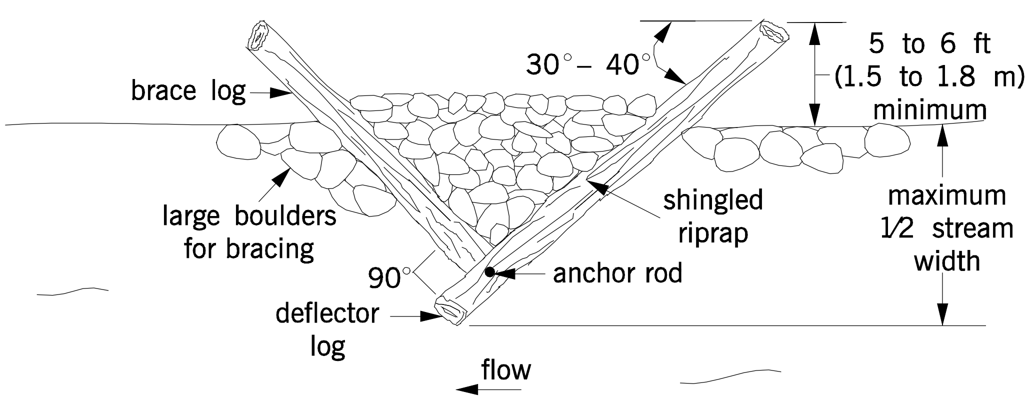
PLAN VIEW: LOG DEFLECTOR



SECTION VIEW: LOG DEFLECTOR



PLAN VIEW: LOG FRAME DEFLECTOR

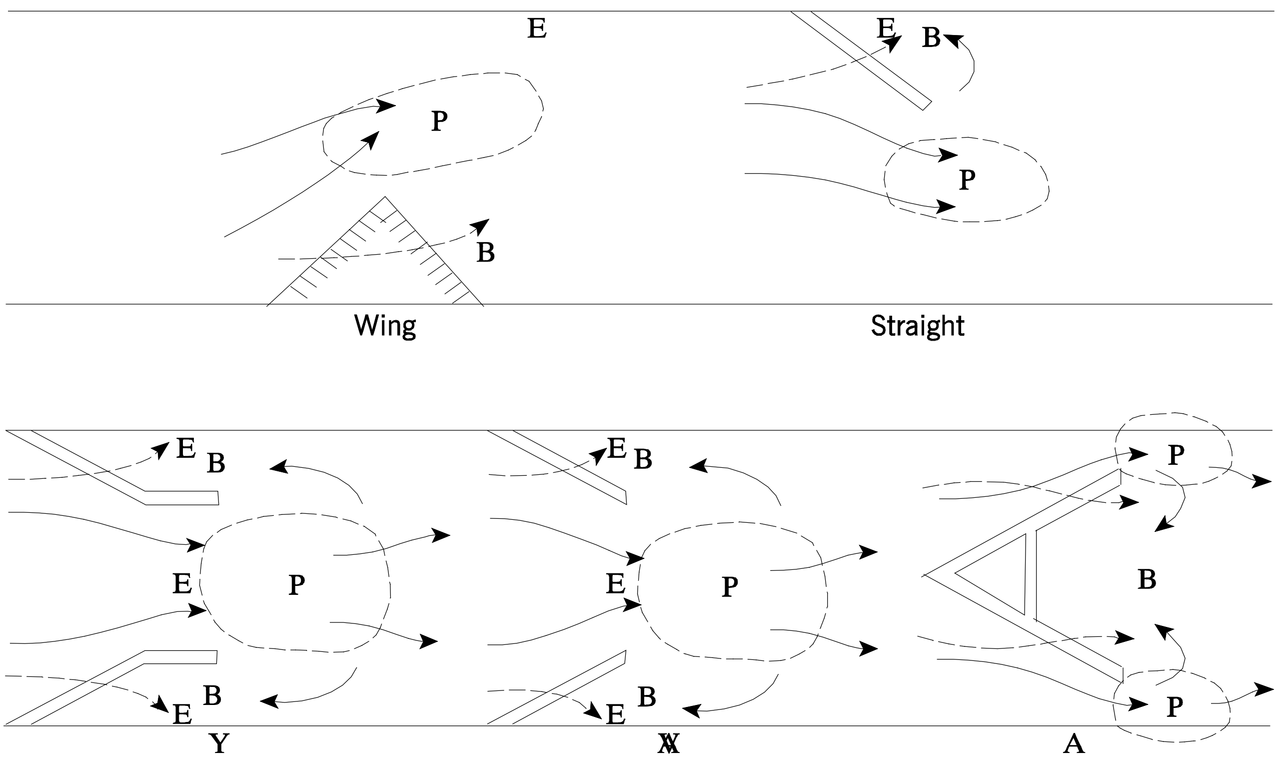


Maryland's Guidelines To Waterway Construction

DETAIL 3.5(b): STREAM DEFLECTORS

PLAN VIEW: ALTERNATIVE DEFLECTOR CONFIGURATIONS

Source: Hey (1995)



LEGEND:

P, pool; B, bar; E, bank erosion; ———▷ main/surface flow; - - - - ▷ near bed flow; — — —▷ over topping flow

MGWC 3.6: LOG & ROCK CHECK DAMS

Rigid engineering techniques for creation of aquatic habitat and channel grade control

DESCRIPTION

Low profile drop structures, such as check dams, are primarily used to create aquatic habitat in the form of scour pools and for grade control on actively incising streams and rivers.

EFFECTIVE USES & LIMITATIONS

Log and rock check dams are best suited to Rosgen stream types B3-B4, C3-C4, E3, and F3-F4. When constructed and spaced properly, check dams can simulate the natural pattern of pools and riffles occurring in undisturbed streams while forming gravel deposits which fish use as spawning grounds.

Check dams have also been used to prevent the movement of fine sediments into the mainstream channel, to aerate water, and to raise water levels past culvert invert elevations, thereby allowing fish passage.

Check dams should be avoided in the following areas:

- channels with bedrock beds or unstable bed substrates;
- channels without well developed, stable banks;
- streams with high bedload transport;
- streams with naturally well developed pools-riffle sequences; and
- reaches where the water temperature regime is negatively impacted when the current is slowed.

MATERIAL SPECIFICATIONS

Check dams, when used as stream restoration and grade control measures, are typically made of rocks, logs, or a combination of the two.

Riprap: Riprap for added stability, bank armoring, and toe protection should be capable of withstanding bankfull flow velocities and designed according to MGWC 2.1: Riprap.

Logs: Native, rot resistant wood such as Sycamore with a minimum diameter of 12 inches (0.30 meters) should be used when available. If more than one layer of logs is to be used, they should be hewn smooth so that they lie flat against each other. Before installation, the log(s) should be grooved or notched to concentrate low flows. On wider shallow streams with gravelly beds, large flat rocks or boulders sized according to MGWC 2.1: Riprap to resist bankfull flows and sealed with gravel and sand may be used in place of logs.

Approximate Cost ($1999):
$395 per log dam

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA. The recommended construction procedure for log and rock check dams should proceed as follows (refer to Detail 3.6):

MGWC 3.6: LOG & ROCK CHECK DAMS

1. The stream should be diverted according to a WMA recommended measure, and the construction area should be dewatered.

2. Check dams should be located in nonriffle areas where the bank is stable and of adequate height. The structure should be embedded as far as possible into the streambed and should be anchored a minimum of 1/3 of the stream width or 6 feet (1.8 meters) into the stream bank, whichever is greater. Generally, a crest height of 1 foot (0.3 meters) above the bed is sufficient for scour pool formation. (For further design guidance, refer to MGWC 3.9: Step Pools).

3. Once in place, the structure should be further secured against movement with rebar pins. Next, to prevent scour, geotextile fabric for scour prevention should be attached to the upstream portion of the log, buried at least 1 foot (0.30 meters) into the streambed, and backfilled with adequately sized rock. Once the excavated portion of the bank has been backfilled, it should be armored with aptly sized riprap, sod mats, or willow transplants to prevent erosion and scour from compromising the integrity of the structure.

4. Adjacent weirs should be spaced sufficiently far apart to allow for proper riffle or pool development according to step-pool and riffle-pool sequences as provided in MGWC 3.9: Step Pools. (Refer to the *1994 MD Standards and Specifications for Soil Erosion and Sediment Control* for spacing guidelines of check dams in ditches and swales.) Additionally, it has been recommended that the overall drop controlled by a set of two consecutive check dams should be less than 2 feet (0.6 meters) for stability purposes.

5. All disturbed sections of the channel, including the banks and streambed, should be stabilized with methods approved by the WMA.

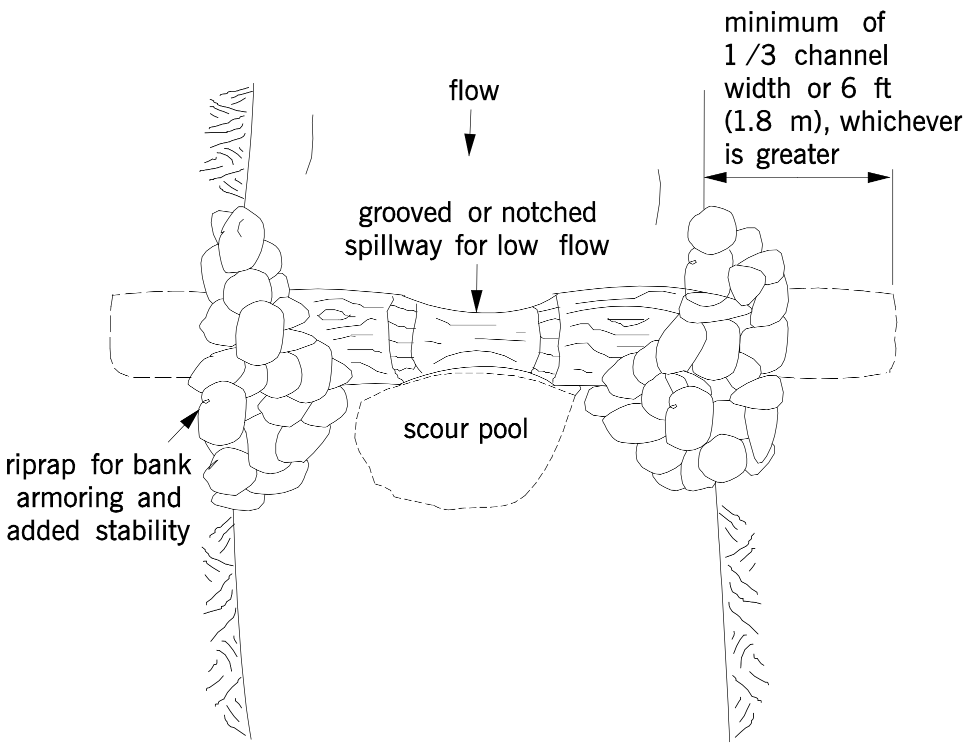
6. All check dams should be monitored to determine if:

   - their orientation and geometry (e.g., the height of the drop) hinder fish migration,
   - their performance is adversely affected by deposited sediment, and
   - their placement causes bank instabilities and undesirable lateral stream movement, especially in the vicinity of the plunge pools.

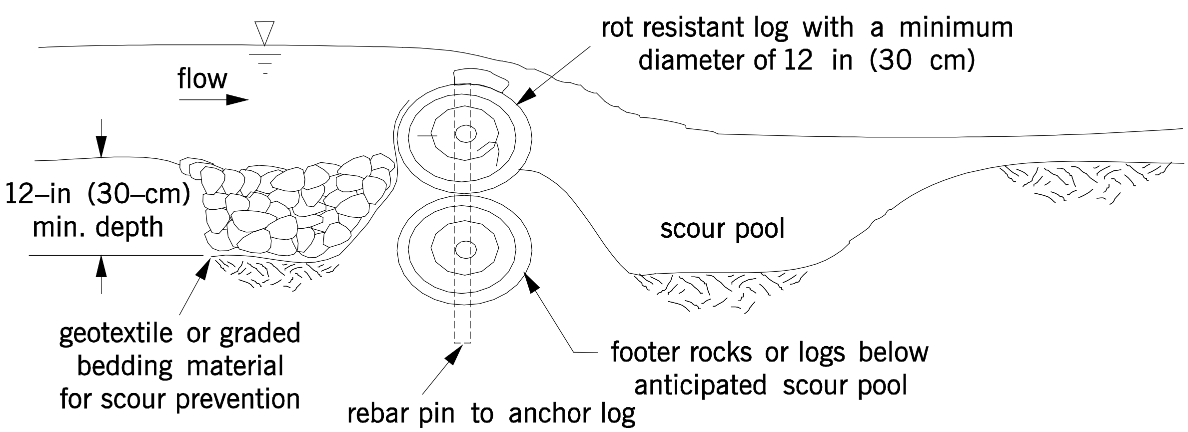
Maryland's Guidelines To Waterway Construction

DETAIL 3.6: LOG & ROCK CHECK DAMS

PLAN VIEW: SINGLE LOG WEIR



SECTION VIEW: SINGLE LOG WEIR



MGWC 3.7: WEIRS

Rigid engineering techniques for creation of aquatic habitat and channel grade control

DESCRIPTION

Low profile in-stream structures such as vortex rock weirs and w-weirs are primarily used to create aquatic habitat in the form of scour pools and for grade control on incising streams and rivers. Additionally, they are well-suited for channeling flow away from unstable banks.

EFFECTIVE USES & LIMITATIONS

Weirs are typically suited for use in moderate to high gradient streams. Vortex weirs are best suited to Rosgen stream types A3-A4, B3-B4, C3-C4, F3-F4, and G3-G4. W-weirs are best suited for types B3-B4, C3-C4, and F3-F4. Additionally, w-weirs are best used in rivers with bankfull widths greater than 40 feet (12 meters). When constructed and spaced properly, weirs can simulate the natural pattern of pools and riffles occurring in undisturbed streams while forming gravel deposits which fish use as spawning grounds. W-weirs can also be used to stabilize banks when designed properly.

Weirs should be avoided in channels with bedrock beds or unstable bed substrates, and streams with naturally well developed pool-riffle sequences.

MATERIAL SPECIFICATIONS

Rock and boulder material for the construction vortex weirs and w-weirs should meet the following requirements:

Vortex and Footer Rocks: Vortex rocks should be large enough to achieve the desired height when partially buried in the stream bed and should be sized to resist movement from shear stresses expected for the design flow. Footer rocks should be long and flat.

Riprap: Riprap for added stability, bank armoring, and toe protection should be capable of withstanding bankfull flow velocities according to MGWC 2.1:Riprap.

Approximate Cost ($1999):
$1,212 per structure

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA. The recommended construction weirs should proceed as follows (refer to Detail 3.7):

1. The stream should be diverted according to a WMA recommended measure, and the construction area should be dewatered.

2. *Vortex Rock Weir Installation*. Vortex weirs are typically modified horseshoe shapes such that the apex of the structure points upstream. The angle the arms make with the upstream bank should be approximately 20 to 30 degrees so that flows are directed away from the banks and deeper pool areas are created directly downstream of the vane or weir. The top layer of vortex rocks should rest upon at least one tier of footer rocks and so that they

are offset in the upstream direction. Vortex rocks should be partially buried in the streambed a minimum of 6 inches (15 centimeters). Vane rocks should be shingled upstream. On unstable bed substrates, two tiers of footer rocks may be required to prevent the downstream face of the vortex weir from being undermined. The top elevation of the center vortex rock(s) at the apex of the weir should be at or near bed level to permit fish passage at low flows, and the end rocks on either bank should be at bankfull level. The vortex rocks of vortex weirs should be spaced 1/3 to 1/2 a rock diameter apart with the exception of the end rocks. The end vortex rocks should be partially buried in the streambank and should touch the adjoining vortex rocks. Once the excavated portion of the bank has been backfilled, it should be armored with appropriately sized riprap, sod mats, or willow transplants as necessary.

3. *W-Weir Installation*. W-weir installation should proceed similarly to vortex weir construction and should account for the more complicated geometry of the structure.

4. Adjacent weirs should be spaced sufficiently far apart to allow for proper riffle or pool development according to step-pool and pool-riffle configurations as provided in MGWC 3.9: Step Pools. Additionally, it has been recommended that the overall drop controlled by a set of weirs should be less than 2 feet (0.6 meters) for stability reasons.

5. All disturbed sections of the channel, including the banks and streambed, should be stabilized with methods approved by the WMA.

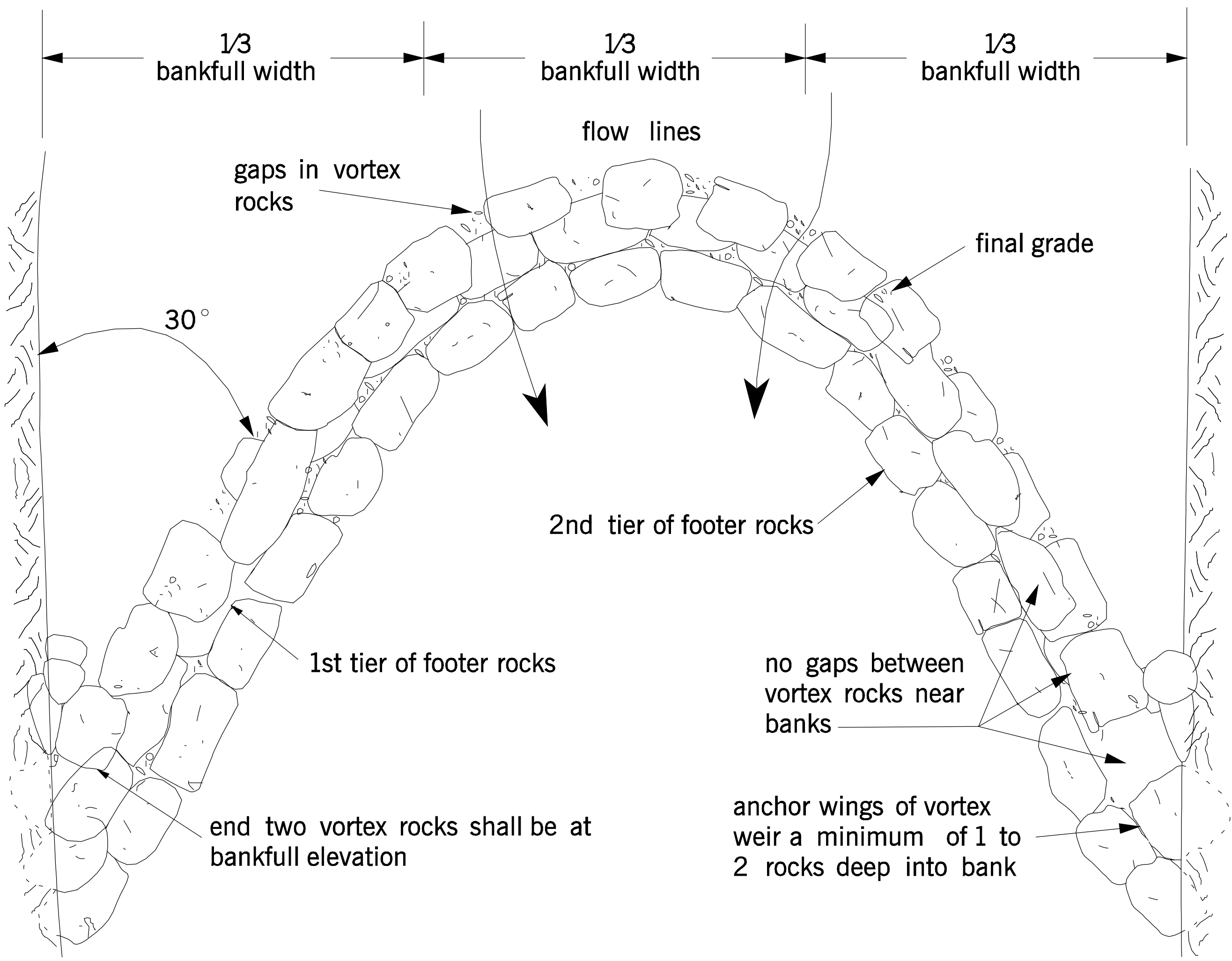
6. All weirs should be monitored to determine if:

- their orientation and geometry (e.g., the height of the drop) hinder fish migration,
- their performance is adversely affected by deposited sediment, and
- their placement causes bank instabilities and undesirable lateral stream movement especially in the vicinity of the plunge pools.

DETAIL 3.7(a): WEIRS

Section & Plan Views Adapted From Rosgen (1999)

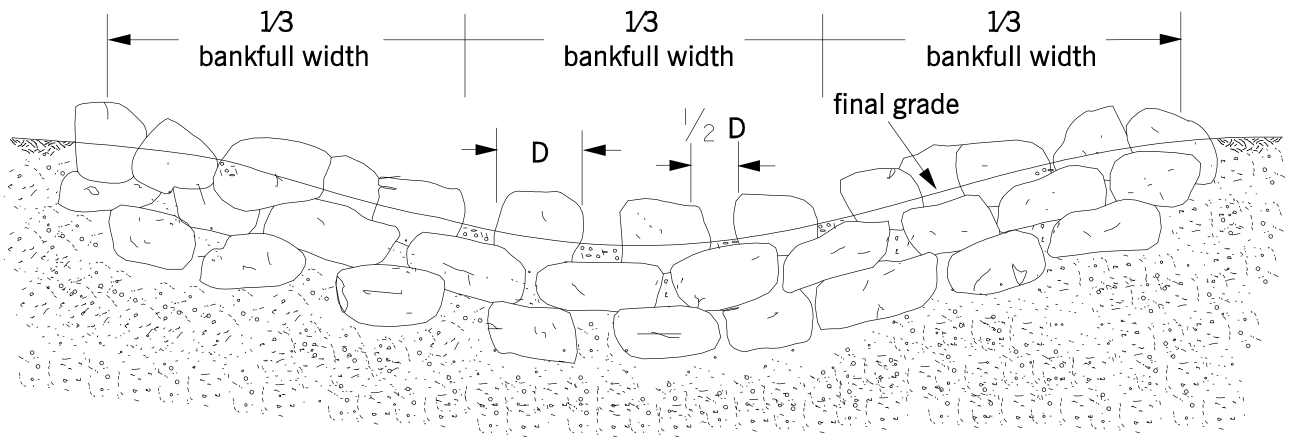
PLAN VIEW: VORTEX ROCK WEIR



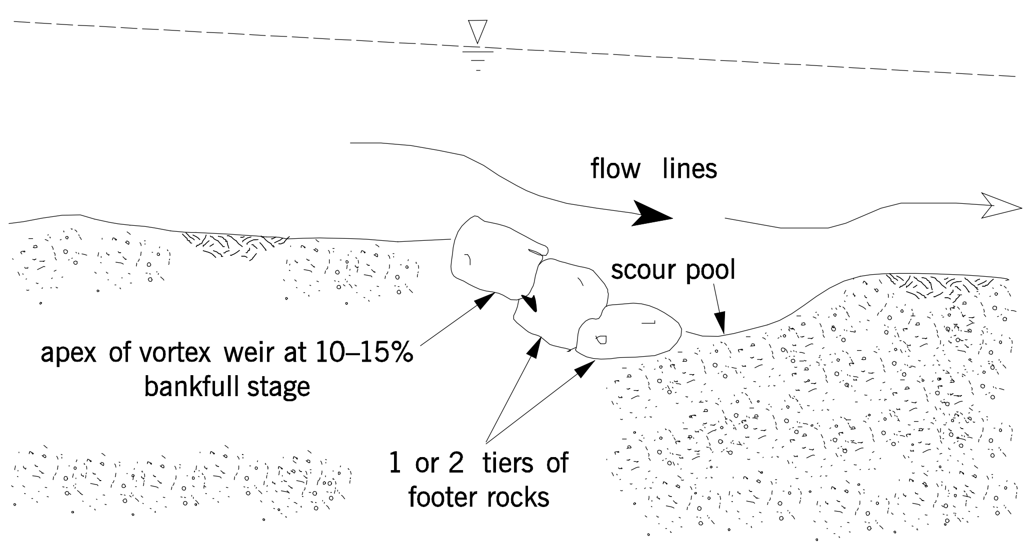
DETAIL 3.7(b): WEIRS

Section & Plan Views Adapted From Rosgen (1999)

SECTION VIEW: VORTEX ROCK WEIR



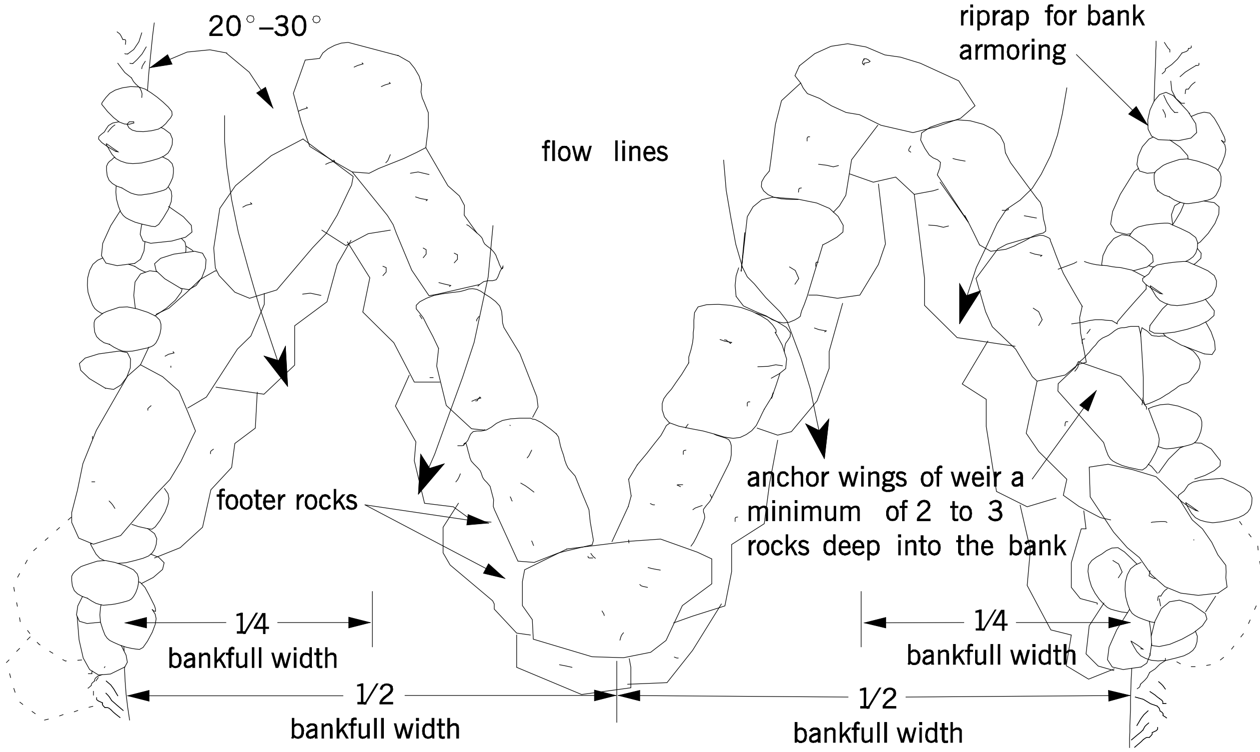
PROFILE VIEW: VORTEX ROCK WEIR



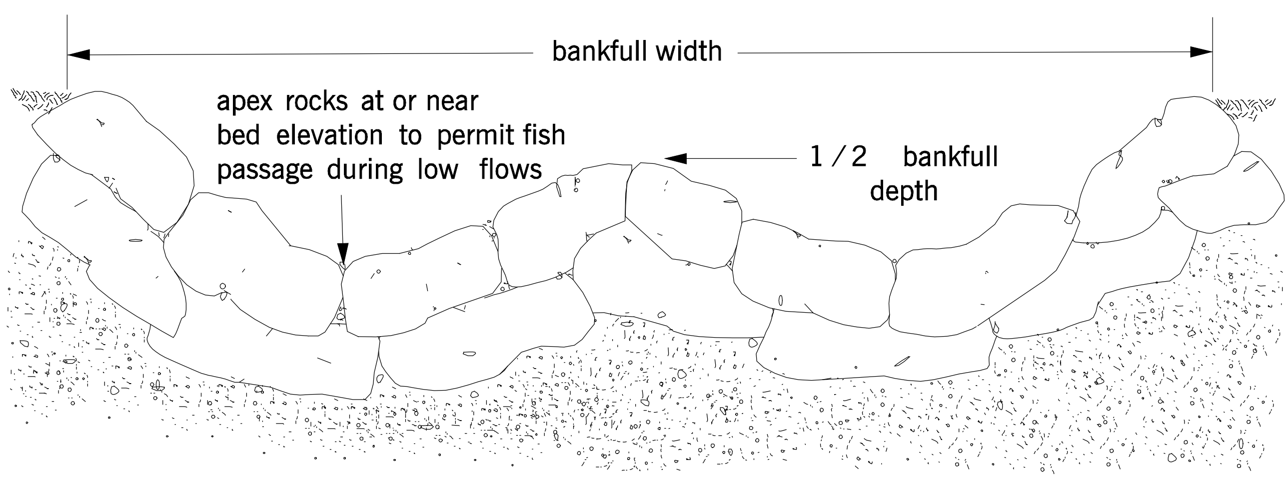
DETAIL 3.7(c): W–WEIRS

Section & Plan Views Adapted
From Rosgen (1993)

PLAN VIEW: W–ROCK WEIR



SECTION VIEW: W–ROCK WEIR



MGWC 3.8: CROSS VANES

Rigid engineering techniques for creation of aquatic habitat and channel grade control

DESCRIPTION

Low profile in-stream structures such as cross vanes are primarily used to create aquatic habitat in the form of scour pools and for grade control on incising streams and rivers. Additionally, they are well-suited for channeling flow away from unstable banks.

EFFECTIVE USES & LIMITATIONS

Cross vanes are typically suited for use in moderate to high gradient streams. Cross vanes are best suited to Rosgen stream types A3-A4, B3-B4, C3-C4, F3-F4, and G3-G4. When constructed and spaced properly, cross vanes can simulate the natural pattern of pools and riffles occurring in undisturbed streams while forming gravel deposits which fish use as spawning grounds. Cross vanes can also be used to stabilize banks when designed properly.

Cross vanes should be avoided in channels with bedrock beds or unstable bed substrates, and streams with naturally well developed pool-riffle sequences.

MATERIAL SPECIFICATIONS

Rock and boulder material for the construction of cross vanes should meet the following requirements:

Footer Rocks: Vortex rocks should be large enough to achieve the desired height when partially buried in the stream bed and should be sized to resist movement from shear stresses expected for the design flow. Footer rocks should be long and flat.

Riprap: Riprap for added stability, bank armoring, and toe protection should be capable of withstanding bankfull flow velocities according to MGWC 2.1: Riprap.

Approximate Cost ($1999): $1,212 per structure

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA. The recommended construction procedure for both cross vanes and weirs should proceed as follows (refer to Detail 3.8):

1. The stream should be diverted according to a WMA recommended measure, and the construction area should be dewatered.

2. Cross vanes are typically designed with a "U" shape such that the apex of the structure points upstream. The angle the arms make with the upstream bank should be approximately 20 to 30 degrees so that flows are directed away from the banks and deeper pool areas are created directly downstream of the vane or weir. All rocks should touch adjacent rocks to form a tight fit. Vane rocks shall be placed on top of footer rocks so that each vane rock rests upon two halves of each footer rock below, and so that the vane rock is offset in the upstream direction. Vane rocks shall be shingled upstream. On unstable bed substrates, two tiers of footer rocks may be required to

prevent the downstream face of the vortex weir or cross vane from being undermined. The top elevation of the center rock(s), at the apex of the weir or vane, should be at or near bed level to permit fish passage at low flows, and the end rocks on either bank should be at bankfull level. Once the excavated portion of the bank has been backfilled, it should be armored with appropriately sized riprap, sod mats, or willow transplants.

3. Adjacent cross vanes should be spaced sufficiently far apart to allow for proper riffle or pool development according to step-pool and pool-riffle configurations as provided in MGWC 3.9: Step Pools. Additionally, it has been recommended that the overall maximum drop controlled by a set of weirs should be less than 2 feet (0.6 meters) for stability reasons.

4. All disturbed sections of the channel, including the banks and streambed, should be stabilized with methods approved by the WMA.

5. All cross vanes should be monitored to determine if:

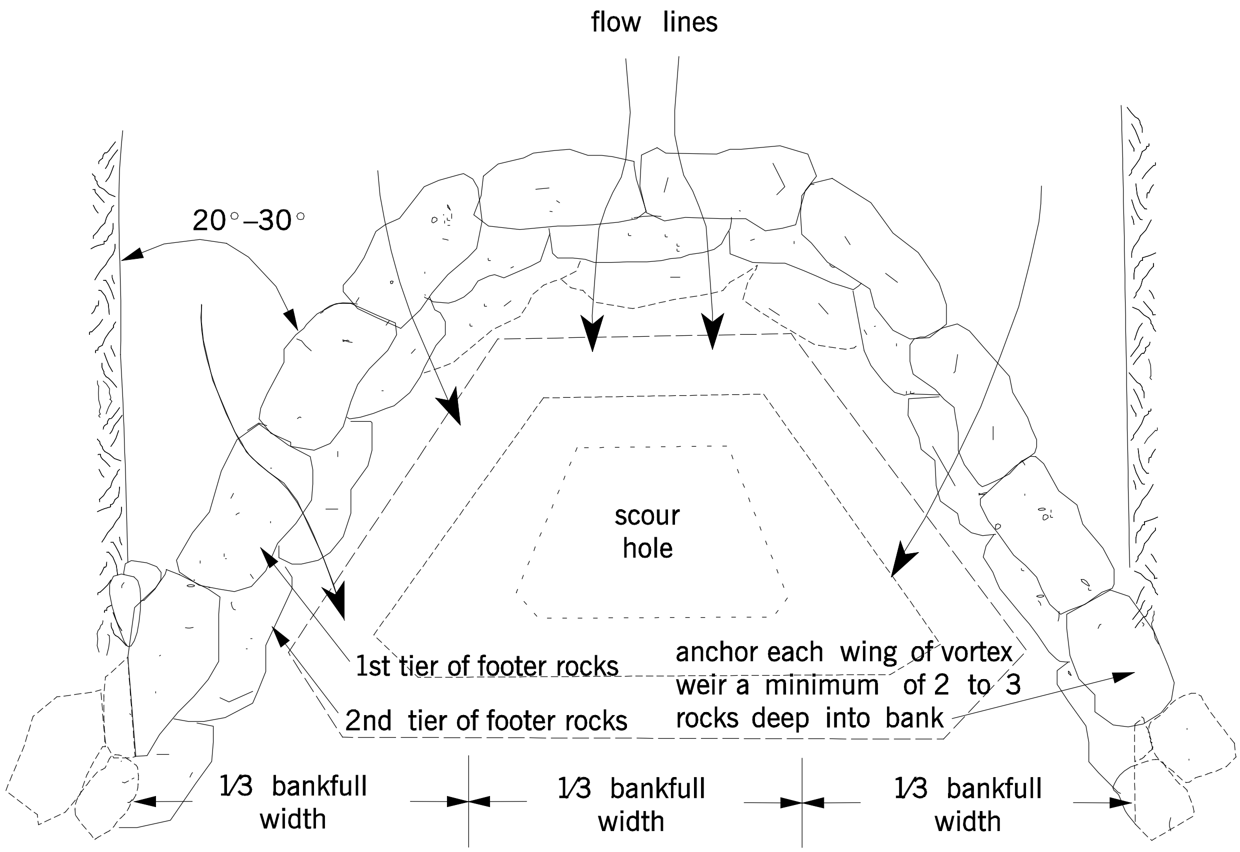
- their orientation and geometry (e.g., the height of the drop) hinder fish migration,
- their performance is adversely affected by deposited sediment, and
- their placement causes bank instabilities and undesirable lateral stream movement especially in the vicinity of the plunge pools.

Maryland's Guidelines To Waterway Construction

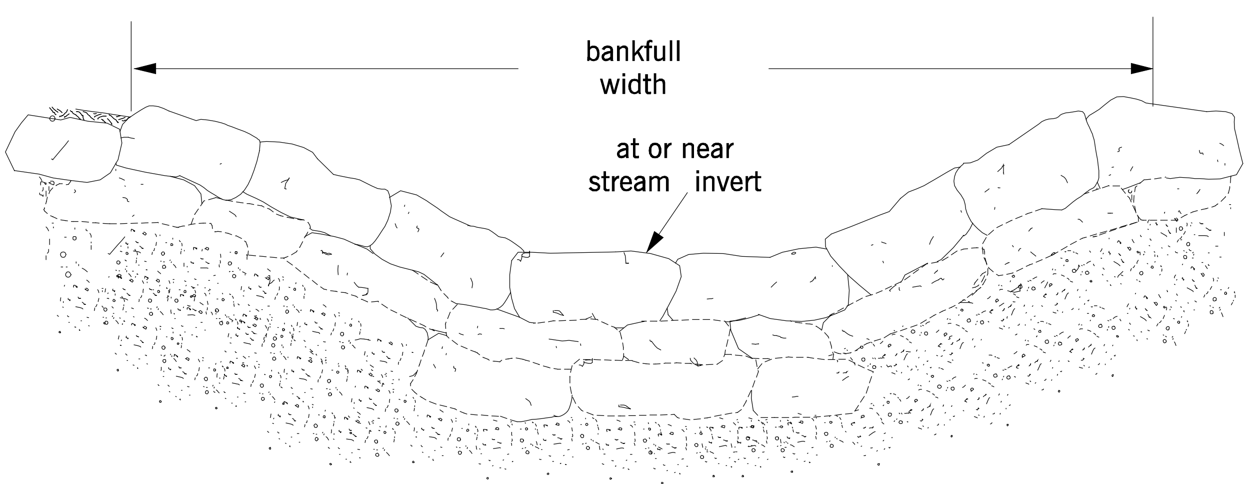
DETAIL 3.8(a): CROSS VANES

Source: Rosgen, 1999

PLAN VIEW: CROSS VANE



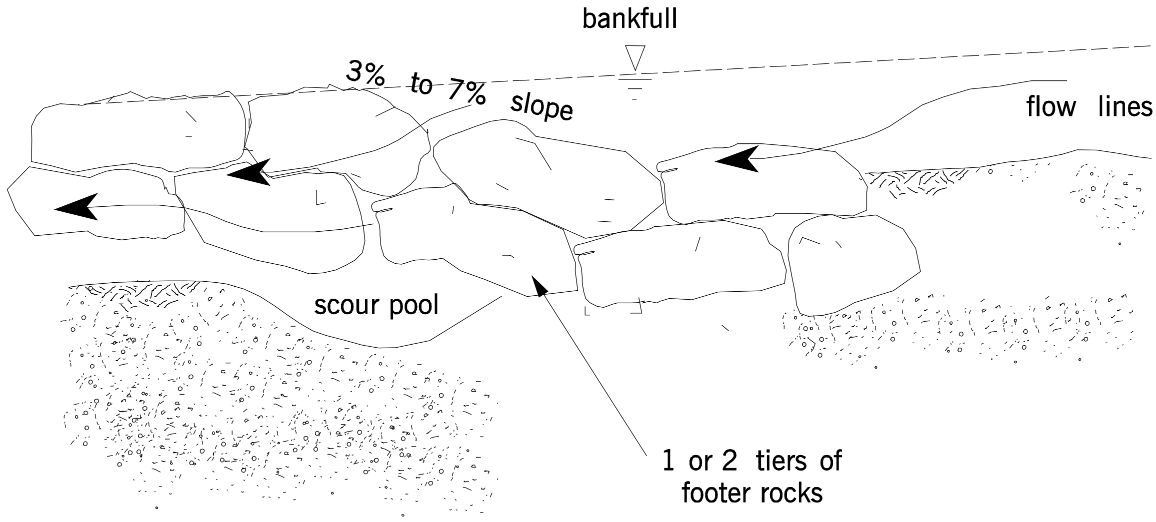
SECTION VIEW: CROSS VANE



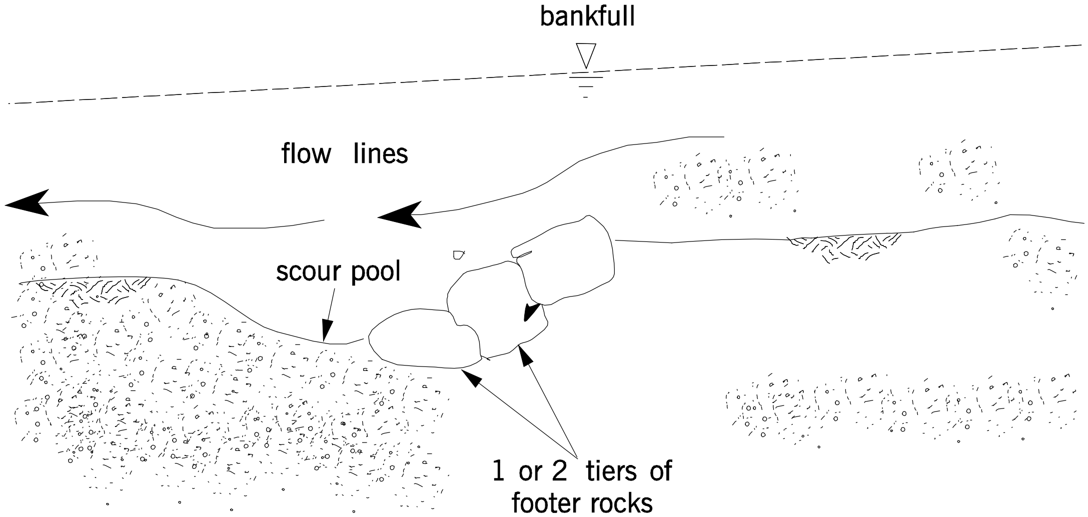
DETAIL 3.8(b): CROSS VANES

Source: Rosgen, 1999

PROFILE: CROSS VANE ARM



PROFILE VIEW OF CENTER OF CROSS VANE



MGWC 3.9: STEP POOLS

Technique for grade control and improvement of aquatic habitat

DESCRIPTION

The work should consist of constructing step-pool sequences in steep headwater stream channels for grade control and the creation of aquatic habitat through flow diversification. Step-pool channels are characterized by a succession of channel-spanning steps formed by large grouped boulders called clasts that separate pools containing finer bed sediments. As supercritical flow tumbles over the step, energy is dissipated in roller eddies and becomes subcritical in the associated downstream plunge pool.

EFFECTIVE USES & LIMITATIONS

Step-pool morphologies are typically associated with well confined, high-gradient channels with slopes greater than 3%, having small width-depth ratios and bed material dominated by cobbles and boulders. Step pools generally function as grade control structures and aquatic habitat features by reducing channel gradients and promoting flow diversity. At slopes greater than roughly 6.5%, similar morphologic units termed cascades spanning only a portion of the channel width are formed in these channel conditions. Step pools and cascades are generally found in the following Rosgen stream types: A1-A3 and B1-B3.

MATERIAL SPECIFICATIONS

Natural steps in step-pool morphologies can be formed by large clasts, bedrock outcrops, and large woody debris aligned across the channel. Engineered steps can be made from boulders, logs, and large woody debris chosen according to the desired height of the step. Additionally, boulders should be sized to resist the design storm event using MGWC 2.1: Riprap as a guide.

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. The proposed construction sequence for step pools is as follows (refer to Detail 3.9):

1. The stream should be redirected by an approved temporary stream diversion (See *Section 1: Temporary Instream Construction Measures, Maryland's Guidelines to Waterway Construction*), the construction area should be dewatered, and any disturbed banks should be stabilized.

2. Step-pool units should be designed and constructed to have a characteristic step height, H, and step length, L, as shown in Detail 3.9, and all steps should be firmly anchored into the stream bank.

3. Step rocks shall be placed on footer rocks so that they rest on two halves of each footer rock below, and so that the step rock is offset in the upstream direction. Footer rocks should extend below the scour hole elevation.

4. As a general guideline, the ratio of the mean steepness, defined as the averaged value of step height over step length, to the channel slope, S, should lie in the range of 1 to 2 $(1\# \{(H/L)_{AVE}/S\}\$ 2)$. Typical spacings for step pools and cascades are provided in Detail 3.9(b) relating to alluvial channel morphologies.

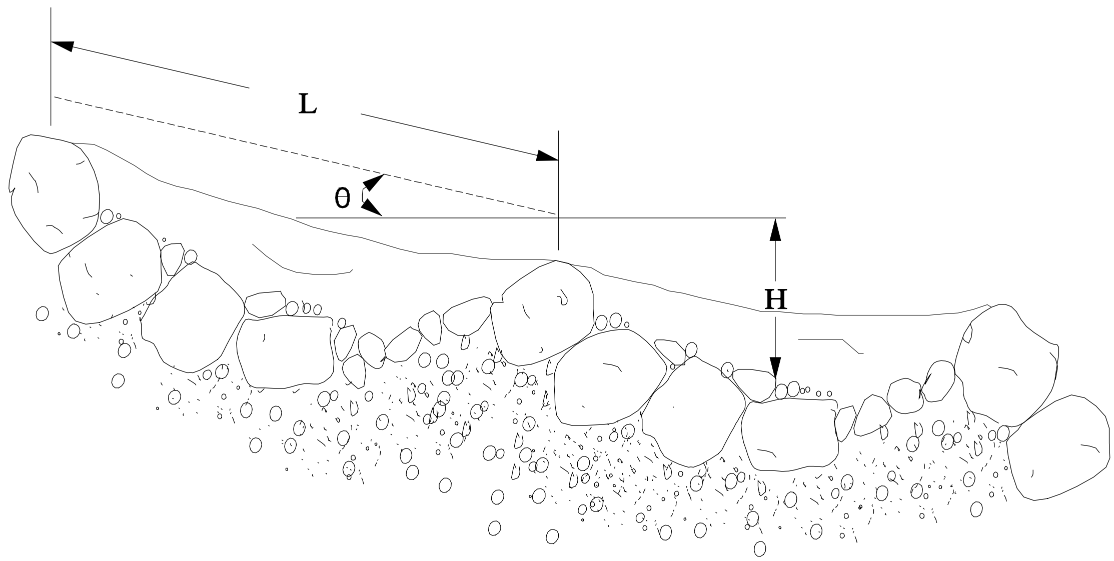
5. Whenever practical, a reference reach with similar flow rates, bed and bank material characteristics, type and density of riparian vegetation, and channel gradient should be surveyed at low flows to determine appropriate values of H and L. At high discharges, step-pool characteristics may be obscured.

6. Once construction is completed, the diversion should be removed from upstream to downstream. Sediment control devices, including perimeter erosion controls, are to remain in place until all disturbed areas are stabilized in accordance with an approved sediment and erosion control plan and the inspection authority approves their removal.

DETAIL 3.9(a): STEP POOLS

Adapted From Abrahams et al. (1995)

DEFINITION SKETCH:
STEP POOL

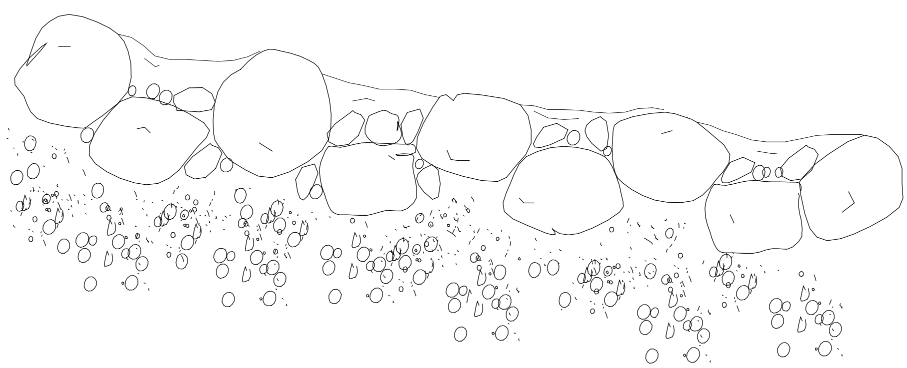


Note: L is measured parallel to the bed slope (tan θ)
H is measured perpendicular to the horizontal

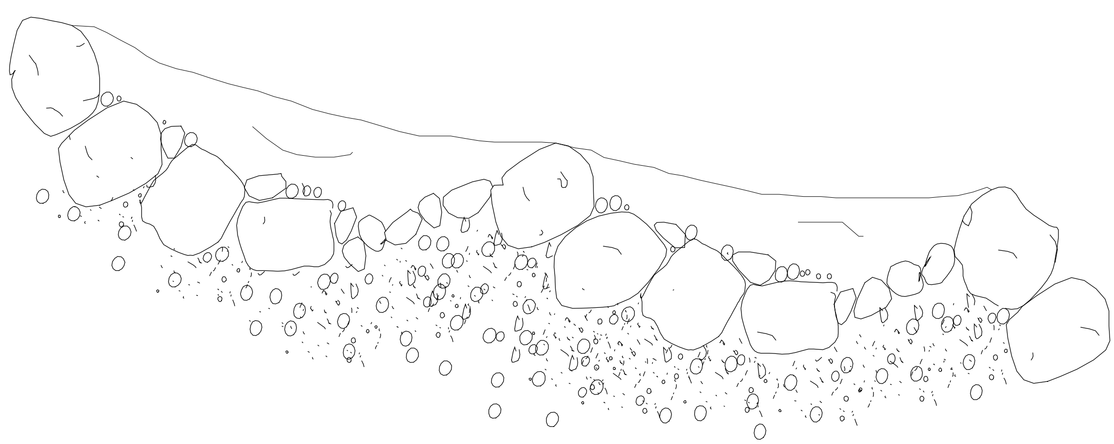
DETAIL 3.9(b): STEP POOLS

Adapted From Montgomery and Buffington (1997)

PROFILE VIEW: CASCADE & STEP POOL MORPHOLOGIES



Approximate channel slope:	Typical pool spacing:	Average step height (Abrahams et al., 1995)
> 0.065	< 1 channel width	$1 \leq \{(H/L)_{AVE}/S\} \leq 2$

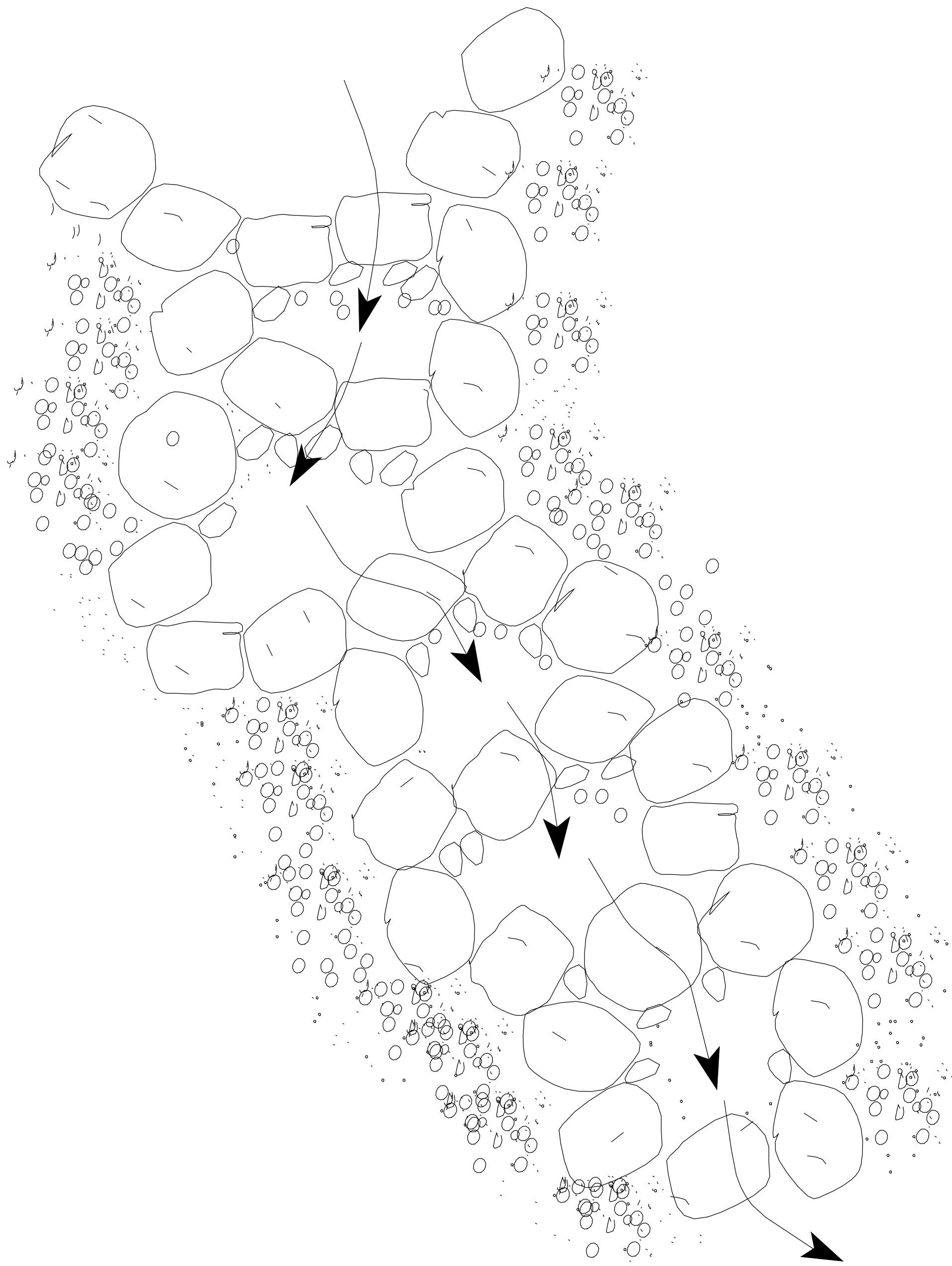


Approximate channel slope:	Typical pool spacing:	Average step height (Abrahams et al., 1995)
0.030–0.065	1–4 channel widths	$1 \leq \{(H/L)_{AVE}/S\} \leq 2$

DETAIL 3.9(c): STEP POOLS

Section & Plan Views Adapted From Rosgen (1996)

PLAN VIEW: STEP POOL



SECTION 4

STREAM CROSSINGS

MGWC 4.1: FORD CROSSING

Permanent in-stream construction

DESCRIPTION

The work should consist of constructing a ford access across a stream.

EFFECTIVE USES & LIMITATIONS

The ford should create a stream crossing that is commensurate with the natural channel while facilitating the natural passage of fish and other stream fauna. Fords should be used only when bridge or culvert crossings are not feasible.

Streams with steep banks or soft silt-clay beds are not suited to this type of crossing. Additionally, the effects of size, type, and frequency of traffic on the structural integrity of the ford should be considered. Finally, vehicles which leak oil or hydraulic fluids should not cross the stream.

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. (See the *1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control*.) The proposed construction sequence is as follows (refer to the attached figure):

1. The contractor should insure that a continuous perimeter control barrier is in place to minimize the amount of pollutants entering the flow.

2. The stream should be diverted by an approved temporary stream diversion (*See Section 1: Temporary Instream Construction Measures, Maryland's Guidelines to Waterway Construction*), the construction area should be dewatered, and any disturbed banks should be stabilized.

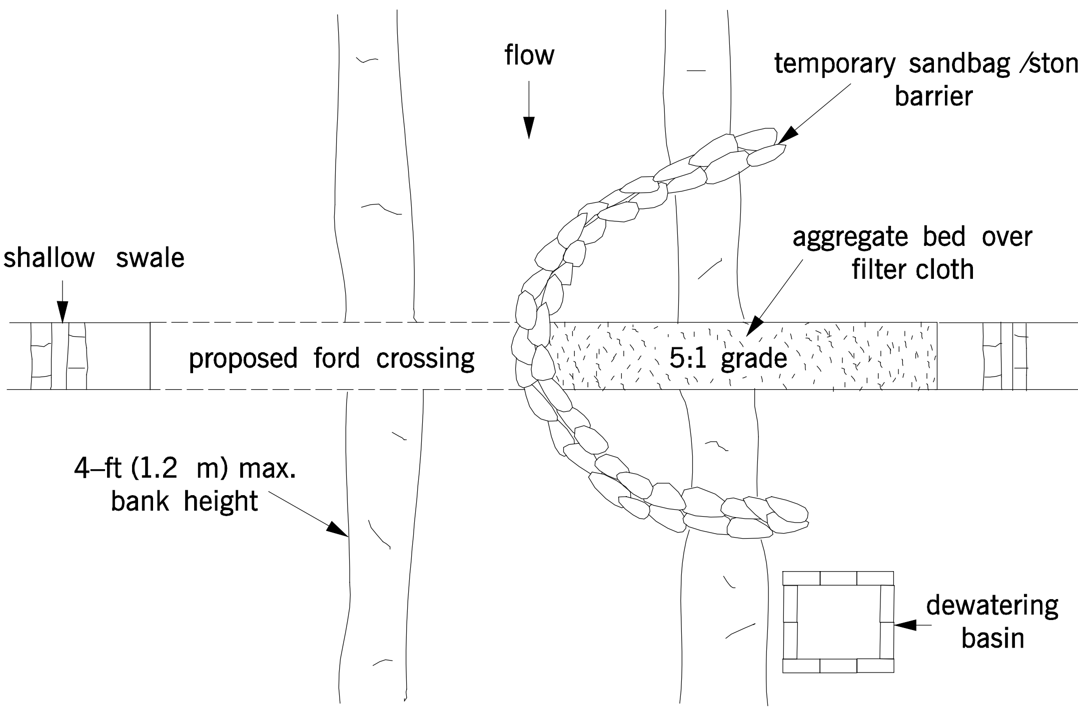
3. The ford should be constructed in accordance with the *1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control*. Shallow swales should be installed as necessary to trap surface runoff, thus collecting pollution from the ford access road.

4. All material excavated from the construction area should be placed in an approved disposal area outside of the 100-year flood plain unless otherwise allowed on the plans by the WMA.

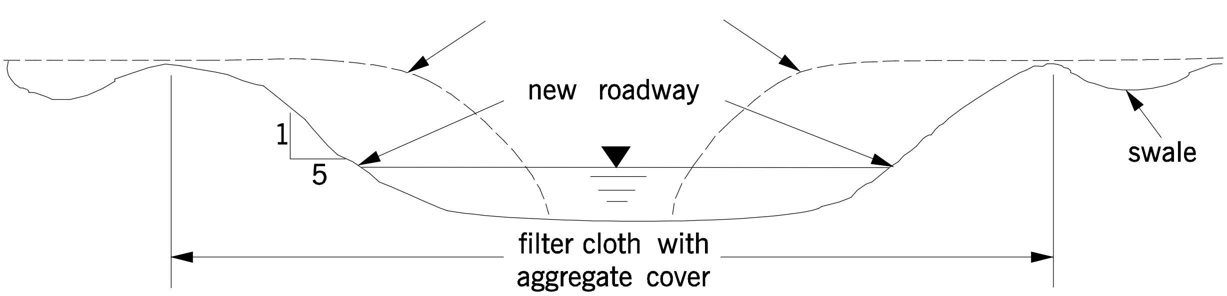
5. Once the crossing is completed, the diversion should be removed from upstream to downstream. Sediment control devices, including perimeter erosion controls, are to remain in place until all disturbed areas are stabilized in accordance with an approved sediment and erosion control plan and the inspection authority approves their removal.

DETAIL 4.1: FORD CROSSING

PLAN VIEW



SECTION VIEW



MGWC 4.2: UTILITY CROSSING

Temporary in-stream construction

DESCRIPTION

The work should consist of installing erosion control devices in and adjacent to the construction of utility crossings.

INSTALLATION GUIDELINES

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. (See *the 1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control*.) The proposed construction sequence is as follows (refer to Detail 4.2):

1. The contractor should insure that a continuous perimeter control barrier is in place to minimize the amount of pollutants entering the flow. A diversion pipe as shown in MGWC 1.4: Diversion Pipe or other measure should be installed and sandbag or stone barriers as shown in MGWC 1.5: Sandbag/Stone Diversion should be constructed according to specifications to divert the streamflow.

2. Excavated topsoil and subsoil should be kept separate, placed on the upland side of the excavation, and replaced in their natural order.

3. All construction should take place during stream low flows. The length of construction time should be limited to a maximum of 5 consecutive days for each crossing.

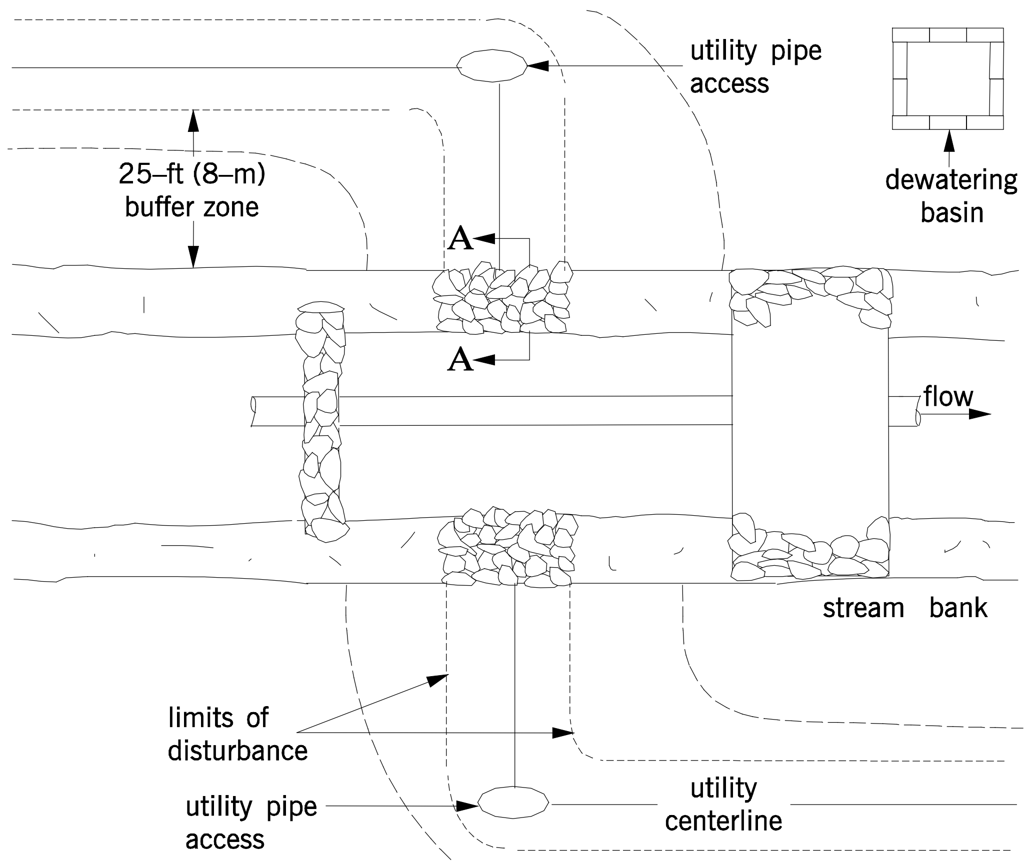
4. All utility crossings should be placed a minimum of 3 feet (1 meter) beneath the stream bed unless an alternative section is specifically approved by the WMA. For instances where a 3-foot cover is not viable, two alternate stabilization options are given in the Detail 4.2. A low flow channel shall be constructed through all riprap placements across the stream bed.

5. The stream should be diverted by an approved temporary stream diversion, the construction area should be dewatered, and any disturbed banks should be stabilized. The contractor may elect to construct the utility crossing in two stages. In this case, a WMA approved flow barrier may be constructed to keep the construction area dry.

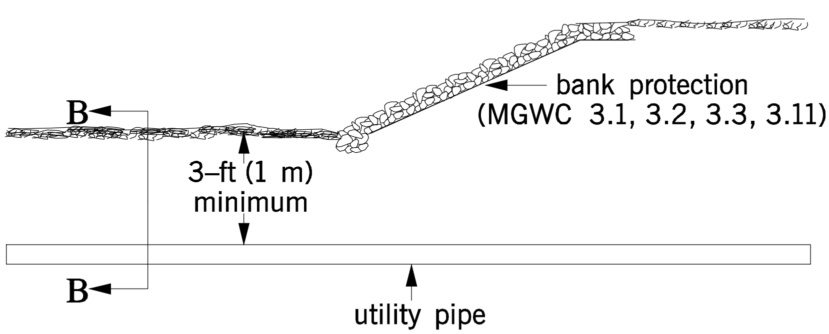
6. Once the crossing is completed, the diversion should be removed from upstream to downstream. Sediment control devices, including perimeter erosion controls, are to remain in place until all disturbed areas are stabilized in accordance with an approved sediment and erosion control plan and the inspection authority approves their removal.

DETAIL 4.2(a): UTILITY CROSSING

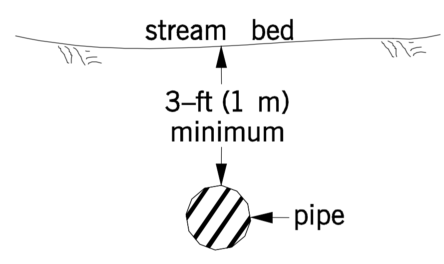
PLAN VIEW



SECTION A–A



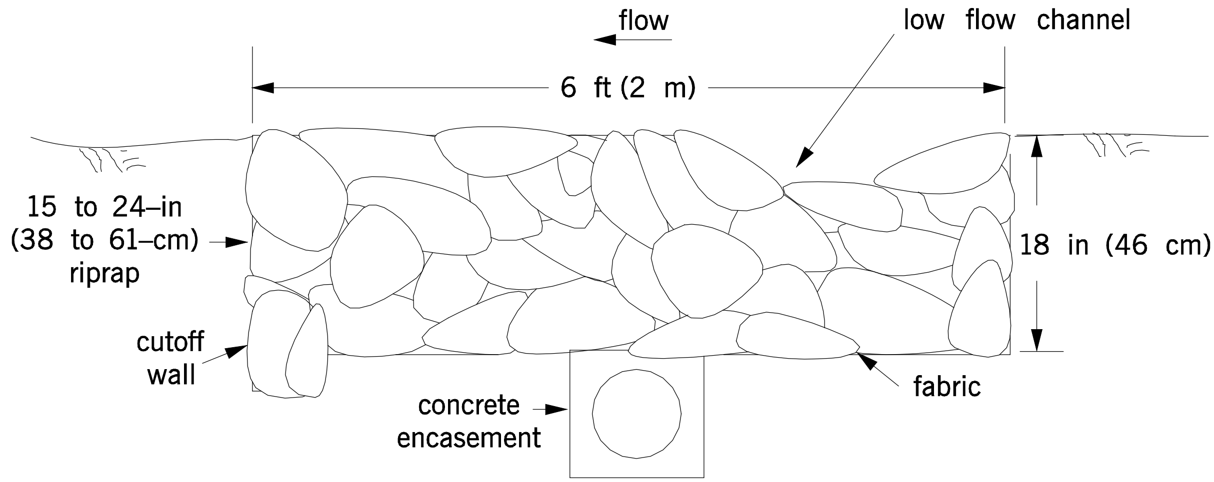
SECTION B–B



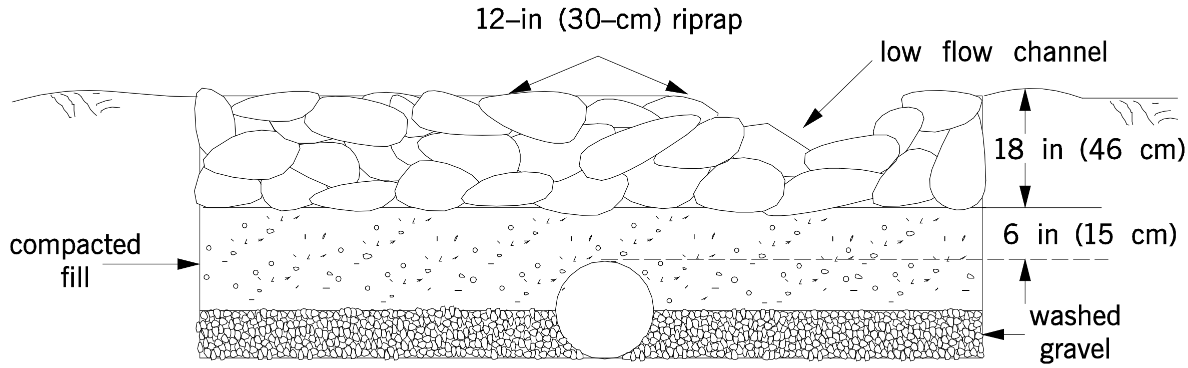
Maryland's Guidelines To Waterway Construction

DETAIL 4.2(b): UTILITY CROSSING

SECTION VIEW: ALTERNATE OPTION 1



SECTION VIEW: ALTERNATE OPTION 2



MGWC 4.3: CULVERT INSTALLATION

Proposed installation sequence for culverts

DESCRIPTION

The following is a typical installation sequence for culverts which details the minimum requirements to be incorporated into the project.

EFFECTIVE USES & LIMITATIONS

This method has been chosen in order to illustrate a general sequence of construction and is not suitable for all projects. Therefore, the construction sequence should be reviewed and modified as necessary to meet specific project needs. Consideration of a bridge or bottomless arch should be made prior to selecting a culvert.

CONSTRUCTION SEQUENCE

All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. (See the *1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control*.) A construction sequence, such as the proposed one listed below, should then be followed (refer to Detail 4.3.)

1. A diversion pipe as shown in MGWC 1.4: Diversion Pipe or other measure should be installed and a sandbag or stone barrier as shown in MGWC 1.5: Sandbag/Stone Diversion should be constructed according to specifications to divert the streamflow into the diversion.

2. A sandbag or stone barrier should be placed downstream to prevent the flow from backwashing into the construction area.

3. Culverts should be installed such that the following requirements are met.

- The culvert slope should match the streambed slope while not exceeding 3%.
- Culverts should be depressed when possible to encourage siltation for improved fish passage as shown in MGWC 4.5: Depressed Culverts.
- For non-depressed culverts, the outfall height should not exceed 5 inches (12 centimeters), and concrete aprons should be avoided whenever possible.
- The stable width/depth ratio of the bankfull stage stream channel should be maintained with the culvert design. Use of elliptical pipe may help attain the proper channel dimension especially for B, C, and E stream types.
- A low flow channel shall be constructed through the riprap placements across the stream bed.

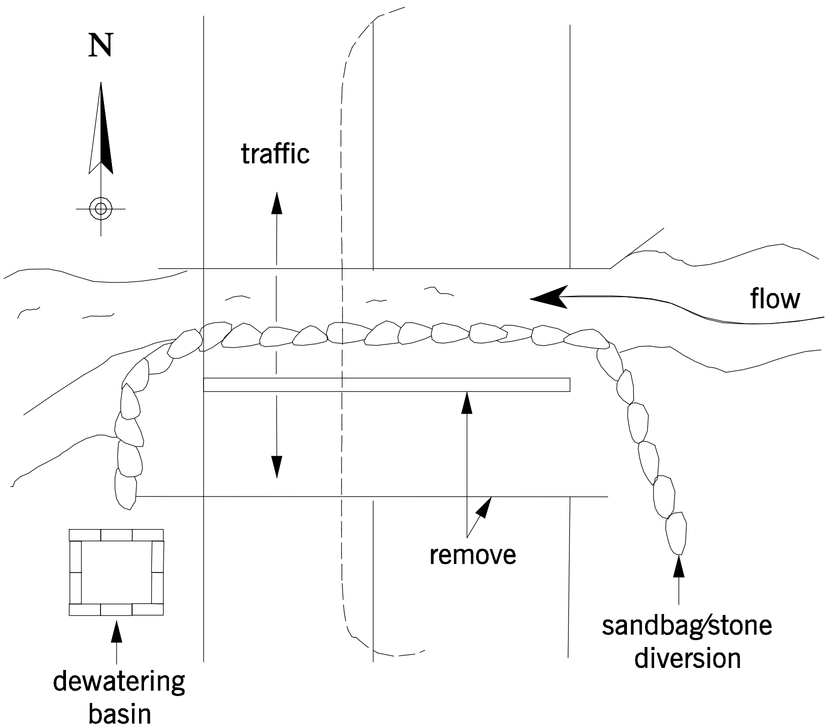
4. The disturbed sections of the channel, including the slopes and streambed, should be stabilized with methods approved by the WMA.

5. The construction area should be dewatered, and the temporary stream diversion removed starting at the downstream section and moving upstream.

6. Finally, the dewatering basin(s) should be restored to the original grade, the silt fence removed, and all disturbed areas seeded and mulched.

DETAIL 4.3: CULVERT INSTALLATION–STAGES 1&2

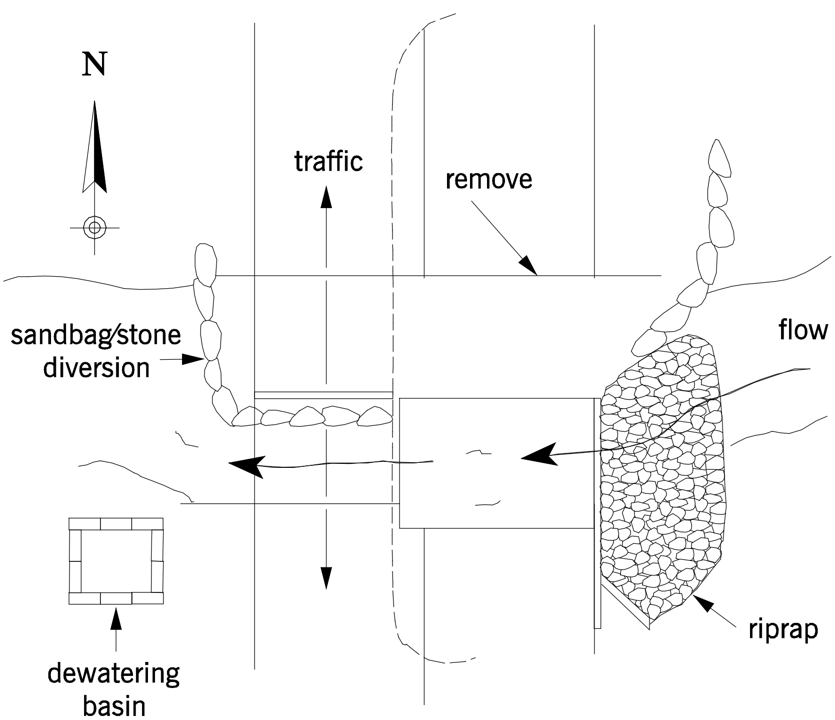
STAGE 1



Installation Guidelines:

1. provide sandbags or stones to divert the channel
2. remove the portion of pier and the southeast abutment and headwall
3. install the first segment of pipe and build the headwall
4. stabilize the stream bed inlet with Class 1 riprap

STAGE 2

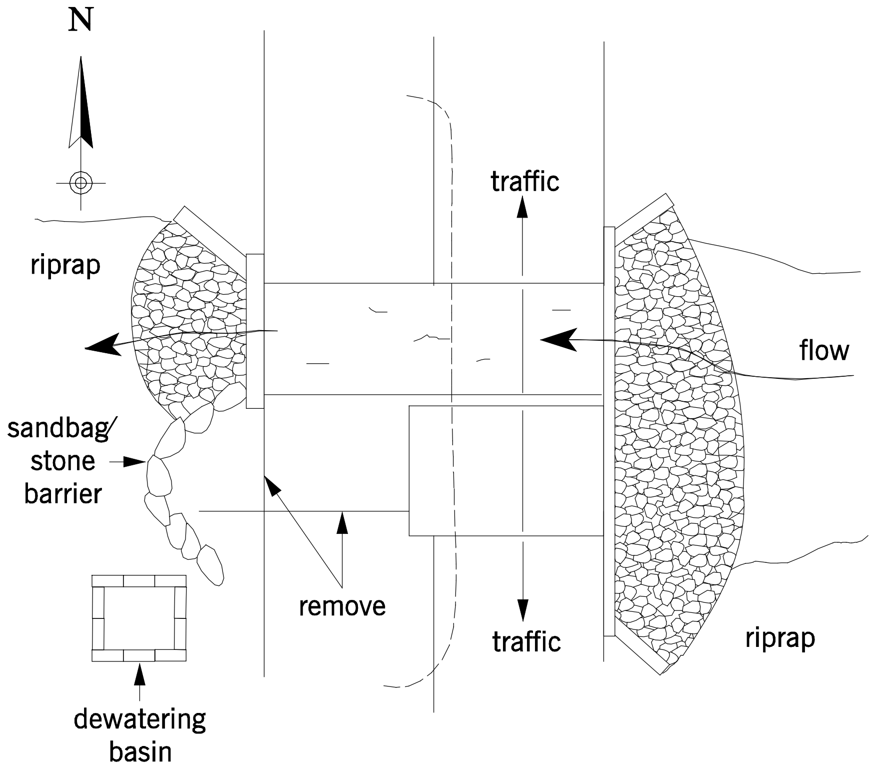


Installation Guidelines:

1. redivert the channel as shown
2. remove the northeast abutment and headwall
3. install the pipe and build the headwall
4. stabilize the remaining stream inlet with Class 1 riprap

Maryland's Guidelines To Waterway Construction
DETAIL 4.3: CULVERT INSTALLATION–STAGES 3&4

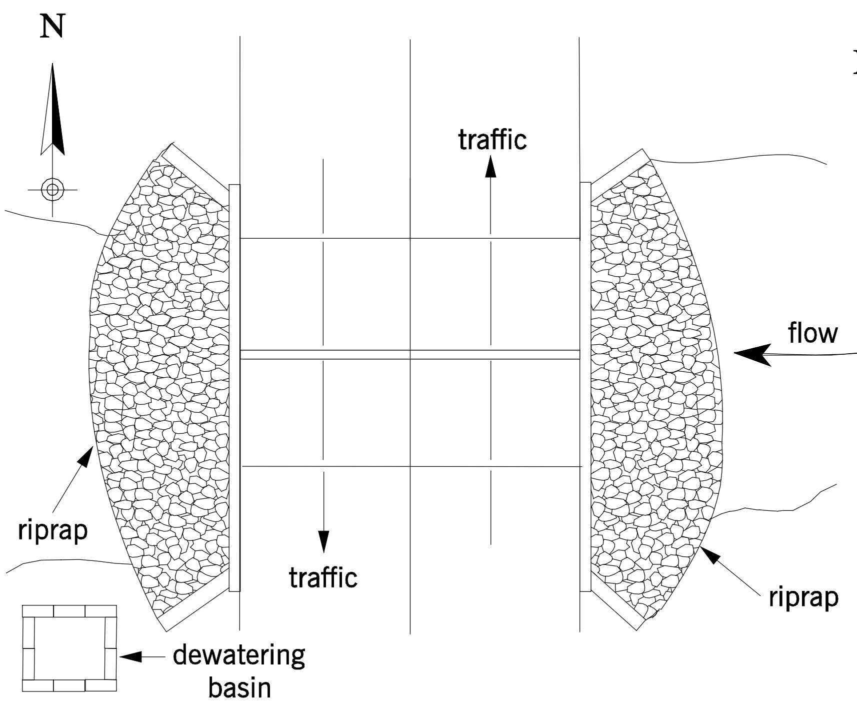
STAGE 3



Installation Guidelines:

1. redivert the channel as shown
2. remove the remaining abutment and wingwall
3. build the last portion of pipe and headwall
4. stabilize the outlet with riprap
5. restore the road surface

STAGE 4



Installation Guidelines:

1. remove traffic barriers
2. stabilize all disturbed areas with seed and mulch
3. remove sediment control devices

MGWC 4.4: MULTI-CELL CULVERTS

Permanent in-stream construction

DESCRIPTION

Multi-cell culverts provide a method of permitting bankfull and lower flow to be conveyed through a single culvert and storm flow to be conveyed across the floodplain without constriction.

EFFECTIVE USES & LIMITATIONS

Multi-cell culverts permit flood waters to flow essentially unimpeded across a floodplain. Multi-cell culverts should not be used in Rosgen Type A streams due to steep slopes, in excess of 3%. They should also not be used in Type D streams due to high bed loads. Placement of culverts in Types A or D streams would likely obstruct fish passage. Single-cell culverts should be used rather than multi-cell culverts in incised (Types F or G) channels since these channel types do not have a well-developed floodplain. If these channels are actively incising, the channels must be stabilized prior to culvert construction; a culvert placed in an actively incising channel will likely result in a perched culvert. Multi-cell culverts are most effective in Types C and E channels since these channels tend to have a well developed floodplain. Floodplain cells are highly susceptible to debris accumulation; therefore, in stream corridors with a significant debris jam potential, a moderate to heavy accumulation of various size debris, present multi-cell systems may not be appropriate.

MATERIAL SPECIFICATIONS

Most culverts are constructed from either corrugated metal pipe (CMP) or concrete. CMP is the preferred material to maintain slower velocities for fish passage but may have a shorter design life than concrete.

INSTALLATION GUIDELINES

Construction of multi-celled or single barrel culverts should proceed the same as for standard culverts as detailed in MGWC 4.3: Culvert Installation. The following are general guidelines for design and installation of single or multi-cell culverts:

1. Assess the Rosgen stream type and the channel stability prior to designing the culvert system. Alternatives to culverts should be considered for Types A and D channels. For all remaining channel types, assess the channel stability to determine whether or not the channel is degrading or widening. If the channels are unstable, widening, or degrading, a culvert system should not be used unless the channel can first be stabilized.

2. For incised stream types F or G which have been stabilized, a single-cell culvert which can convey the design storm flow can be designed and constructed.

3. For stable stream types C or E in which debris jam potential is not significant, a multi-cell culvert system should be constructed where practical. One cell is placed within the bankfull channel which is designed to carry the bankfull flow. The invert of this barrel should be depressed according to MGWC 4.5: Depressed Culverts. One to three cells are placed on either side of the floodplain to convey the design storm flow with minimum constriction of the flow. All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the WMA or local authority. (See the *1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control*.)

MGWC 4.5: DEPRESSED CULVERTS

Depressed instream culverts to encourage fish passage and channelization

DESCRIPTION

The work should consist of depressing instream culverts 1 foot (0.3 meters) below the natural stream invert.

EFFECTIVE USES & LIMITATIONS

Depressed culverts encourage channelization and enhance fish passage by allowing water to pool and sediments to deposit in the culvert barrel. During storm events, deposited sediments wash away, insuring the effectiveness and integrity of the culvert.

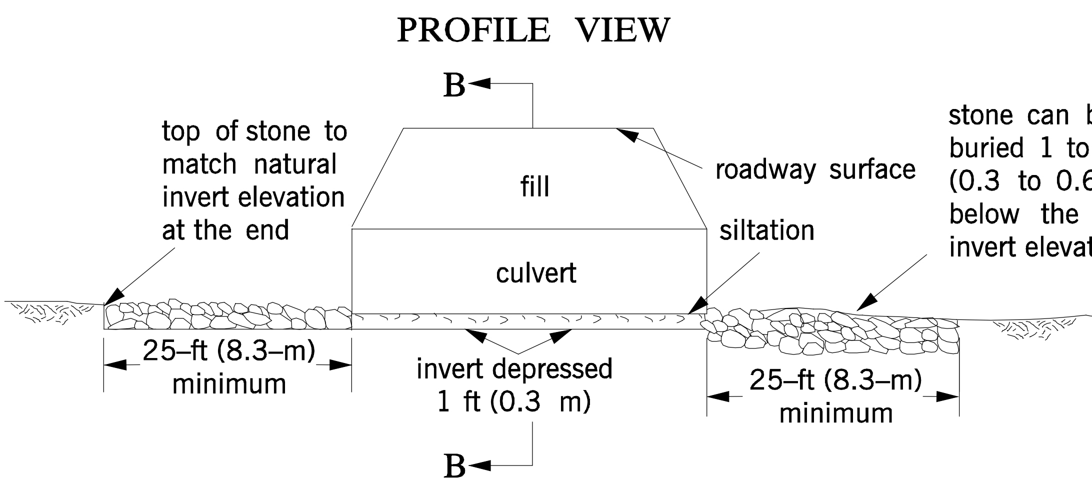
Depressed culverts may not be suited to streams with high slope gradients since high flow velocities may scour the barrel and restrict sedimentation.

INSTALLATION GUIDELINES

Construction of depressed culverts should proceed the same as for standard culverts as detailed in MGWC 4.3: Culvert Installation. In the case of double or triple-celled culverts, only one or two cells should be depressed as necessary. Additionally, the streambed adjacent to the entrance and exit of the barrel should be reinforced with riprap and filter fabric.

Refer to Detail 4.5 for typical details of depressed culverts.

DETAIL 4.5: DEPRESSED CULVERTS



MGWC 4.6: CULVERT BAFFLES

Installation guidelines for culvert baffles

DESCRIPTION

The work consists of installing baffles in culverts to provide energy dissipation and areas of low flow velocity for fish passage.

EFFECTIVE USES & LIMITATIONS

Baffled culverts may require routine maintenance to remove sediment deposits.

MATERIAL SPECIFICATIONS

Wood, concrete, or metal can be used for culvert baffles. Wood provides greater resiliency and is more easily replaced than either concrete or metal. Concrete baffles can be precast and drilled or grouted into place while metal baffles are bolted into the culvert floor.

INSTALLATION GUIDELINES

The following are some general specifications for culvert baffles (refer to Detail 4.6):

1. Baffles should be installed upon recommendation of a biologist if all possible alternatives to improved fish passage have been thoroughly explored.

2. To achieve optimum effectiveness, baffles should be designed to just overtop. For this purpose, a minimum height of 1 foot (0.3 meters) is recommended.

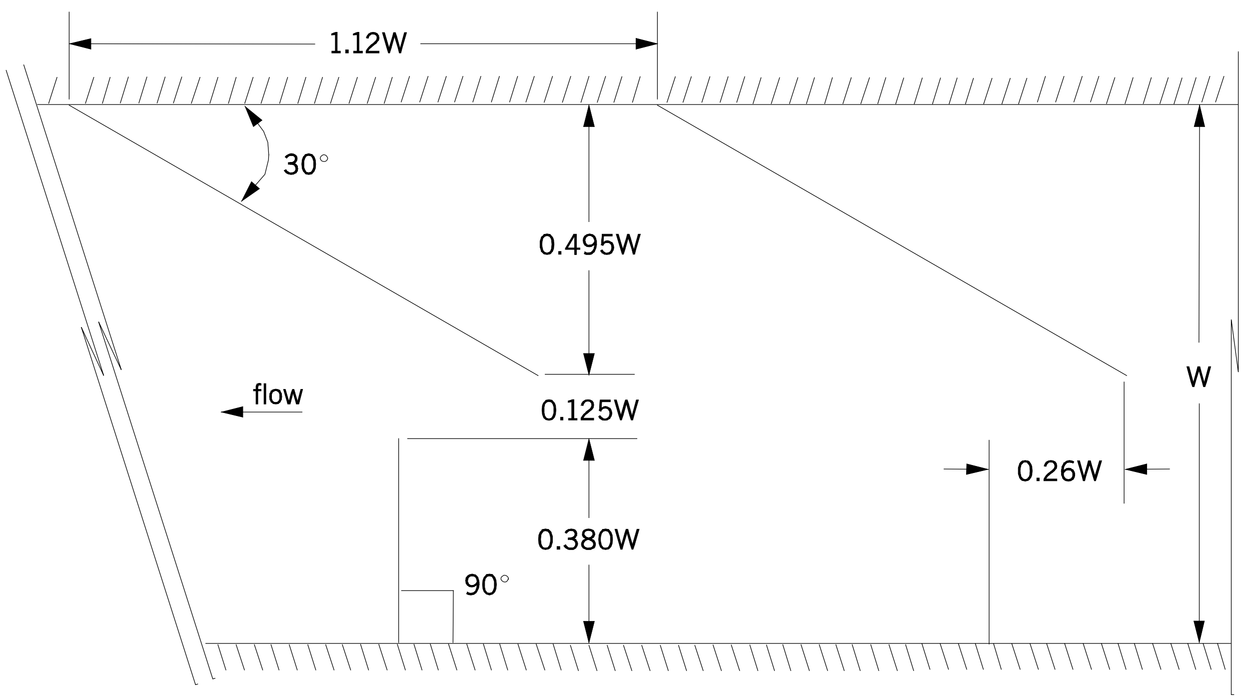
3. Only one cell of a multi-celled culvert should be employed for fish passage. Each culvert cell does not need to be baffled.

4. Box culverts should be designed according to channel capacity and dimensions. Round, corrugated metal pipes should be at least 5 feet (1.6 meters) in diameter. A separating wall should be installed in culverts greater than 6 feet (1.8 meters) in width and should be 3 times the height of the baffles.

DETAIL 4.6: CULVERT BAFFLES

PLAN VIEW

From Washington Dept. of Fisheries



Construction Notes: For a box culvert, W is the clear width; for a round or arch culvert, W is measured 1 ft (0.3 m) above the invert intercept; for any culvert, 4 ft (1.2 m) $\leq W \leq$ 6 ft (1.8 m); Dimensions may need to be adjusted for baseflow rates so that the depth is sufficient for fish passage

MGWC 4.7: SMALL BRIDGE INSTALLATION

Proposed construction sequence for small bridges

DESCRIPTION

The following is a typical sequence of construction for a small bridge installation and details the minimum requirements to be incorporated into the project.

EFFECTIVE USES & LIMITATIONS

This method has been chosen in order to illustrate a general sequence of construction and is not suitable for all projects. Therefore, the construction sequence should be reviewed and modified as necessary to meet specific project needs.

MATERIAL SPECIFICATIONS

Materials for sandbag and stone stream diversions should meet the following requirements:

- *Riprap*: Riprap should be washed and have a minimum diameter of 6 inches (15 centimeters).
- *Sandbags*: Sandbags should consist of materials which are resistant to ultra-violet radiation, tearing, and puncture and should be woven tightly enough to prevent leakage of the fill material (i.e., sand, fine gravel, etc.).

INSTALLATION GUIDELINES

All erosion and sediment control devices, should be implemented as the first order of business according to a plan approved by the WMA or local authority. (See the *1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control*.) The proposed construction sequence is as follows:

1. Install a sandbag or stone stream diversion according to specifications to divert the stream flow away from one bank.

2. Build dewatering basins as needed.

3. Install the first bridge abutment, and dewater and stabilize the disturbed area according to a plan approved by the WMA.

4. Redivert the channel to protect the opposite bank.

5. Build the second bridge abutment, dewater as necessary, and stabilize the area.

6. Remove the flow diversions.

7. Restore the dewatering basin(s) to the original grade, remove any silt fence installed before construction, and seed and mulch all disturbed areas.

MGWC 4.8: TEMPORARY ACCESS BRIDGE

Temporary stream crossing intended for minimum corridor disturbance

DESCRIPTION

A temporary access bridge is a stream crossing made of wood, metal, or other materials designed to limit the amount of disturbance to the stream banks and bed.

EFFECTIVE USES & LIMITATIONS

Temporary access bridges are the preferred method of waterway crossing since they typically cause the least disturbance to the waterway bed and banks, pose the least chance for interference with fish migration, and can be quickly removed and reused.

MATERIAL SPECIFICATIONS

- *Stringers*: Stringers should either be logs, sawn timber, prestressed concrete beams, metal beams, or other approved materials.
- *Deck Materials*: Deck materials should be of sufficient strength to support the anticipated load.

CONSTRUCTION SEQUENCE

All erosion and sediment control devices, including stream diversions, should be implemented as the first order of business according to a plan approved by the WMA or local authority. Dewatering basins should be built as needed and swales or ditches should be used to prevent surface drainage from entering the stream via the bridge crossing. (See the *1994 Maryland Standards and Specifications for Soil Erosion and Sediment Control*.) The proposed construction, maintenance, and removal sequence is as follows:

1. Abutments should be placed parallel to, and on, stable banks such that the structure is at or above bankfull depth to prevent the entrapment of floating materials and debris.

2. Temporary access bridges should be constructed to span the entire channel. If the bankfull channel width exceeds 8 feet (2.5 meters), then a footing, pier, or other bridge support may be constructed within the waterway. No support will be permitted within the channel for waterways less than 8 feet wide. One additional bridge support will be permitted for each additional 8-foot width of the channel.

3. All decking members should be placed perpendicularly to the stringers, butted tightly, and securely fastened to the stringers. Decking materials must be butted tightly to prevent any soil material tracked onto the bridge from falling into the waterway.

4. Although run planks are optional, they may be necessary to properly distribute loads. One run plank should be provided for each track of the equipment wheels and should be securely fastened to the length of the span.

5. Curbs or fenders may be installed along the outer sides of the deck to provide additional safety.

6. Bridges should be securely anchored at one end using steel cable or chain to prevent the bridge from floating downstream and possibly causing an obstruction to the flow. Anchoring at only one end will prevent channel obstruction in the event that flood waters float the bridge. Acceptable anchors are large trees, boulders, or driven steel anchors.

7. All areas disturbed during installation should be stabilized within 14 calendar days in accordance with a revegetation plan approved by the WMA.

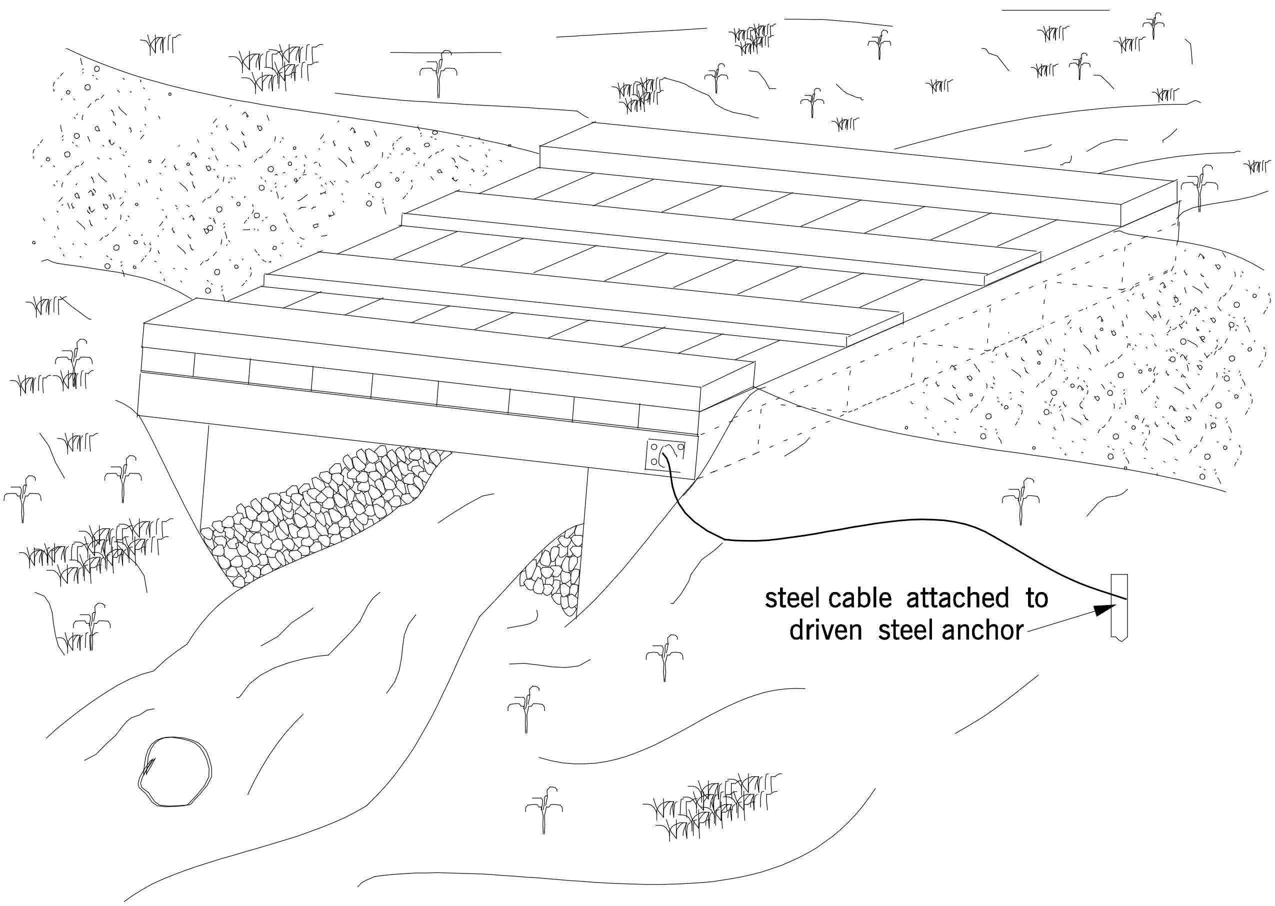
8. Periodic inspection should be performed by the user to ensure that the bridge, streambed, and stream banks are maintained and not damaged.

9. Maintenance should be performed as needed to ensure that the structure complies with all standards and specifications. This should include the removal of trapped sediment and debris which should then be disposed of and stabilized outside the floodplain.

10. When the temporary bridge is no longer needed, all structures including abutments and other bridging materials should be removed within 14 calendar days. In all cases, the bridge materials should be removed within 1 year of installation. Removal of the bridge and clean-up of the area, including protection and stabilization of disturbed stream banks, should be accomplished without the use of construction equipment in the waterway.

DETAIL 4.8: TEMPORARY ACCESS BRIDGE

SKETCH



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