Section H – WATERWAYS & STREAM PROTECTION

FORWARD

The need for this guidance related to waterways and stream protection 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 softer, more environmentally acceptable approach, commonly referred to as biotechnical engineering, thereby necessitating revision of the previous guidelines.

The site-specific characteristics coupled with the level of watershed urbanization lend to the dissimilar behavior of streams in the District. Although the purpose of this guidance 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 these specifications is to address a wide range of common biotechnical engineering techniques and conventional 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 23. Additionally, a listing of the principal limitations of each practice is given in Table 24. 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 25). 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:

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 figure 3 of <u>29.1 Standards and Specifications for Riprap.</u> The average boundary shear stress at a cross section can be estimated from:

where γ = specific weight of water. The Watershed Protection Division 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.

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 23: Summary of the Uses of Common Restoration and Stabilization Practices

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 23: 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 24: Limitations of Common Restoration and Stabilization Practices

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 24: Limitations of Common Restoration and Stabilization Practices (Continued)

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 25: 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.

Installation of Structures Under Wave and/or Tidal Action

The installation of riprap, gabions or deflectors under significant wave action or under tidal conditions requires special design considerations to ensure stability of the measure and the area it protects. The design/installation of these measures for tidal areas is beyond the scope of the District's Erosion and Sediment Control Law and Erosion and Sediment Control Regulations. The Watershed Protection Division and the Army Corp of Engineers can be consulted in regard to minimum design parameters for tidal installations. For situations where there is significant wave action affecting the shoreline of a nontidal lake or pond the design parameters presented in Section F Inlet and Outlet Protection, should be used. Notably, there are many other site specific factors which should be incorporated into a design; hence, it is recommended that the design parameters presented only be used as minimum requirements and that a qualified professional be consulted when the installation of such a structure is contemplated.

28.1 STANDARDS AND SPECIFICATIONS

FOR

PUMP-AROUND PRACTICE

Definition

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 instream 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 37):

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 Watershed Protection Division 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 Watershed Protection Division 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 Watershed Protection Division.

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.

6. The sequence of construction must be followed unless the contractor gets written approval for deviations from the Watershed Protection Division. 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.

7. 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.

8. 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.

9. 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 31, Stream Crossings*).

10. 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.

11. 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.

12. 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.

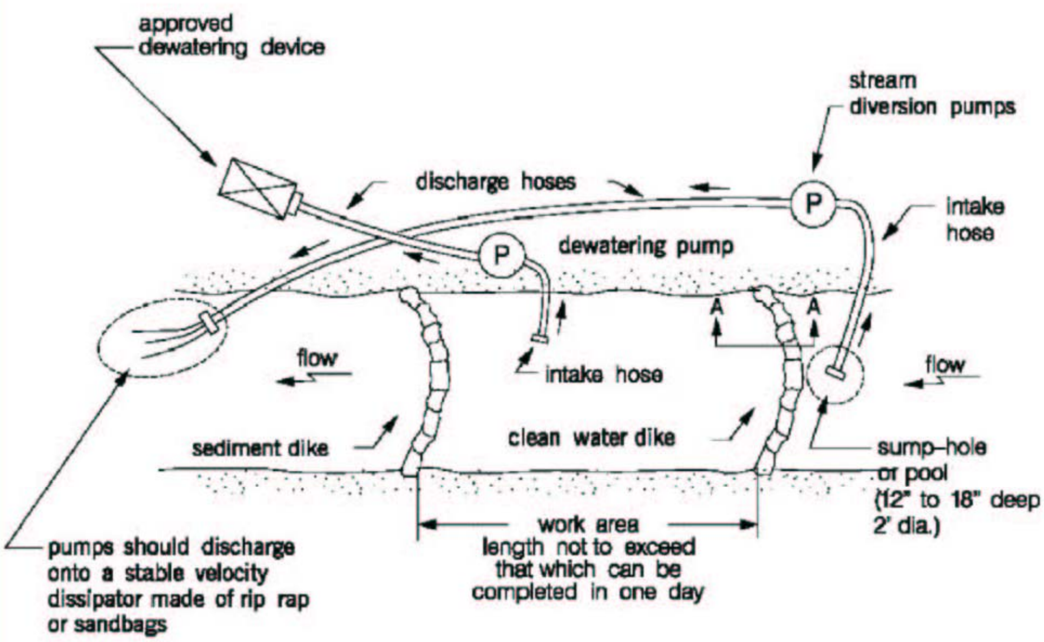
13. If a tributary is to be restored, construction should take place on the tributary before work on the main stem reaches the tributary confluence. Construction in the tributary, including pump around practices, should follow the same sequence as for the main stem of the river or stream. When construction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

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

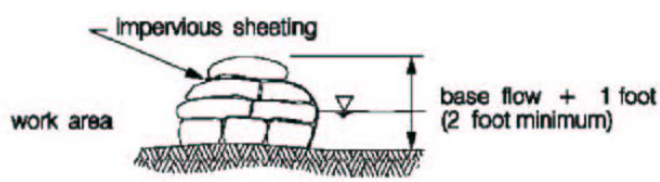
15. After construction, all disturbed areas should be regraded and revegetated as per the planting plan.

DETAIL 42 - PUMP-AROUND PRACTICE

PLAN VIEW



SECTION A-A



cross section of sandbag dike

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H31.2-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

28.2 STANDARDS AND SPECIFICATIONS

FOR

CULVERT PIPE WITH ACCESS ROAD

Definition

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.

Design Criteria

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 Watershed Protection Division. 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 Watershed Protection Division.

A culvert pipe with a temporary access road should be constructed as follows (refer to Detail 38):

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 S&S 28.4: Sandbag/Stone Channel Diversion. The materials should be sized to withstand normal streamflow velocities.

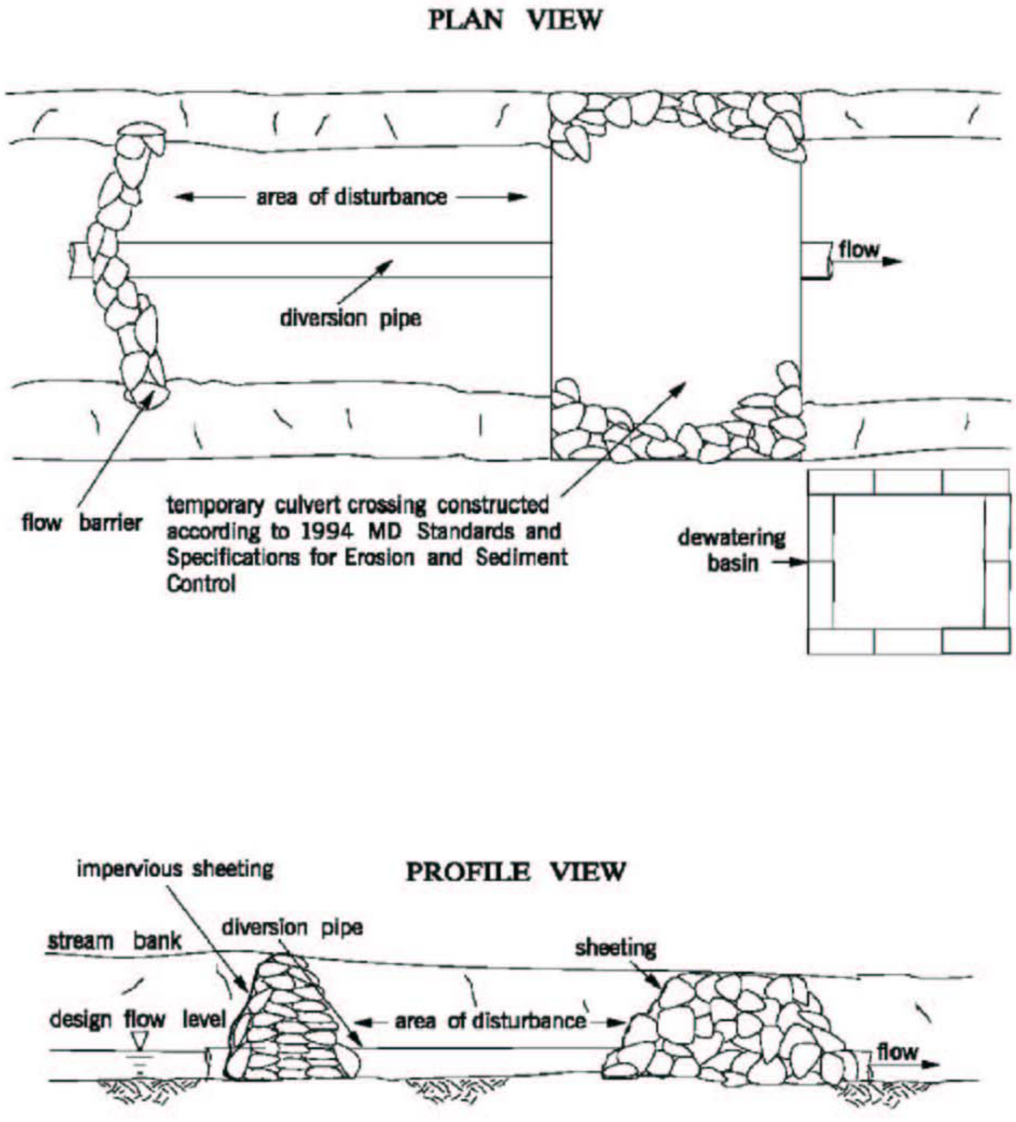
3. All sediment laden flow from the construction site should be pumped to a dewatering basin built according to S&S 27: Dewatering Basins prior to re-entering the stream.

4. Temporary culvert crossings should be constructed in accordance with this manual and *Section 31, Stream Crossings*.

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 S&S 29.1: 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.

DETAIL 43 – CULVERT PIPE W/ACCESS ROAD



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H31.3-3	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

28.3 STANDARDS AND SPECIFICATIONS

FOR

DIVERSION PIPE

Definition

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.

Design Criteria

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 Watershed Protection Division. 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.

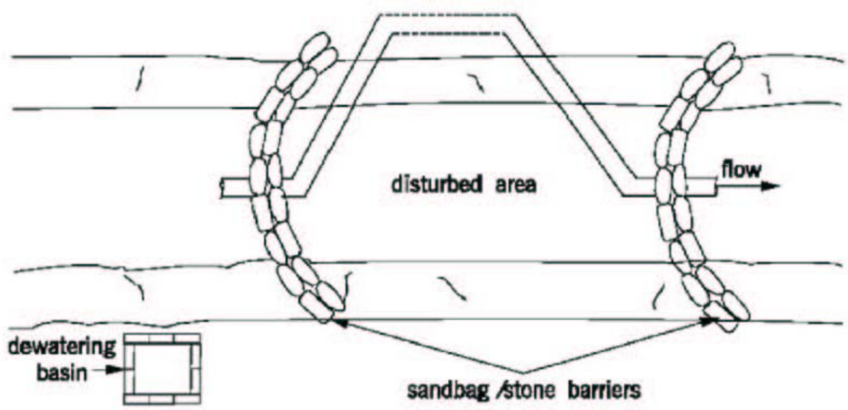
Diversion pipes with sandbag or stone barriers should be completed as follows (refer to Detail 39):

1. Sandbag/stone barriers should be sized and installed as detailed in S&S 28.4: Sandbag/Stone Diversion. The materials should be sized to withstand baseflow velocities.

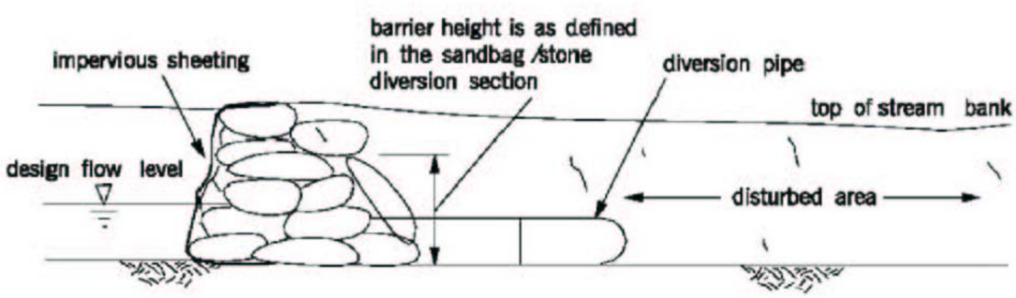
2. All excavated material should be deposited and stabilized in an approved area outside the 100-year floodplain unless otherwise authorized by the Watershed Protection Division.
3. Sediment-laden water from the construction area should be pumped to a dewatering basin.
4. The diversion pipe should have 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 44 - DIVERSION PIPE

PLAN VIEW



LONGITUDINAL SECTION VIEW



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H31.4-3	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

28.4 STANDARDS AND SPECIFICATIONS

FOR

SANDBAG/STONE CHANNEL DIVERSION

Definition

Temporary measure for dewatering inchannel 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.

Design Criteria

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 Watershed Protection Division. 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 40):

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 Watershed Protectin Division.

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

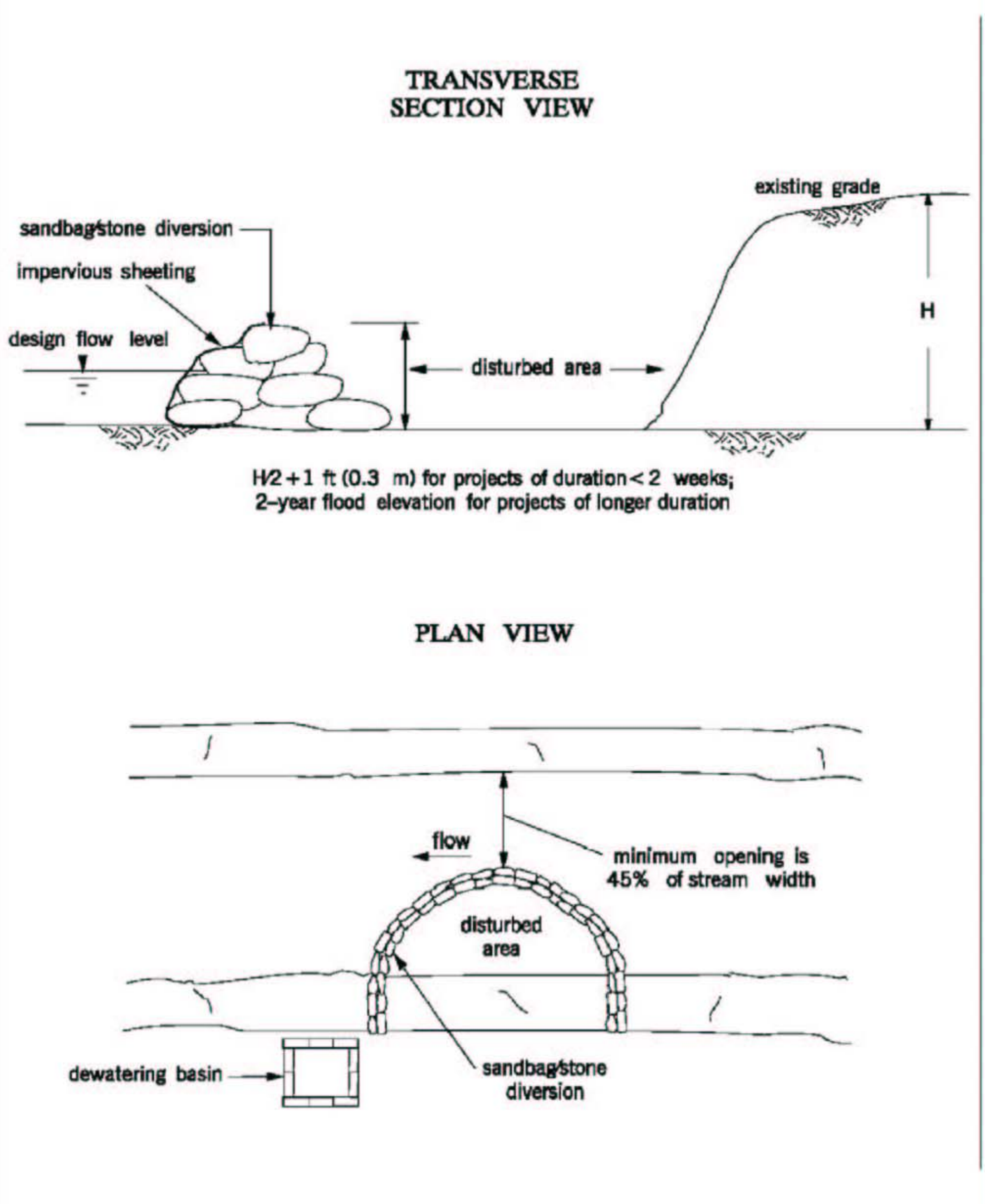
5. Sheeting on the diversion should be positioned such that the upstream portion covers the downstream portion with at least a 18-inch (0.45 meters) overlap.

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 Watershed Protectin Division.

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.

DETAIL 45 - SANDBAG/STONE DIVERSION



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H31.5-3	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

28.5 STANDARDS AND SPECIFICATIONS

FOR

FABRIC-BASED CHANNEL DIVERSION

Definition

Temporary measure for dewatering inchannel 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.

Design Criteria

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 Watershed Protection Division. 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 41).

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.

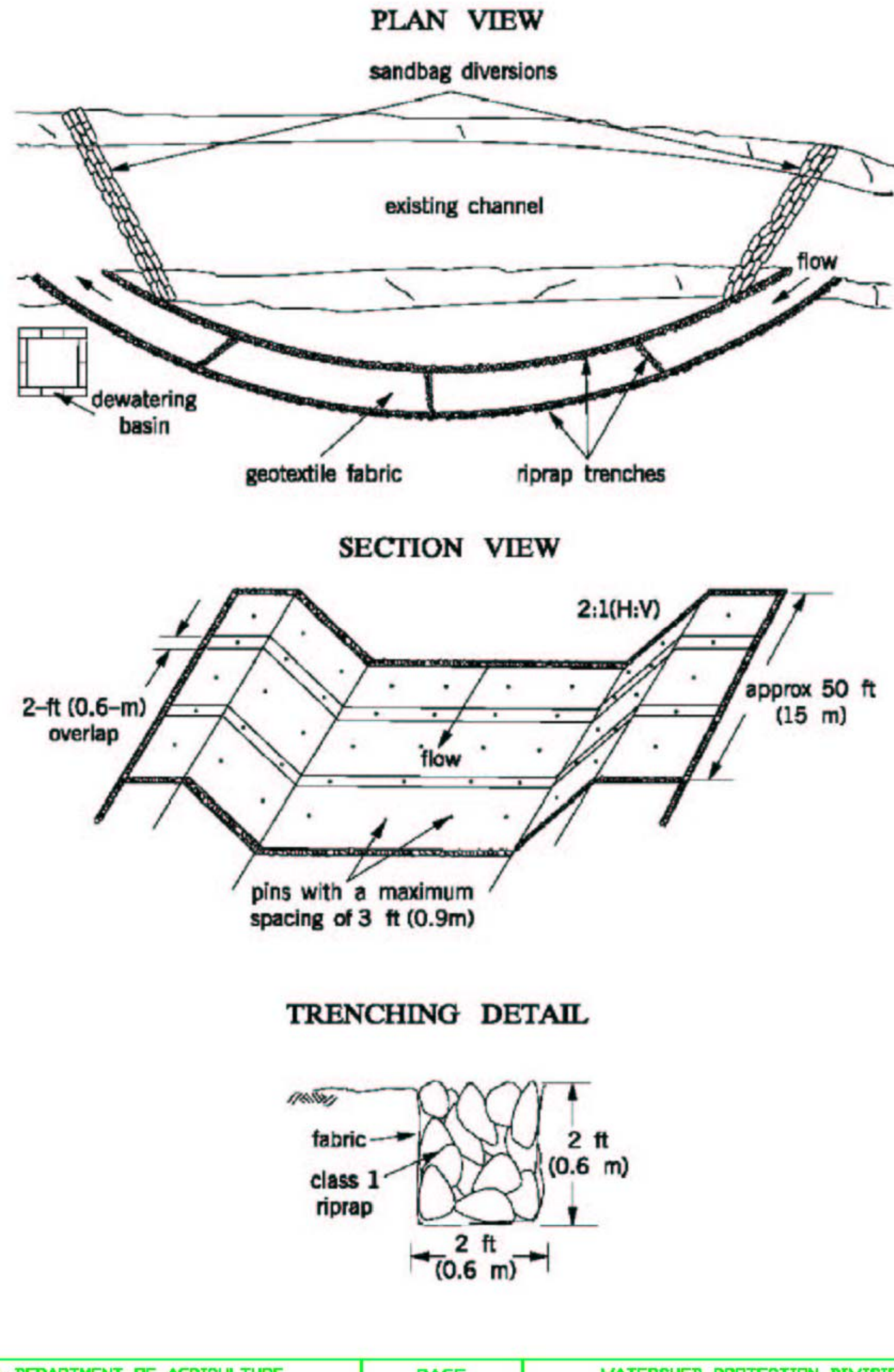
3. The entire bottom of the channel could be riprapped if high velocities are anticipated. When the area is riprapped, it is not required that the geotextile fabric underneath the riprap be pinned.

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 46 - FABRIC - BASED DIVERSION



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H31.6-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.1 STANDARDS AND SPECIFICATIONS

FOR

RIPRAP

Definition

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 26.

Table 26: 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.

- *Riprap:* The maximum diameter or weight of stone for riprap should be based upon the design flow velocity using Figure 3. This chart is based on a maximum slope of 2H:1V. The stone gradations for Classes I – III are found in Table 27.

Table 27: 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.

Design Criteria

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 Watershed Protection Division. 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 42):

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 Watershed Protection Division.

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.

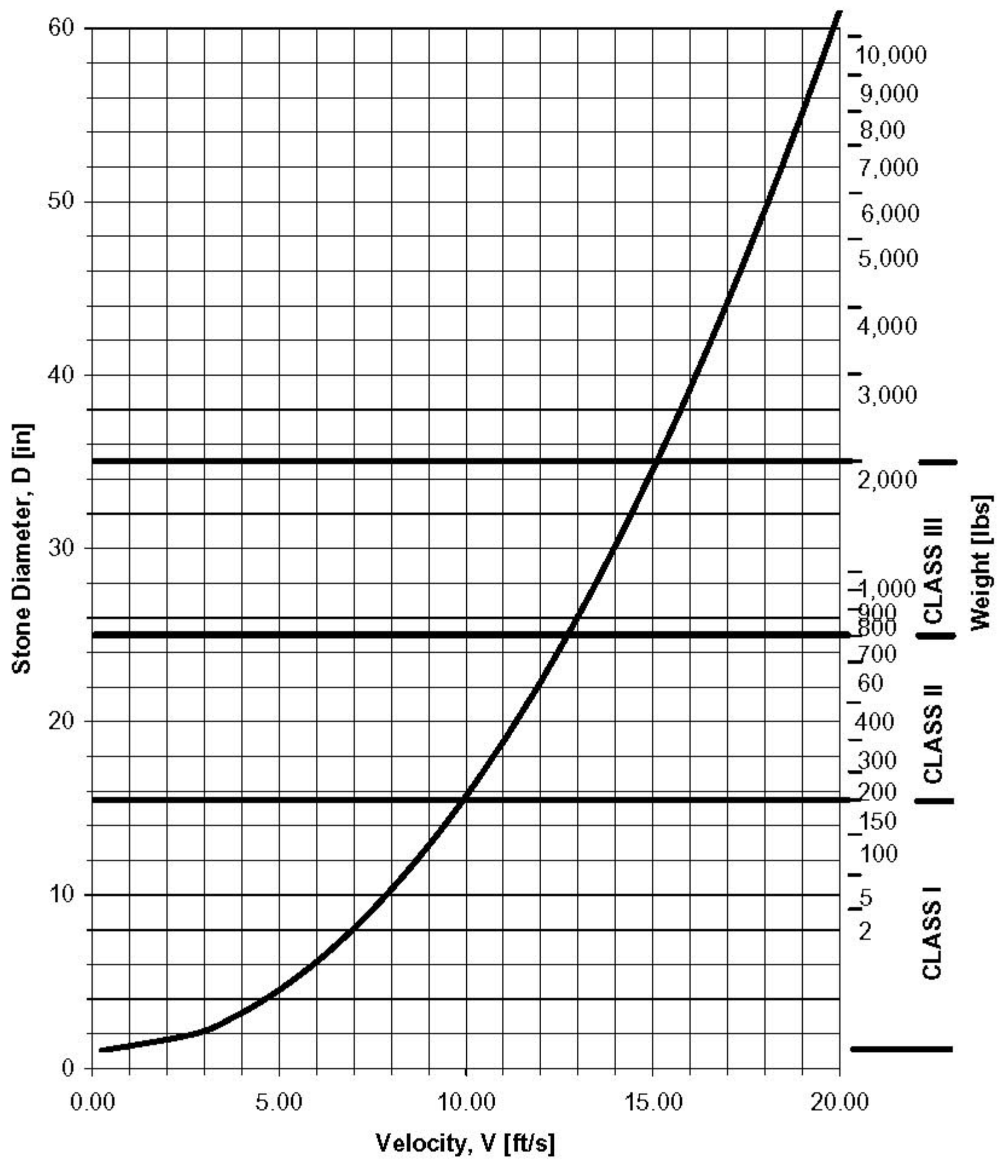
6. Riprap placement should begin with the toe. The larger stones, as specified by the design gradation, should be placed in the toe and along the perimeter of the slope and channel protection. The riprap should be placed with suitable equipment in such a manner as to produce a reasonably graded mass 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.

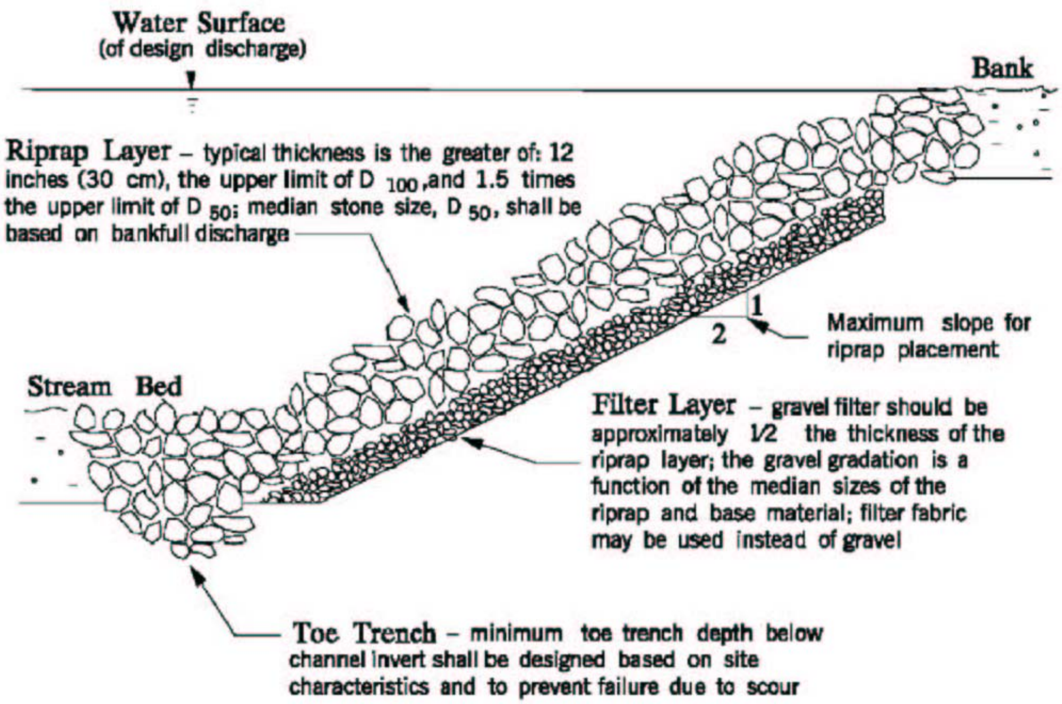
Note: The use of rock vanes (S&S 30.3: Rock Vanes) should be considered to redirect high-velocity flows at the toe.

Figure 3: Riprap Diameter as a Function of Stream Velocity
(Based on Ishbash Equation)



DETAIL 47 – RIPRAP

SECTION VIEW



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H32.1–4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.2 STANDARDS AND SPECIFICATIONS

FOR

IMBRICATED RIPRAP

Definition

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 based on this manual. Whenever possible, however, granular filters with a minimum thickness of 6 inches (15 cm) should be used with a gradation as found in Table 28.

Table 28: 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 S&S 29.1: Riprap and Figure 42.

- *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 S&S 29.1: Riprap. A typical minimum axis length is 24 inches (0.6 meters).

Design Criteria

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 Watershed Protection Division. The recommended construction procedure for imbricated riprap is as follows (refer to Detail 43):

1. The stream should be diverted according to a Watershed Protection Division recommended procedure (see *Section 28, Temporary Instream Construction Measures*), 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.

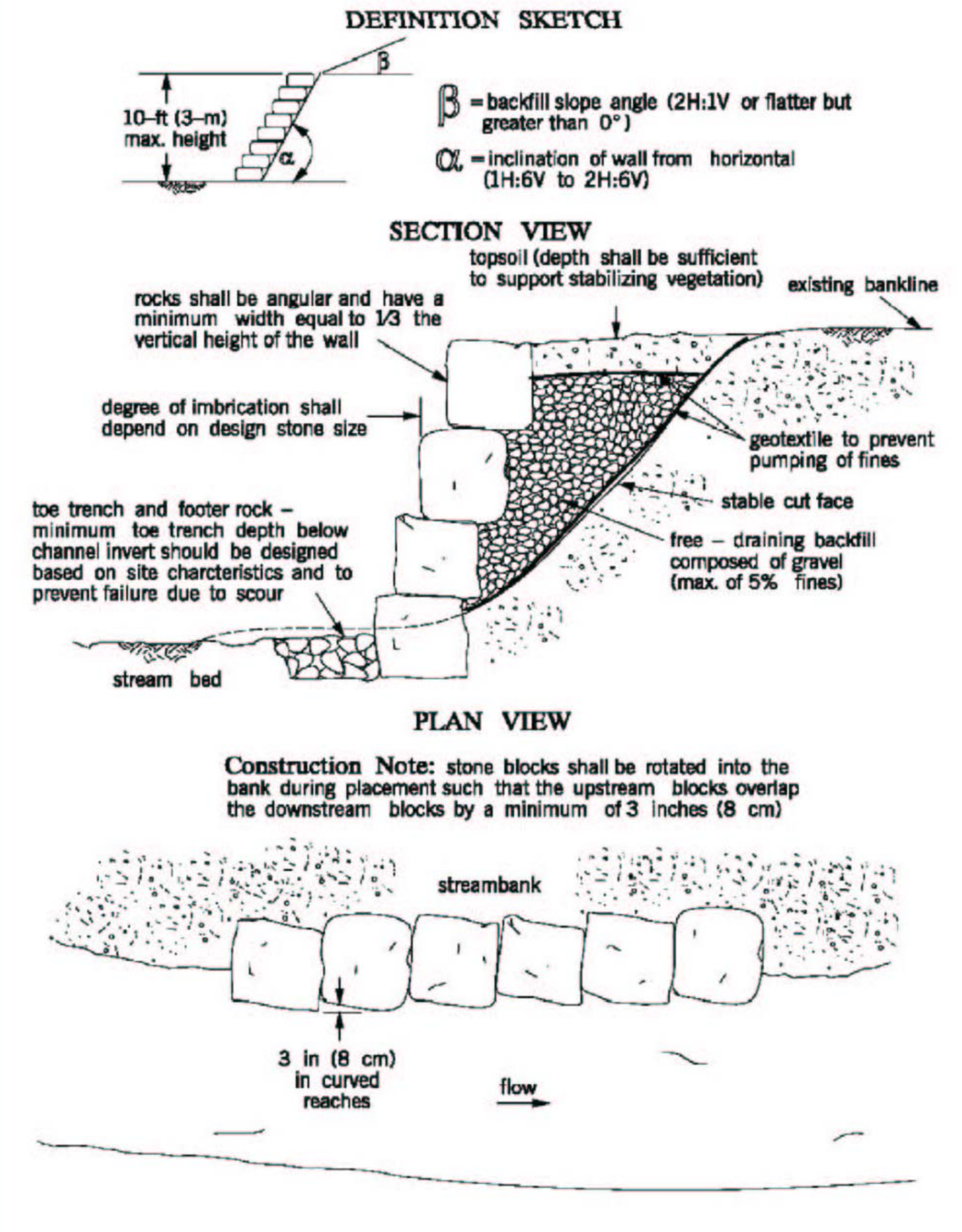
4. The rock layers should be neatly stacked with staggered joints so that each stone rests firmly on two stones in the tier below. Additionally, smaller stones should be used to fill voids so that each rock rests solidly on the previous rock layer with minimal opportunity for movement. Upon completion of the first layer of stone, the toe trench should be filled with Class III riprap sized according to S&S 29.1: 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 Watershed Protection Division.

   Note: The use of rock vanes (S&S 30.3: Rock Vanes) should be considered to dissipate excessive toe velocities.

DETAIL 48 – IMBRICATED RIPRAP



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H32.2-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.3 STANDARDS AND SPECIFICATIONS

FOR

GABIONS

Definition

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 25). 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 this manual.
- *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 29: 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)

Design Criteria

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 Watershed Protection Division . The recommended construction procedure for gabions is as follows (refer to
Detail 44):

1. The stream should be diverted according to a Watershed Protection Division recommended measure, and the construction area should be dewatered during placement of the gabion revetment’s foundation (See *Section 28: Temporary Instream Construction Measures*).

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.

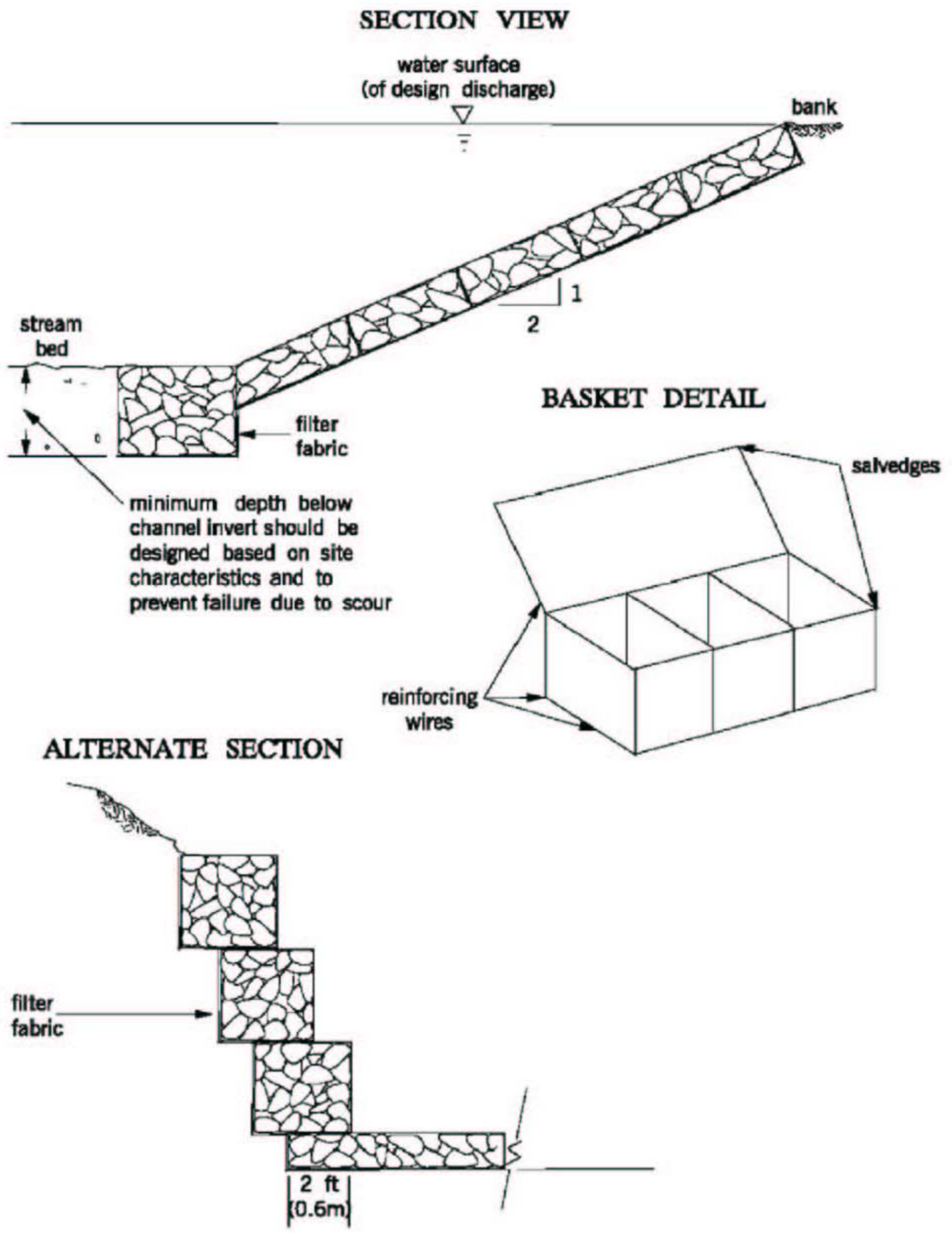
3. Filter fabric should be carefully and loosely placed on the prepared subgrade and secured. Adjacent strips should overlap a minimum of 8 inches (0.20 meters). To avoid damaging the filter cloth, care should be exercised in placing, stretching, and holding the empty basket units in good alignment.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

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.

DETAIL 49 - GABIONS



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H32.3-3	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.4 STANDARDS AND SPECIFICATIONS

FOR

LIVE STAKES

Definition

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 30.

- 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.

Design Criteria

Live stake installation should proceed as follows (refer to Detail 45):

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.

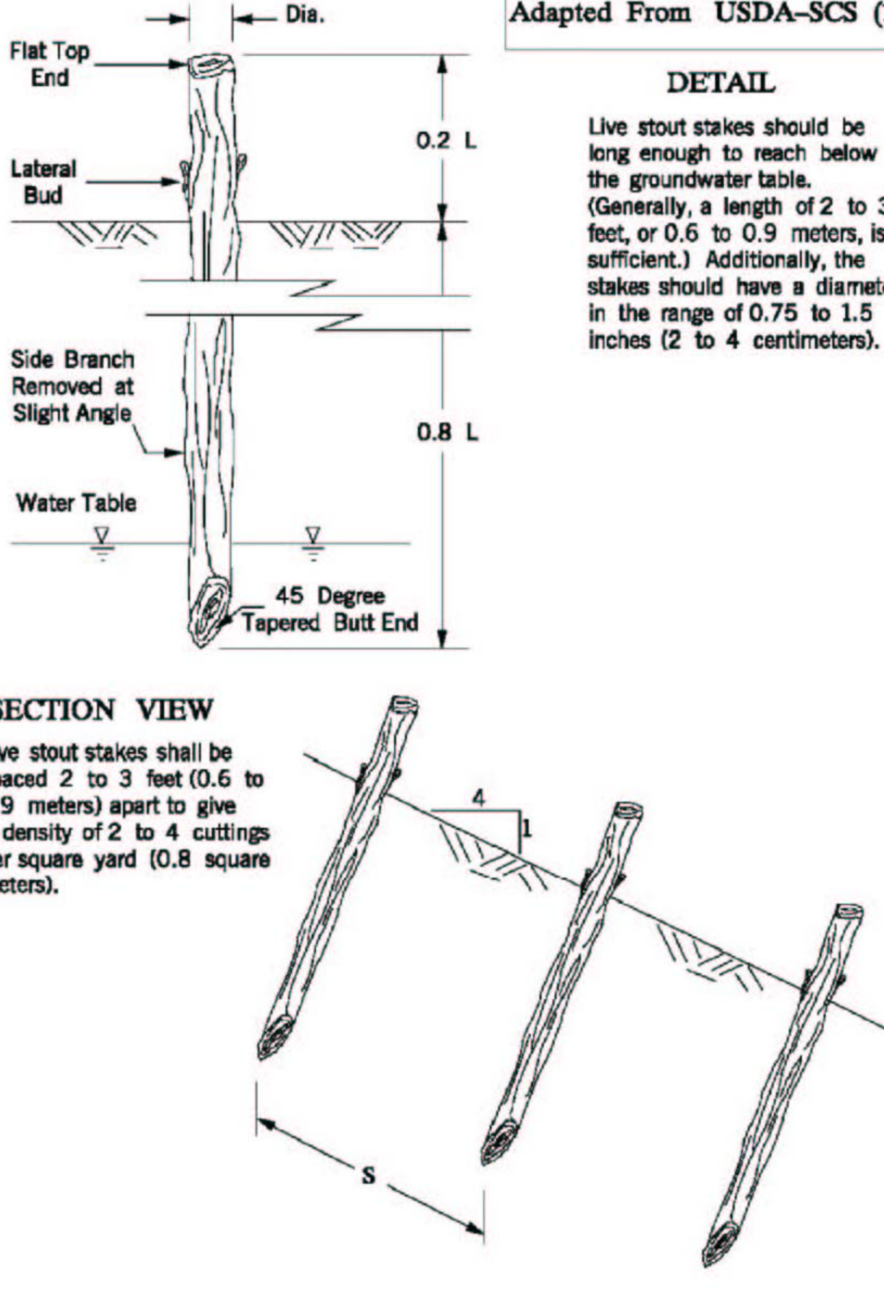
Table 30: Live Stakes

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

Table 30: Live Stakes

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

DETAIL 50 – 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).

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE 32.4-5	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.5 STANDARDS AND SPECIFICATIONS

FOR

LIVE FASCINES

Definition

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.

Design Criteria

Live fascine construction should occur during the dormancy period, usually late fall to early spring, with bundle preparation proceeding as follows (refer to Detail 46):

- 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 31.

Table 31: 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 32.

Table 32: 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)

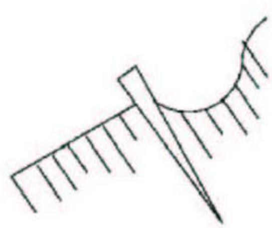
Straw or mulching material should be spread between fascine rows on slopes flatter than 1.5:1, and jute or coir fabric should be used on slopes greater than 1.5:1 to control erosion until the fascine rows and supporting vegetation become established.

DETAIL 51 - LIVE FASCINES

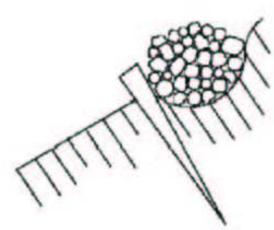
Preliminary Step – prepare fascine bundles as follows: cigar–shaped bundles of live, rootable brush and branches with butts alternating, 4 to 10–inch (10 to 25–cm) diameters, tied 12 to 18 inches (30 to 45 cm) on center

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

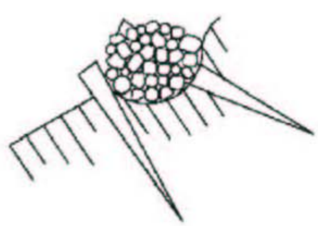
Step 1 – insert stakes on contour



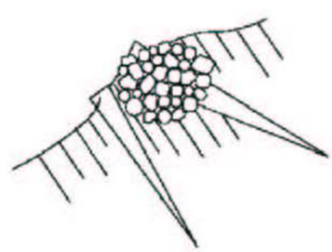
Step 2 – dig trench (1/2 bundle diameter in depth) above the stakes



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

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H32.5-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.6 STANDARDS AND SPECIFICATIONS

FOR

NATURAL FIBER ROLLS

Definition

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.

Design Criteria

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 Watershed Protection Division. The recommended construction procedure for natural fiber logs should proceed as follows (refer to Detail 47):

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.

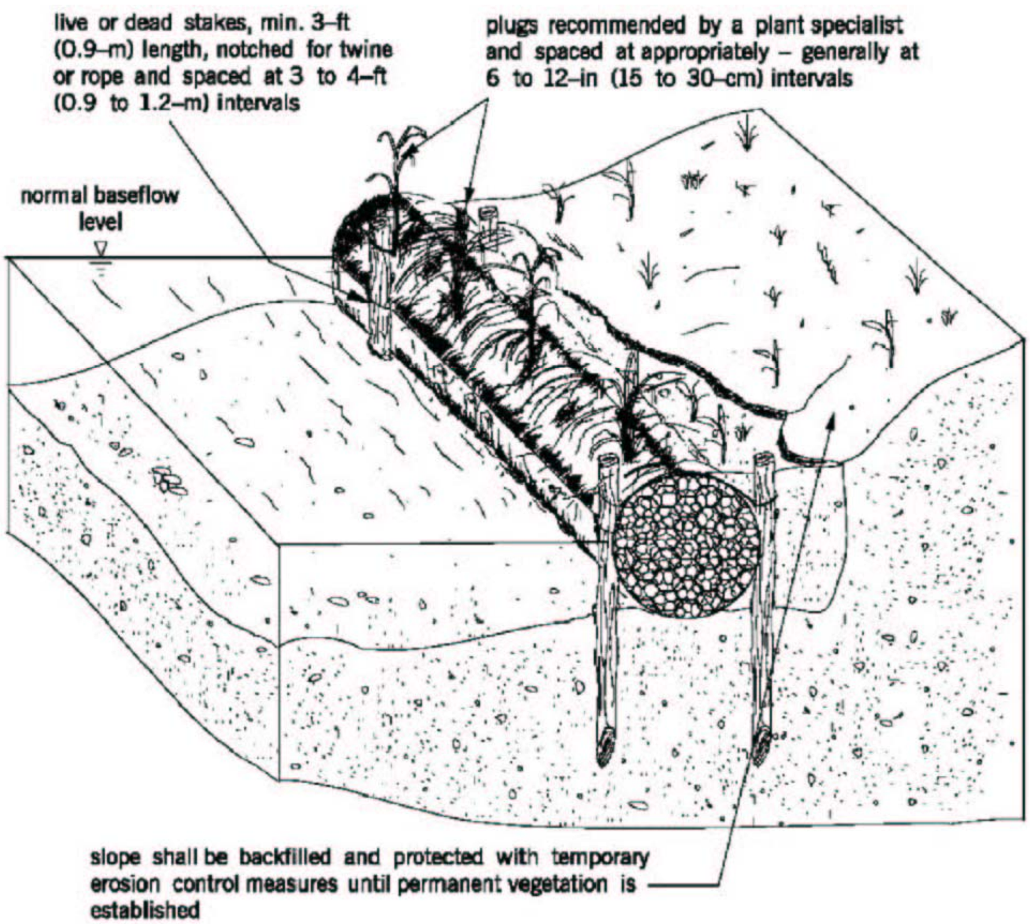
5. Successive rows of fiber rolls should be offset 3 to 8 inches (8 to 20 centimeters). Additionally, to ensure that roots extend into the soil, plants should be plugged into the sides of the fiber log near the soil. The need to backfill/contour the soil behind the fiber logs and between successive lifts 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 52 - NATURAL FIBER ROLLS

DETAIL

Adapted From Goldsmith and Bestmann (1992)



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H32.6-3	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.7 STANDARDS AND SPECIFICATIONS

FOR

BRUSH LAYERING

Definition

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 S&S 29.4: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.

Design Criteria

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 S&S 29.1: Riprap must first be constructed below the normal baseflow level according to riprap sizing and installation guidelines (refer to Detail 48a).

- 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).

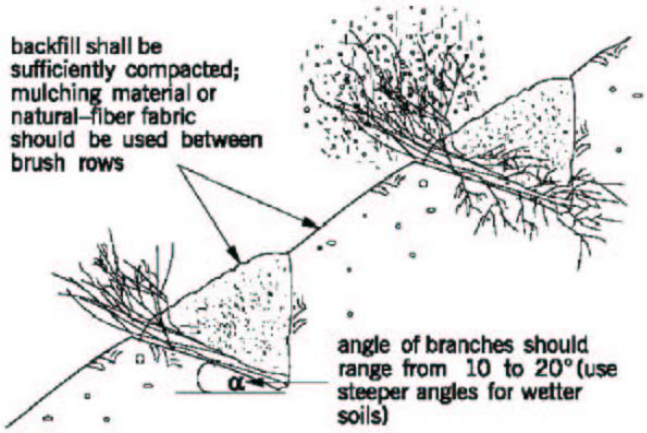
- Subsequent rows of brush layers should be spaced as follows, though frequently wet and unstable slopes may require closer spacing:

Table 33: 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.

DETAIL 53A – BRUSH LAYERING

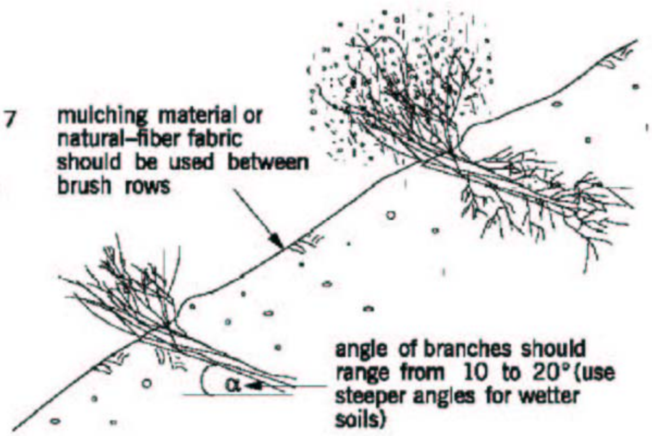


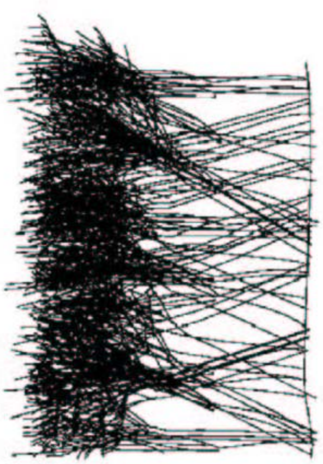
SECTION VIEW: FILL

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)

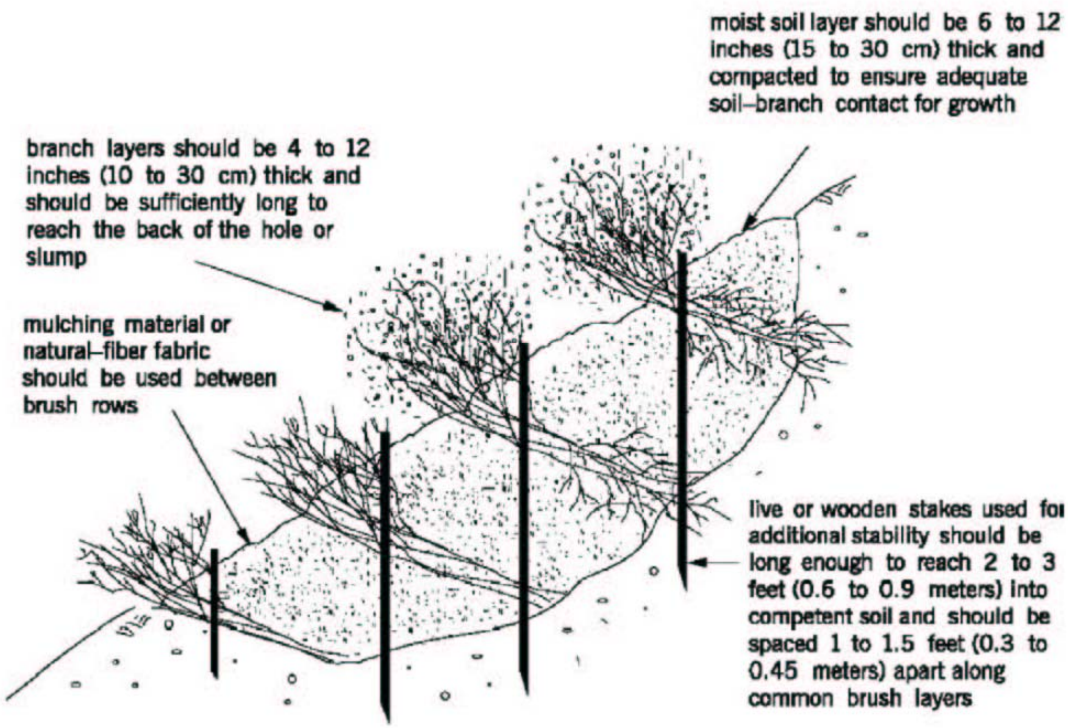
Adapted From Gray & Sotir (1996)

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H32:7-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

DETAIL 53B – BRUSH LAYERING

Adapted From Gray & Sotir (1996)

SECTION VIEW



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H32:7-5	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.8 STANDARDS AND SPECIFICATIONS

FOR

BRUSH MATTRESSES

Definition

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 S&S 29.4: 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.

Design Criteria

Brush mattresses should be installed as follows (refer to Detail 49):

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.

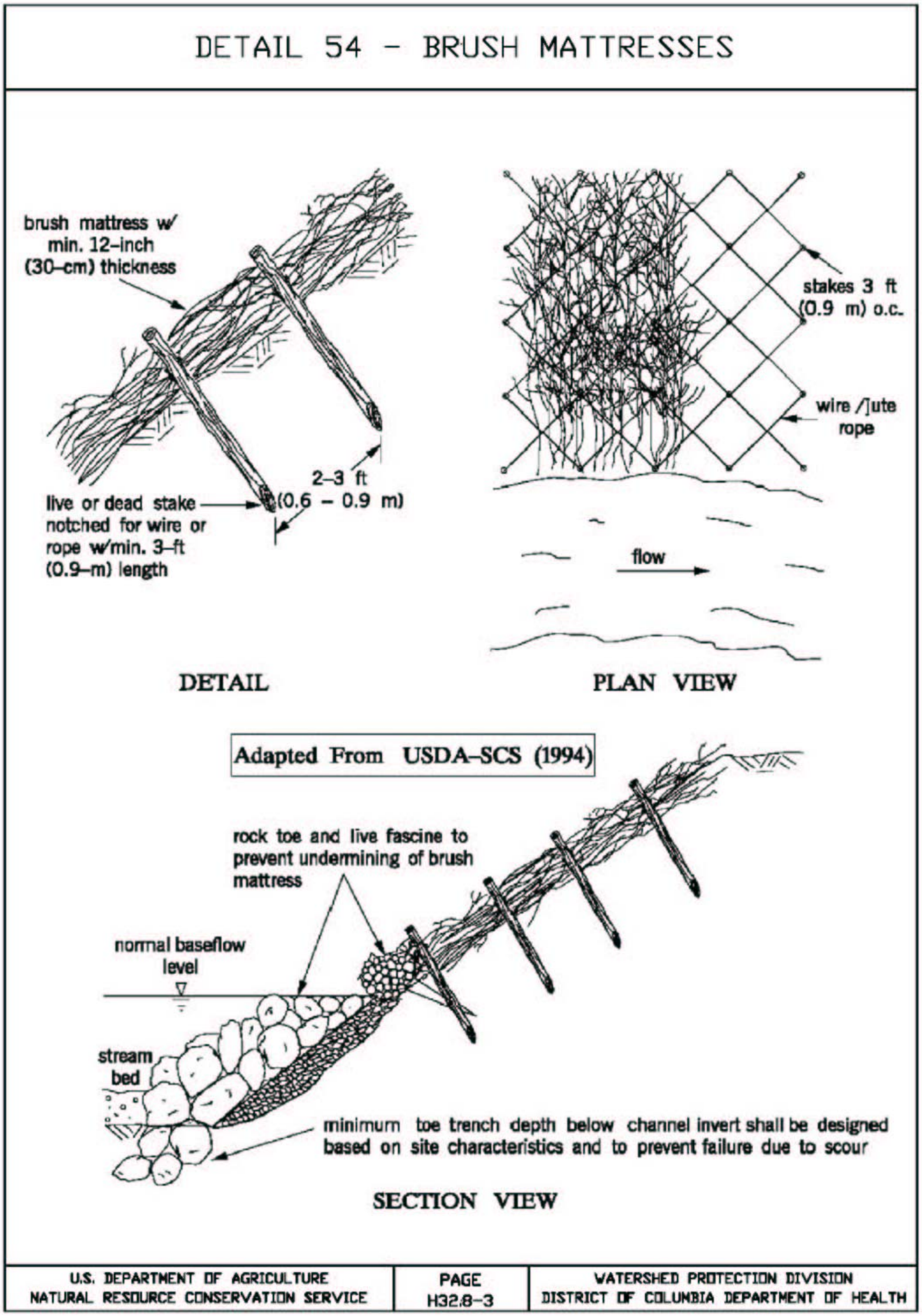
    - C Approximately 20 to 50 branches should be used per running meter provided their lengths are the same as the slope length.

    - C 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 S&S 29.1: Riprap and Figure 3.)


DETAIL 54 - BRUSH MATTRESSES
brush mattress w/ min. 12-inch (30-cm) thickness
live or dead stake notched for wire or rope w/min. 3-ft (0.9-m) length
2-3 ft (0.6 - 0.9 m)
stakes 3 ft (0.9 m) o.c.
wire /jute rope
flow
DETAIL
PLAN VIEW
Adapted From USDA-SCS (1994)
rock toe and live fascine to prevent undermining of brush mattress
normal baseflow level
stream bed
minimum toe trench depth below channel invert shall be designed based on site characteristics and to prevent failure due to scour
SECTION VIEW
U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCE CONSERVATION SERVICE
PAGE
H32.8-3
WATERSHED PROTECTION DIVISION
DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.9 STANDARDS AND SPECIFICATIONS

FOR

LIVE CRIB WALL

Definition

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 S&S 29.4: 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 S&S 29.1: 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.

Design Criteria

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 Watershed Protection Division. Live crib walls should be installed as follows (refer to Details 50a):

1. The location of the crib wall revetment should vary depending upon flow conditions and the reach's degree of curvature (refer to Detail 50b).

2. Stream flow should be diverted away from the site according to a plan approved by the Watershed Protection Division. (See *Section 28, Temporary Instream Construction Measures*).

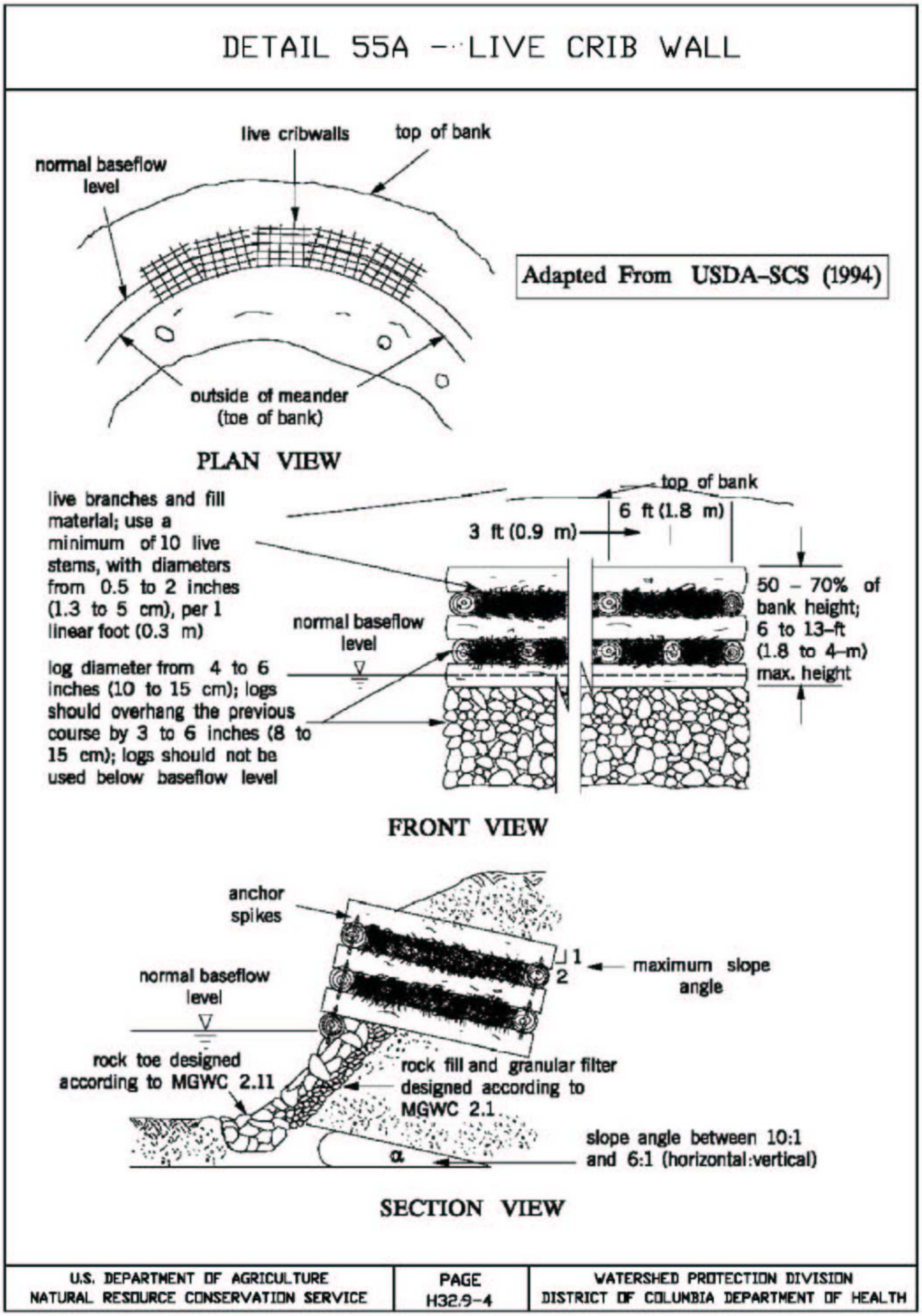
3. Loose material at the toe of the embankment should be excavated until a stable foundation is reached, usually within 2 to 3 feet (0.6 to 0.9 meters) of the surface. The crib foundation and structure should be inclined into the slope at a minimum angle (measured from the horizontal) ranging from 10H:1V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

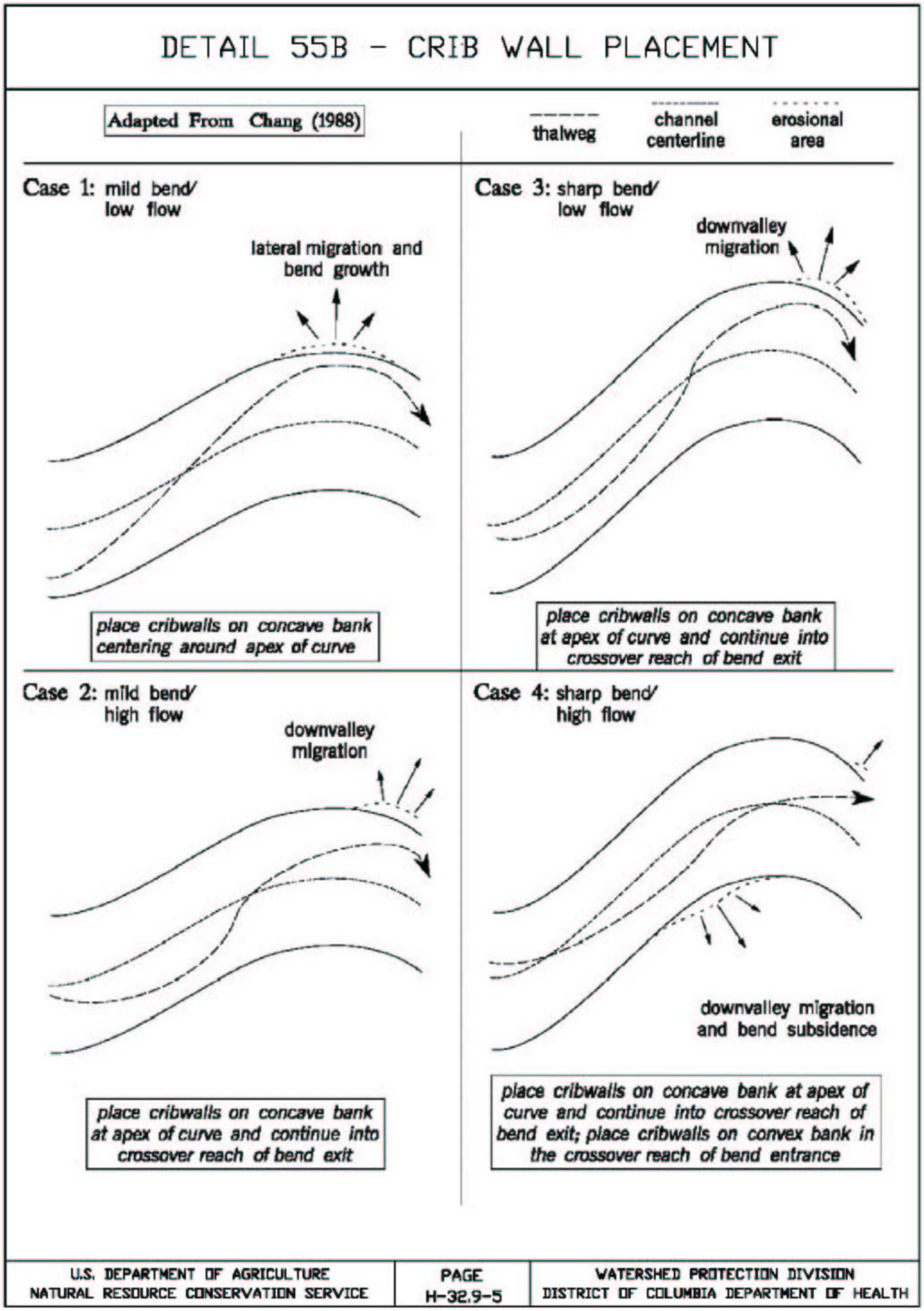
4. The first course of logs or timbers should be positioned at the front and back of the excavated foundation approximately 3 to 6 feet (0.9 to 1.8 meters) apart and parallel to the slope contour. Successive courses of logs or timbers should be situated at right angles on top of the previous course such 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 55A -- LIVE CRIB WALL
live cribwalls
top of bank
normal baseflow level
Adapted From USDA-SCS (1994)
outside of meander (toe of bank)
PLAN VIEW
live branches and fill material; use a minimum of 10 live stems, with diameters from 0.5 to 2 inches (1.3 to 5 cm), per 1 linear foot (0.3 m)
top of bank
6 ft (1.8 m)
3 ft (0.9 m)
normal baseflow level
50 – 70% of bank height; 6 to 13–ft (1.8 to 4–m) max. height
log diameter from 4 to 6 inches (10 to 15 cm); logs should overhang the previous course by 3 to 6 inches (8 to 15 cm); logs should not be used below baseflow level
FRONT VIEW
anchor spikes
1
2
maximum slope angle
normal baseflow level
rock toe designed according to MGWC 2.11
rock fill and granular filter designed according to MGWC 2.1
slope angle between 10:1 and 6:1 (horizontal:vertical)
α
SECTION VIEW
U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCE CONSERVATION SERVICE
PAGE
H32.9-4
WATERSHED PROTECTION DIVISION
DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH


DETAIL 55B – CRIB WALL PLACEMENT
Adapted From Chang (1988)
thalweg
channel centerline
erosional area
Case 1: mild bend/ low flow
lateral migration and bend growth
place cribwalls on concave bank centering around apex of curve
Case 3: sharp bend/ low flow
downvalley migration
place cribwalls on concave bank at apex of curve and continue into crossover reach of bend exit
Case 2: mild bend/ high flow
downvalley migration
place cribwalls on concave bank at apex of curve and continue into crossover reach of bend exit
Case 4: sharp bend/ high flow
downvalley migration and bend subsidence
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
U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCE CONSERVATION SERVICE
PAGE
H-32.9-5
WATERSHED PROTECTION DIVISION
DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.10 STANDARDS AND SPECIFICATIONS

FOR

ROOT WADS

Definition

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 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.

Design Criteria

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 Watershed Protection Division. The construction of a root wad revetment should proceed as follows (refer to Detail 51a):

1. The location of the revetment should vary depending upon flow conditions and the reach’s degree of curvature (refer to Detail 51b).

2. Stream flow should be diverted away from the site and sediment control devices installed according to a plan approved by the Watershed Protection Division or local authority. (See *Section 28, Temporary Instream Construction Measures*.)

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.

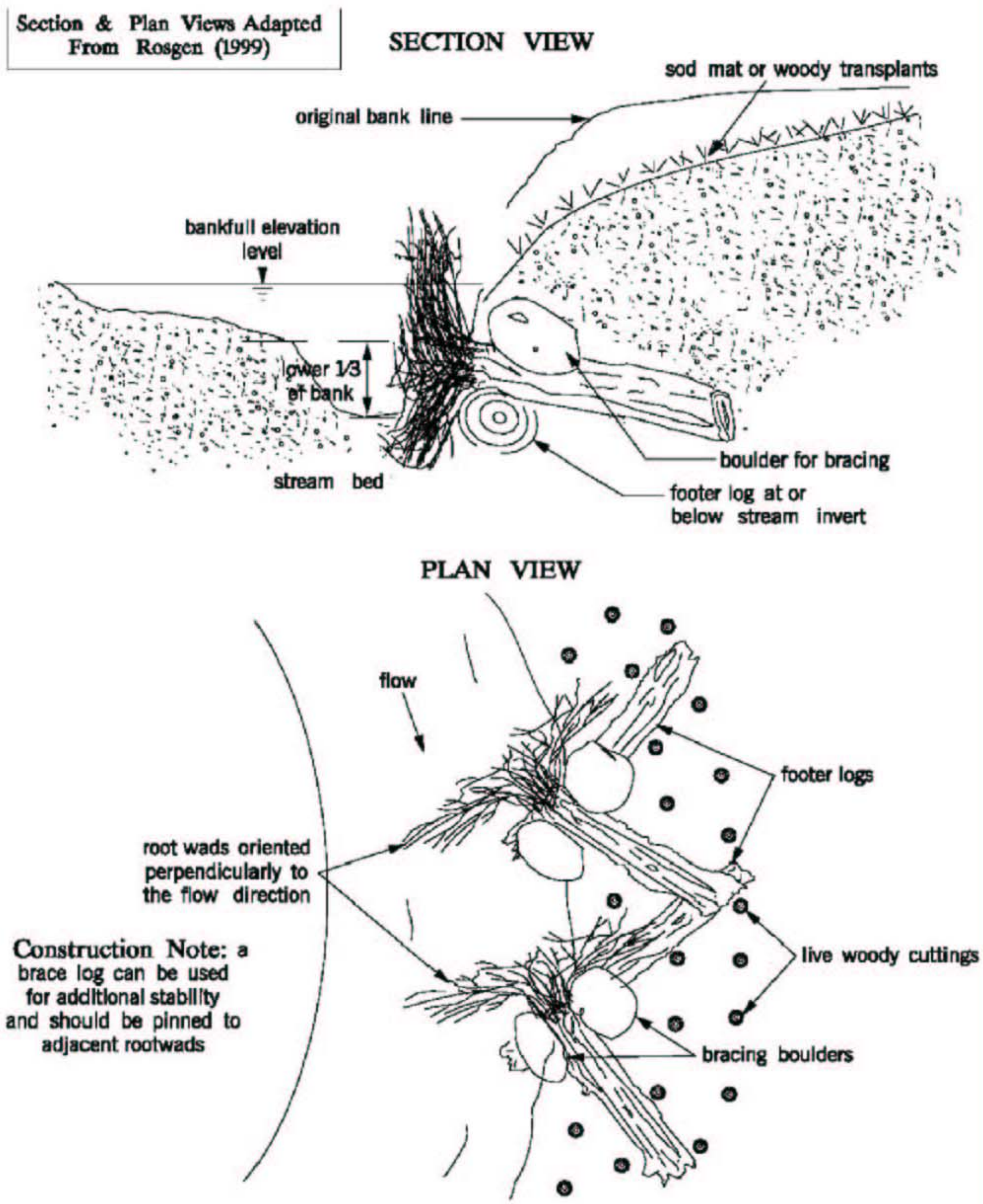
4. Placement of the root wad components should be as follows:

    - Footer logs should be positioned in the trench below the stream invert such that each upstream log is shingled over its downstream neighbor.

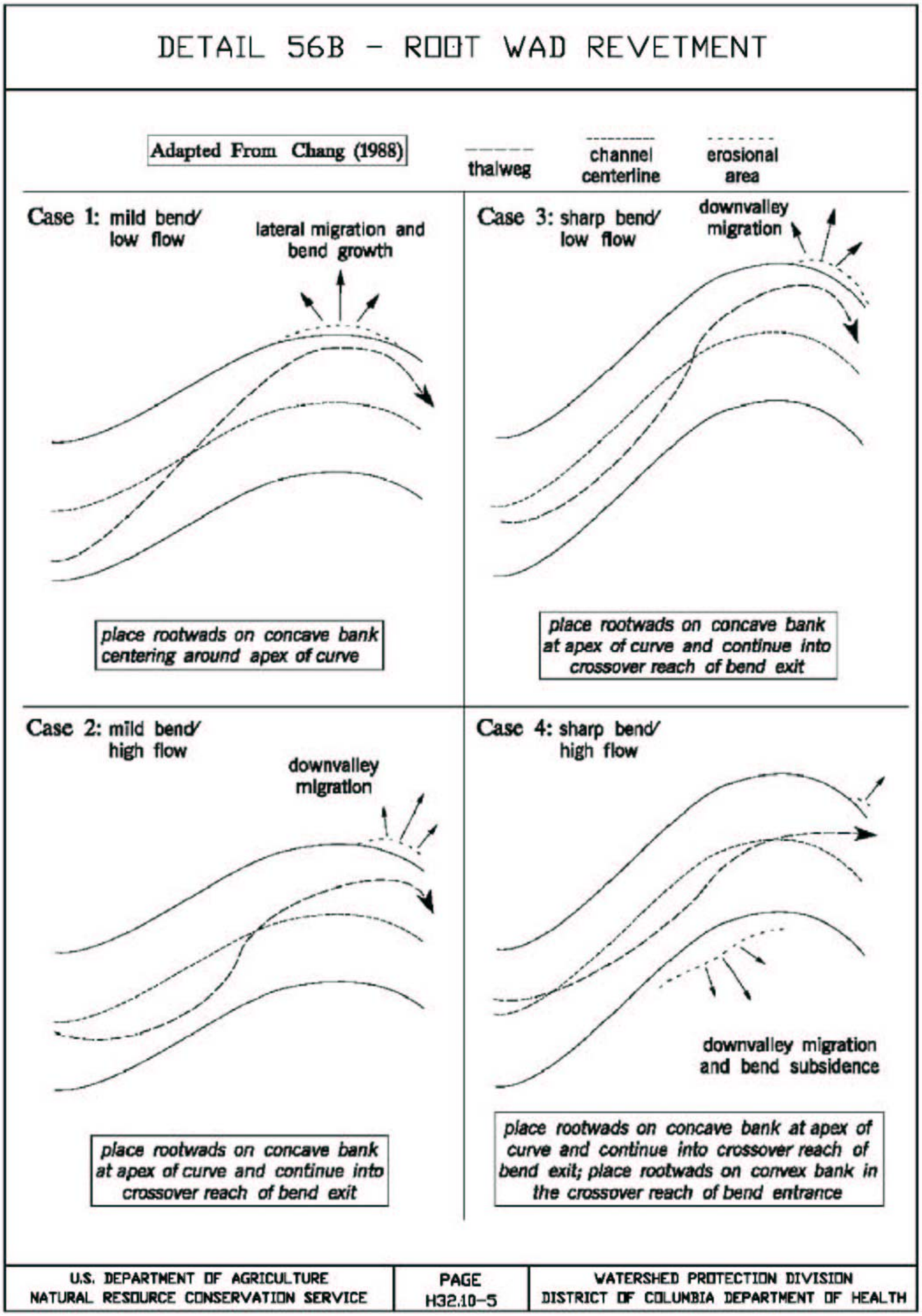
- In cut sections, root wads should be positioned in trenches such that the root mass of the trunk sits level with the cut end of the stump. The root mass should be oriented perpendicularly to the direction of flow. An angle of 30 to 60 degrees to the channel center line is usually adequate. Subsequent 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.

DETAIL 56A - ROOT WAD REVETMENT



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H32.10-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH


DETAIL 56B - ROOT WAD REVETMENT
Adapted From Chang (1988)
thalweg
channel centerline
erosional area
Case 1: mild bend/ low flow
lateral migration and bend growth
place rootwads on concave bank centering around apex of curve
Case 3: sharp bend/ low flow
downvalley migration
place rootwads on concave bank at apex of curve and continue into crossover reach of bend exit
Case 2: mild bend/ high flow
downvalley migration
place rootwads on concave bank at apex of curve and continue into crossover reach of bend exit
Case 4: sharp bend/ high flow
downvalley migration and bend subsidence
place rootwads on concave bank at apex of curve and continue into crossover reach of bend exit; place rootwads on convex bank in the crossover reach of bend entrance
U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCE CONSERVATION SERVICE
PAGE
H32.10-5
WATERSHED PROTECTION DIVISION
DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

29.11 STANDARDS AND SPECIFICATIONS

FOR

TOE PROTECTION

Definition

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 52A 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 nonincising 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 S&S 29.4:Live Stakes for material and Detail 52 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 S&S 29.1: Riprap. The minimum toe trench depth should be sufficient to resist scour or at a minimum of 1.5 times the maximum riprap diameter.

Design Criteria

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 Watershed Protection Division. The proposed construction sequence for toe protection measures are as follows:

1. The stream should be redirected by an approved temporary stream diversion (See *Section 28: Temporary Instream Construction Measures*), 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 52. Installation will vary according to material used.

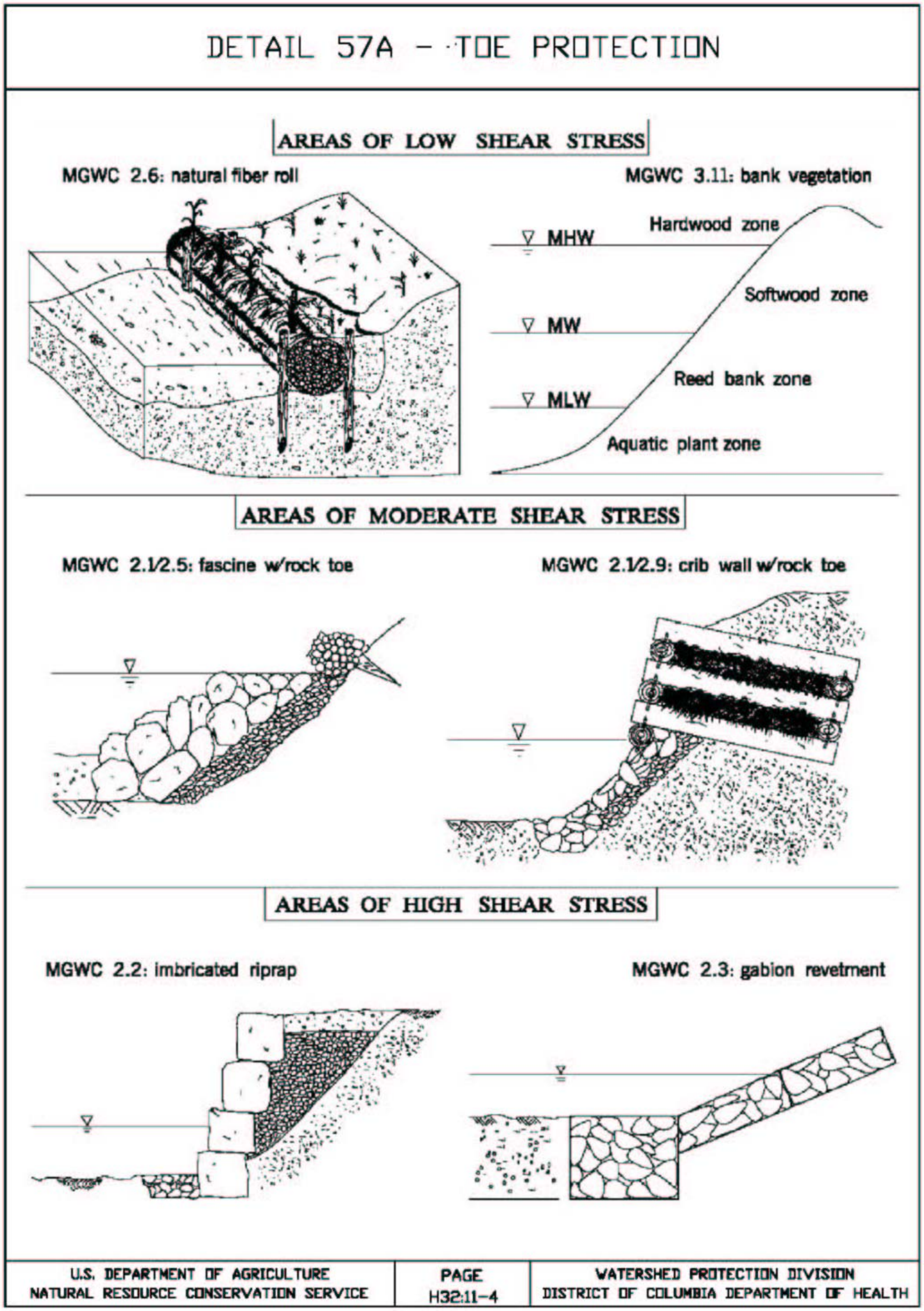
   Vegetated Toe Protection Measures
   - *Vegetation:* Refer to S&S 29.6: Natural Fiber Rolls
   - *Live Fascines*: Refer to S&S 29.5: Live Fascines
   - *Crib Walls*: Refer to S&S 29.9: Live Crib Walls

   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 S&S 29.1: Riprap and Figure 3.
   - *Imbricated Riprap*: Refer to S&S 29.2: Imbricated Riprap
   - *Gabion*: Refer to S&S 29.3: Gabion

3. The use of rock vanes (S&S 30.3: 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.

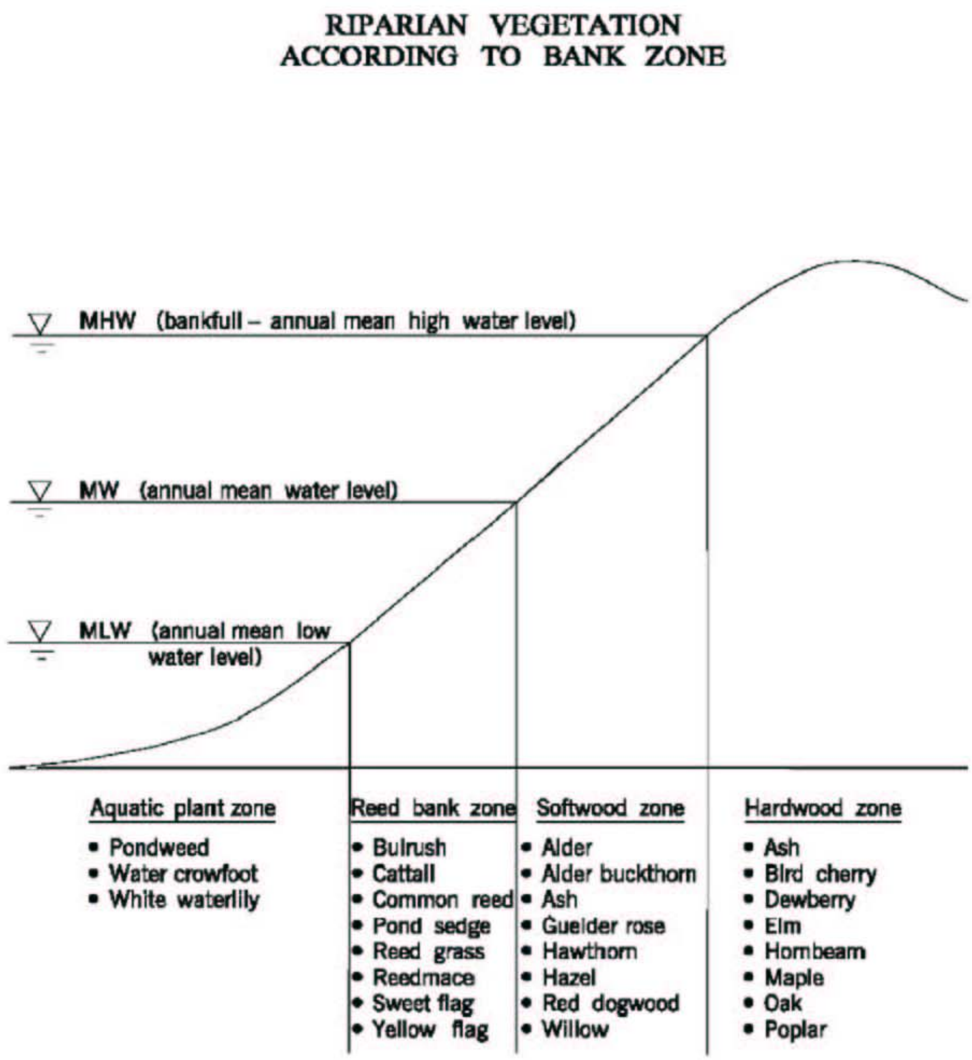
4. Once construction is completed, the diversion should be removed from upstream to downstream. Sediment control devices, including perimeter erosion controls, are to remain in place until all disturbed areas are stabilized in accordance with an approved sediment and erosion control plan and the inspection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



DETAIL 57A - TOE PROTECTION
AREAS OF LOW SHEAR STRESS
MGWC 2.6: natural fiber roll
MGWC 3.11: bank vegetation
MHW
Hardwood zone
Softwood zone
MW
Reed bank zone
MLW
Aquatic plant zone
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
U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCE CONSERVATION SERVICE
PAGE
H32:11-4
WATERSHED PROTECTION DIVISION
DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

DETAIL 57B - TOE PROTECTION

Adapted From Seibert (1968)



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H32.11-5	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

30.1 STANDARDS AND SPECIFICATIONS

FOR

BOULDER PLACEMENT

Definition

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 S&S 29.1: 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.

Design Criteria

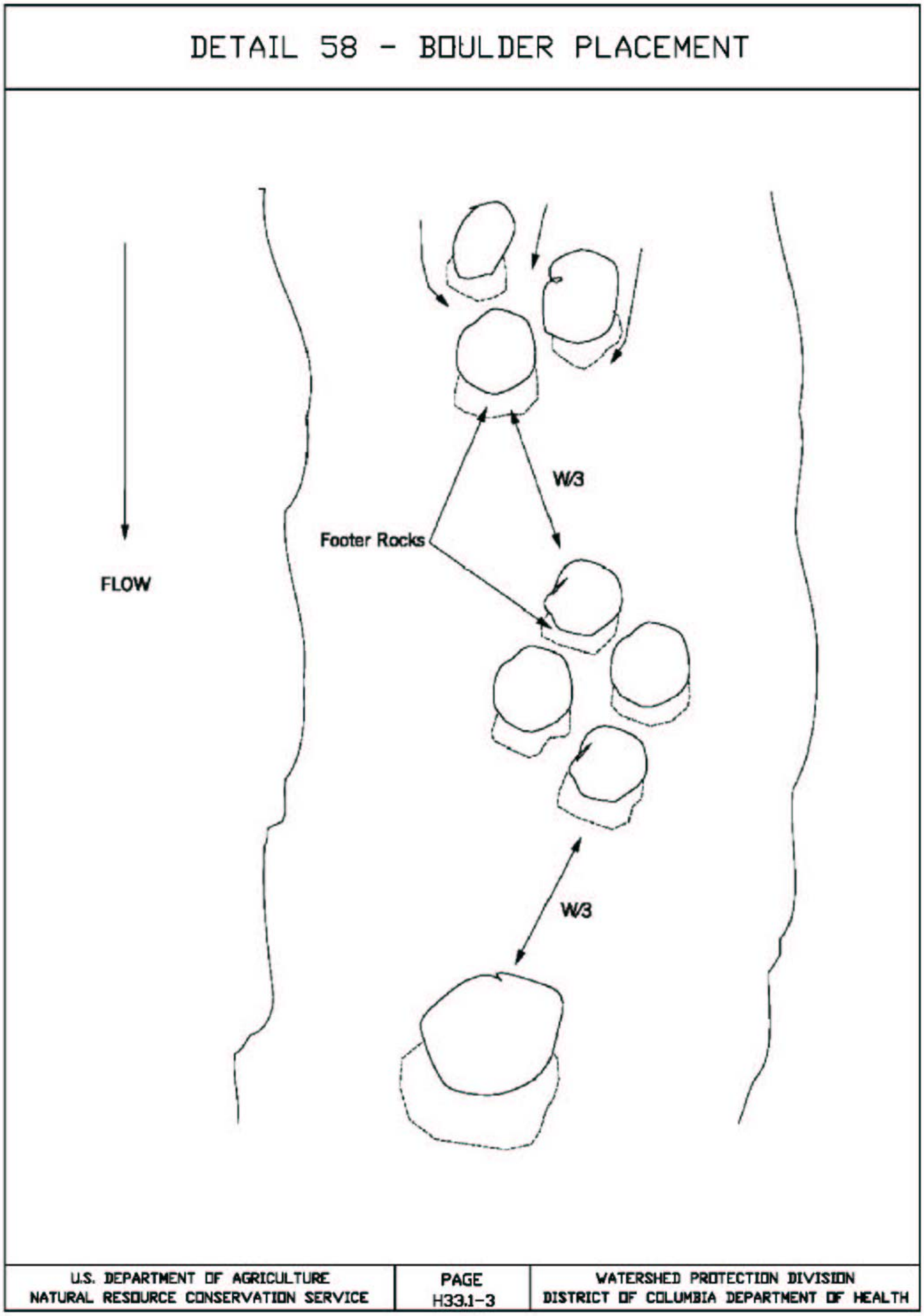
All erosion and sediment control devices, including dewatering basins, should be implemented as the first order of business according to a plan approved by the Watershed Protection Division. Boulder placement should proceed as follows (refer to Detail 53):

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.


DETAIL 58 - BOULDER PLACEMENT
FLOW
Footer Rocks
W/3
W/3
U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCE CONSERVATION SERVICE
PAGE
H33.1-3
WATERSHED PROTECTION DIVISION
DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

30.2 STANDARDS AND SPECIFICATIONS

FOR

LOG VANES

Definition

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.

Design Criteria

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 Watershed Protection Division. Recommended construction requirements for log vanes are as follows (refer to Detail 54):

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 Watershed Protection Division. 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.

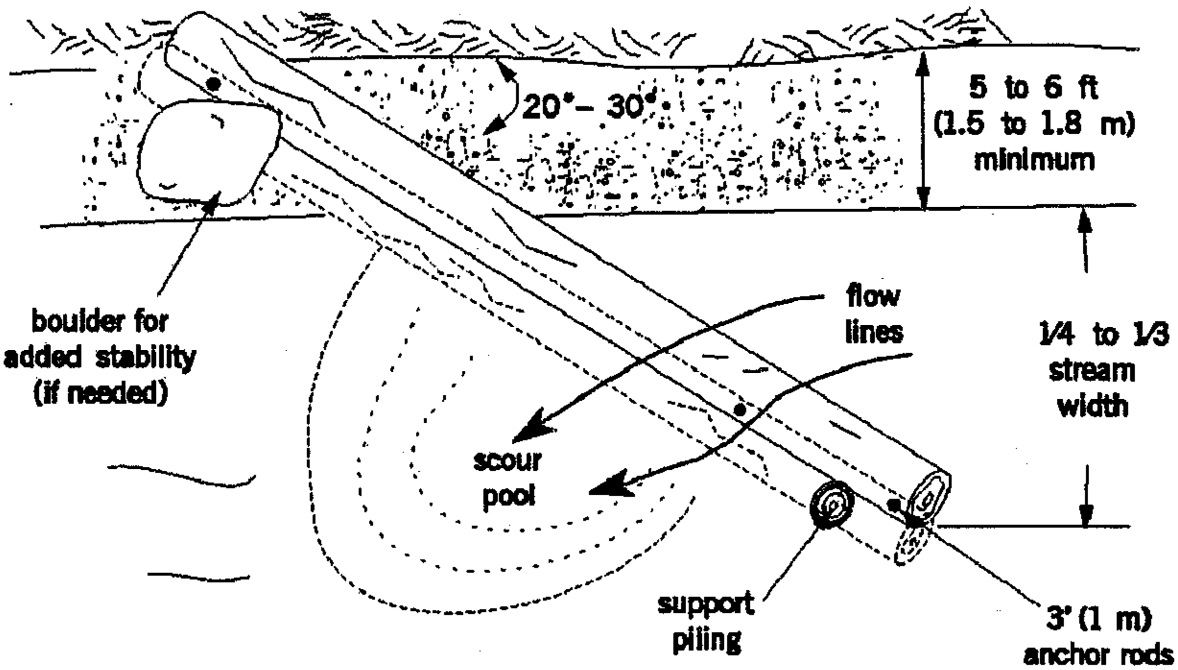
3. When installing vanes, the bank end of the structure should be firmly anchored a minimum of 5 to 6 feet (1.5 to 1.8 meters) into the slope. When two or more smaller logs are used in place of one larger log, they should be anchored to each other with 3-foot (0.9-meter) rods of 1/2 to 5/8-inch (1.3 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.

4. Large rocks can be positioned on the downstream face of the vanes to provide further stability. The rocks should be installed in accordance with S&S 30.1: Boulder Placement.

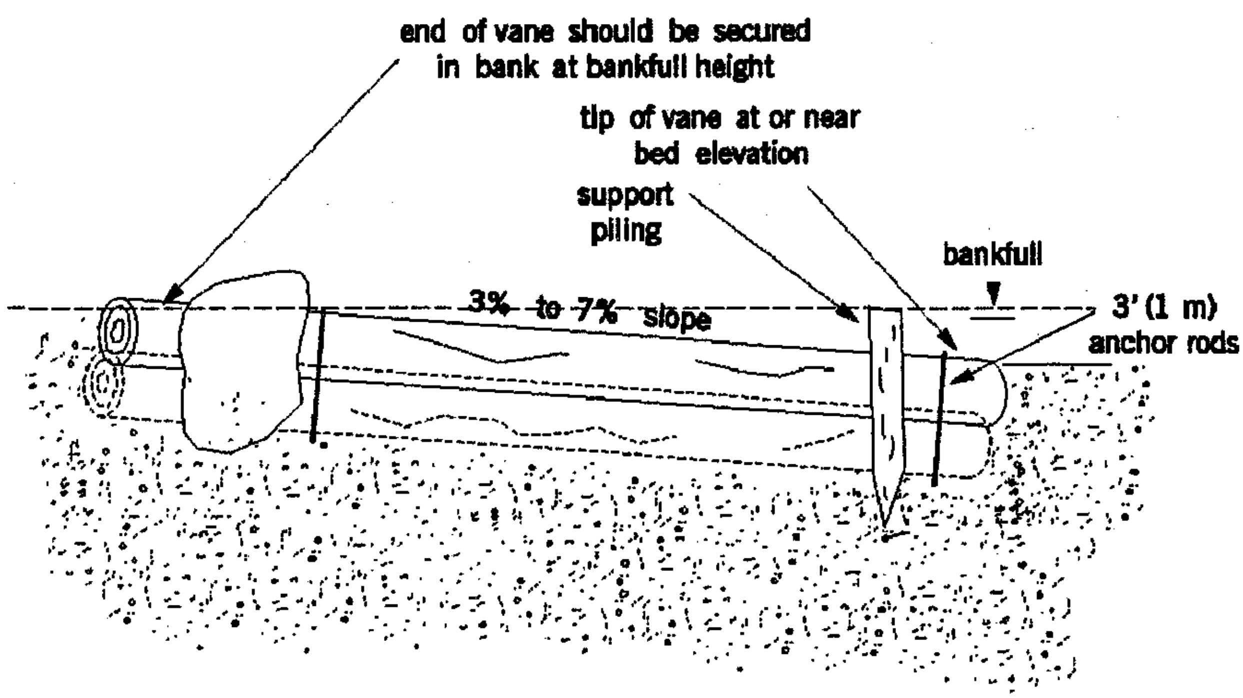
5. All disturbed areas should be permanently stabilized in accordance with an approved sediment and erosion control plan.

DETAIL 54A – LOG VANES

PLAN VIEW: LOG VANE



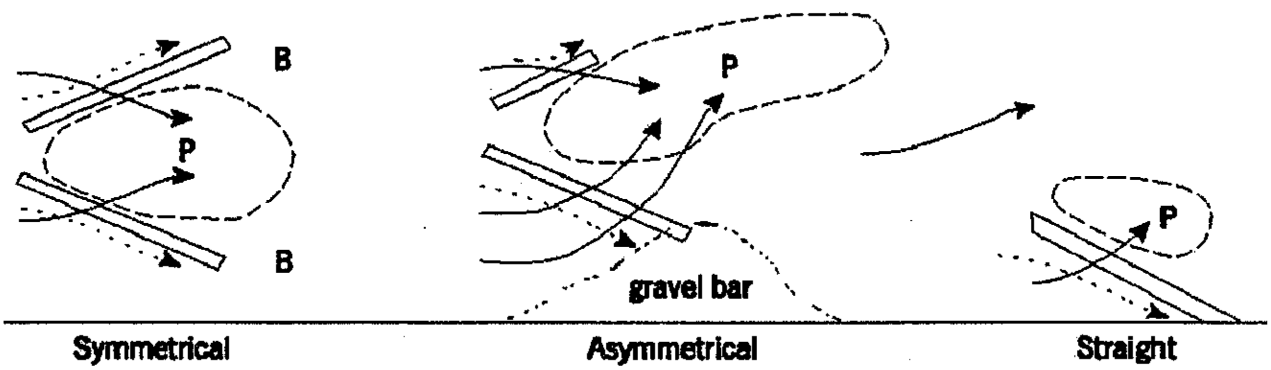
SECTION VIEW: LOG VANE



DETAIL 54B - ALTERNATE VANE PLACEMENT

PLAN VIEW: ALTERNATIVE VANE CONFIGURATIONS

Source: Hey (1995)



LEGEND:

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

30.3 STANDARDS AND SPECIFICATIONS

FOR

ROCK VANES

Definition

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 S&S 29.1: Riprap and Figure 3. 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.

Design Criteria

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 Watershed Protection Division. Recommended construction requirements for rock vanes are as follows (refer to Detail 55):

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 Watershed Protection Division. 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.

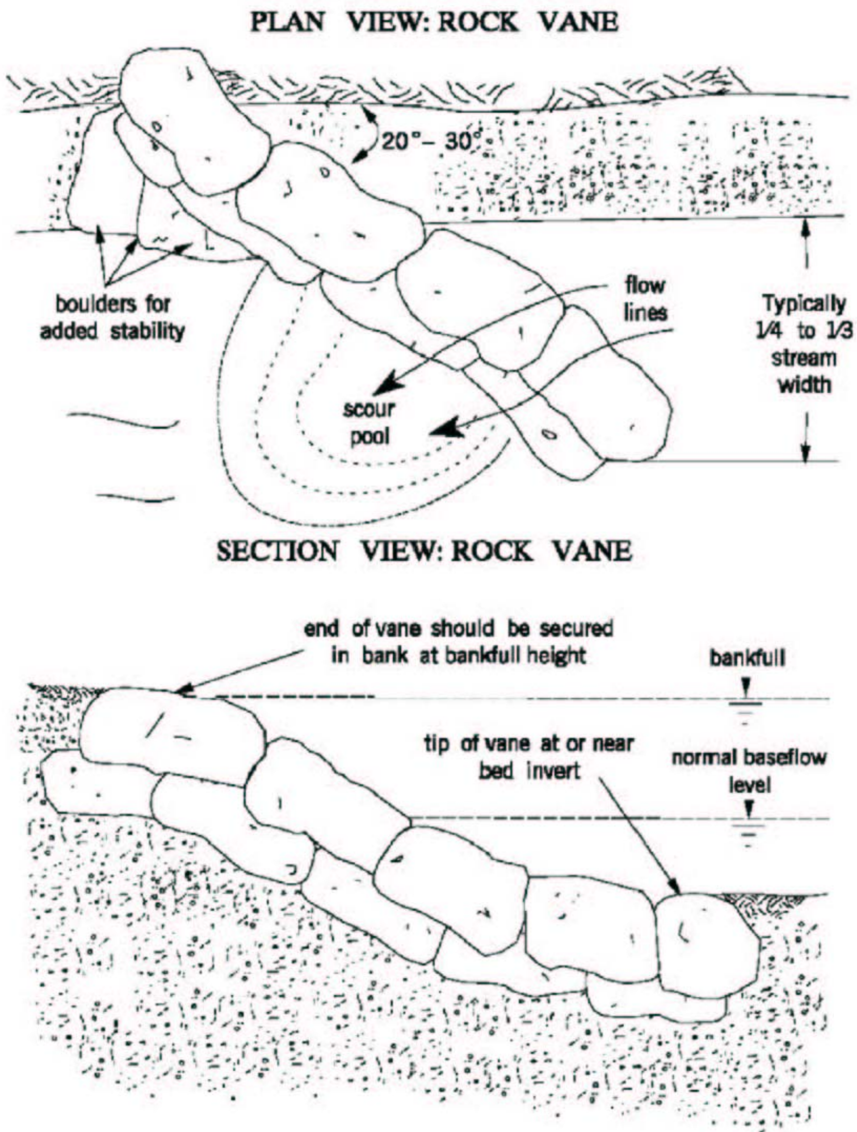
3. When installing vanes, the bank end of the structure should be firmly anchored a minimum of 2-3 rocks into the bank.

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 60A - ROCK VANES

Section & Plan Views Adapted From Rosgen (1999)

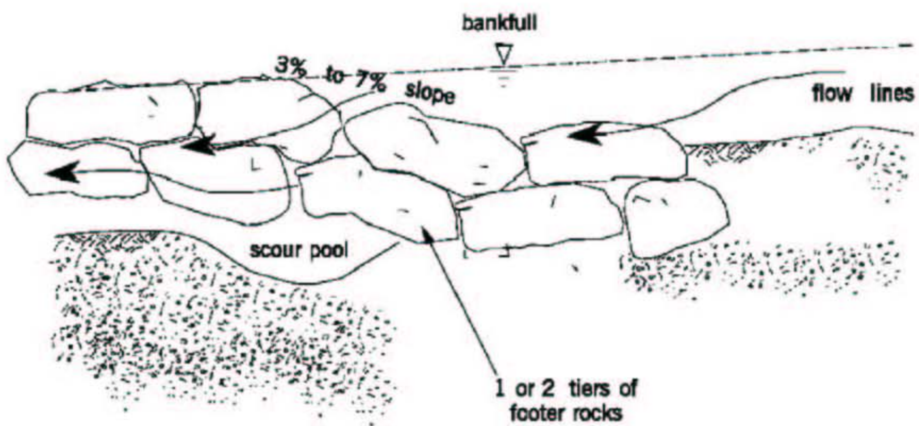


U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.3-3	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

DETAIL 60B – ROCK VANES

Section & Plan Views Adapted
From Rosgen (1999)

PROFILE VIEW: STRAIGHT VANE



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.3-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

30.4 STANDARDS AND SPECIFICATIONS

FOR

J-HOOK VANES

Definition

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 S&S 29.1: Riprap and Figure 3. 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.

Design Criteria

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 Watershed Protection Division. Recommended construction requirements for J-hook vanes are as follows (refer to Detail 56):

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 Watershed Protection Division. 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.

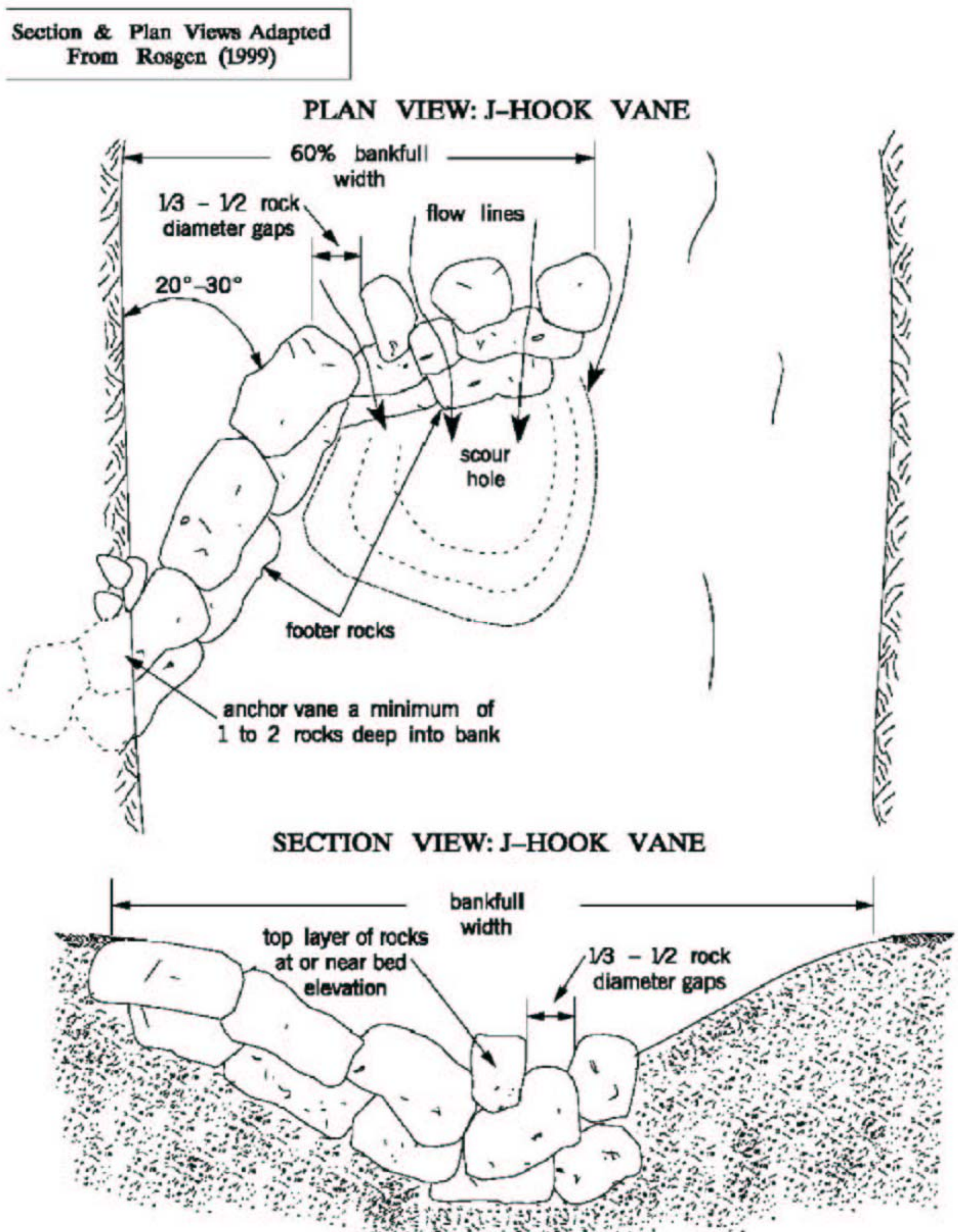
3. When installing vanes, the bank end of the structure should be firmly anchored a minimum of 1-2 rocks into the bank.

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.

DETAIL 61A – J-HOOK VANES

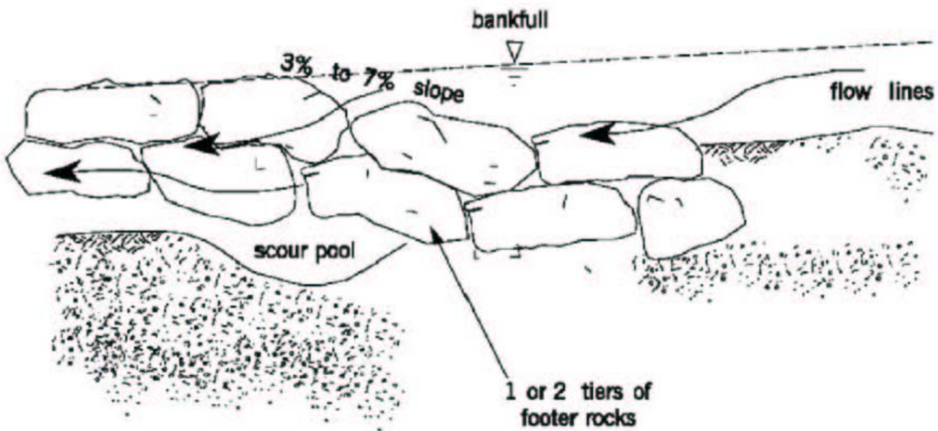


U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.4-3	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

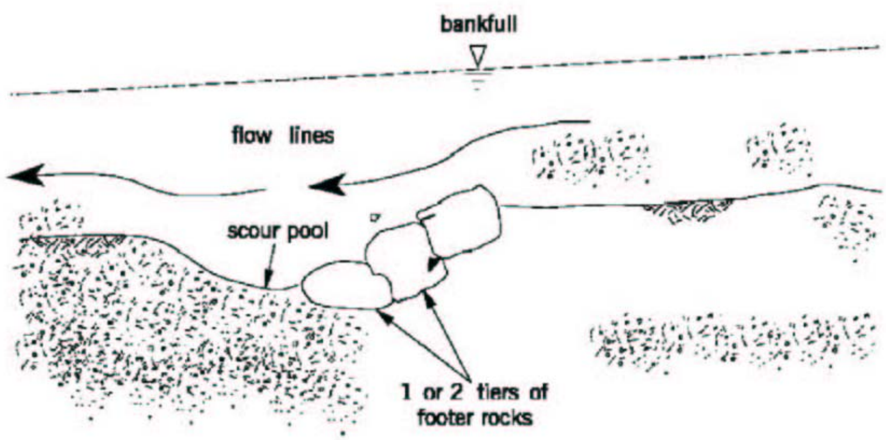
DETAIL 61B – J-HOOK VANES

Section & Plan Views Adapted From Rosgen (1999)

PROFILE VIEW OF VANE ARM



PROFILE VIEW OF J-HOOK



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.4-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

30.5 STANDARDS AND SPECIFICATIONS

FOR

STREAM DEFLECTORS

Definition

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 57.
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 S&S 29.1: Riprap. Additionally, large rocks and boulders can be positioned on the downstream side of straight and triangular deflectors to provide further stability.

Design Criteria

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 Watershed Protection Division. Recommended construction requirements for stream deflectors are as follows (refer to Detail 57):

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 Watershed Protection Division. 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.

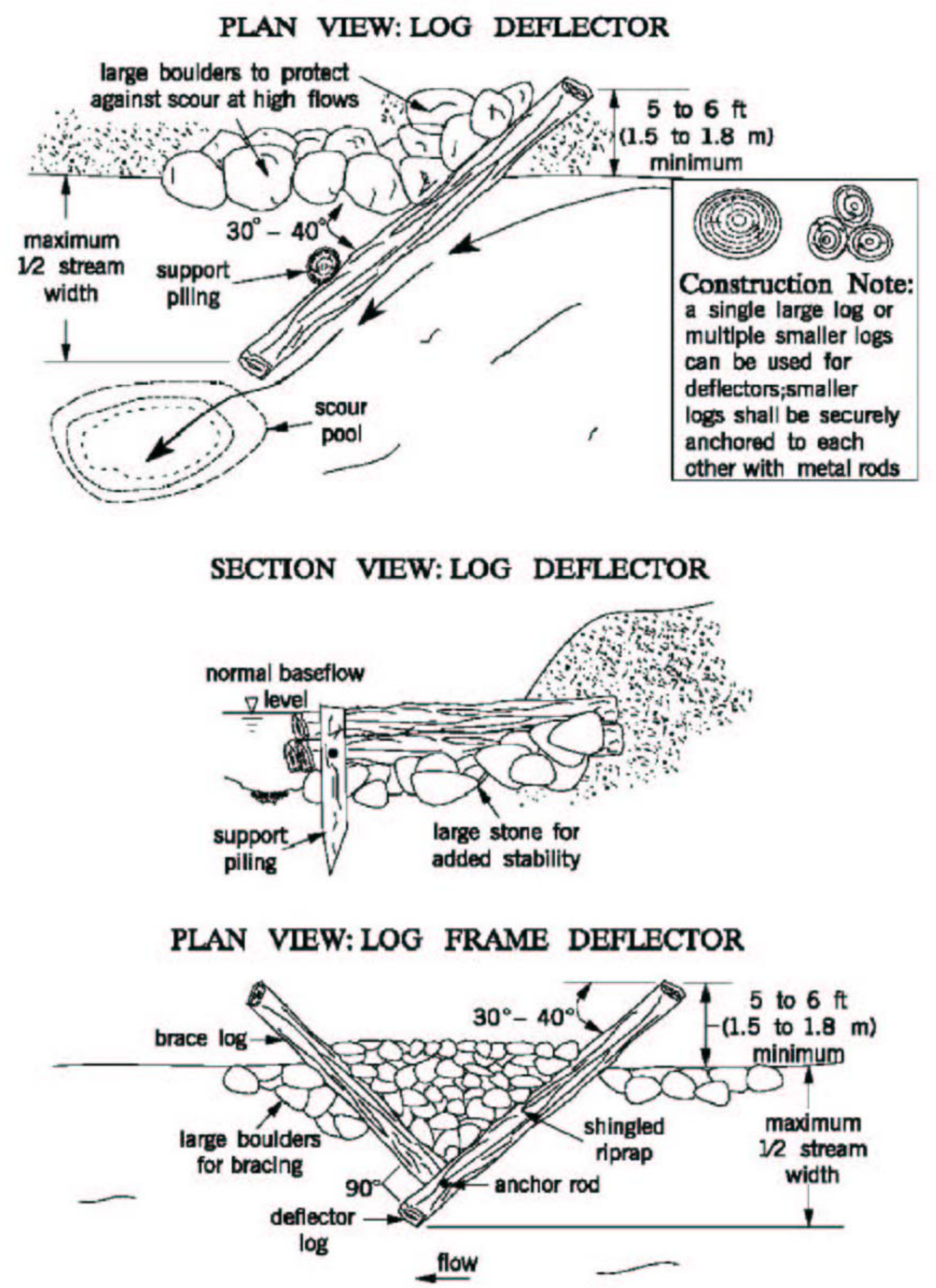
5. If a wing deflector is to be constructed entirely from stone, rocks sized for bankfull flow according to S&S 29.1: Riprap should be employed to form the upstream and downstream edges. Keying theses rocks into the bank and channel bed helps to stabilize the structure. Once the upstream and downstream 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.

6. 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 S&S 30.9: Step Pools).

7. 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.

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

DETAIL 62A - STREAM DEFLECTORS

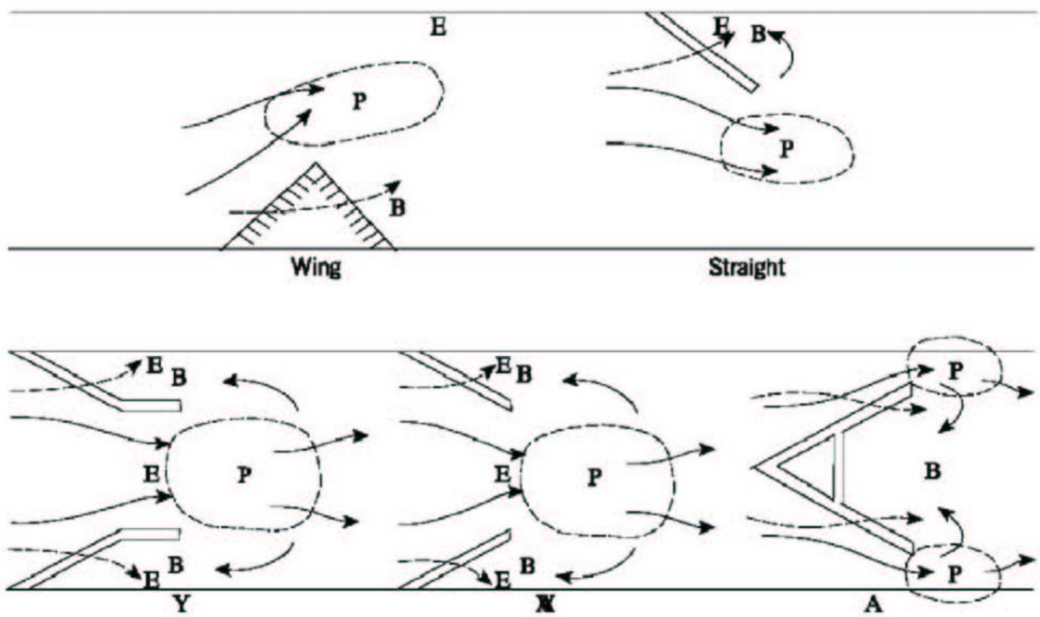


U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.5-5	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

DETAIL 62B - 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

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.5-6	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

30.6 STANDARDS AND SPECIFICATIONS

FOR

LOG & ROCK CHECK DAMS

Definition

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 S&S 29.1: 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 S&S 29.1: Riprap to resist bankfull flows and sealed with gravel and sand may be used in place of logs.

Design Criteria

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 Watershed Protection Division. The recommended construction procedure for log and rock check dams should proceed as follows (refer to Detail 58):

1. The stream should be diverted according to a Watershed Protection Division 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 S&S 30.9: 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 S&S 30.9: Step Pools. 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 Watershed Protection Division.

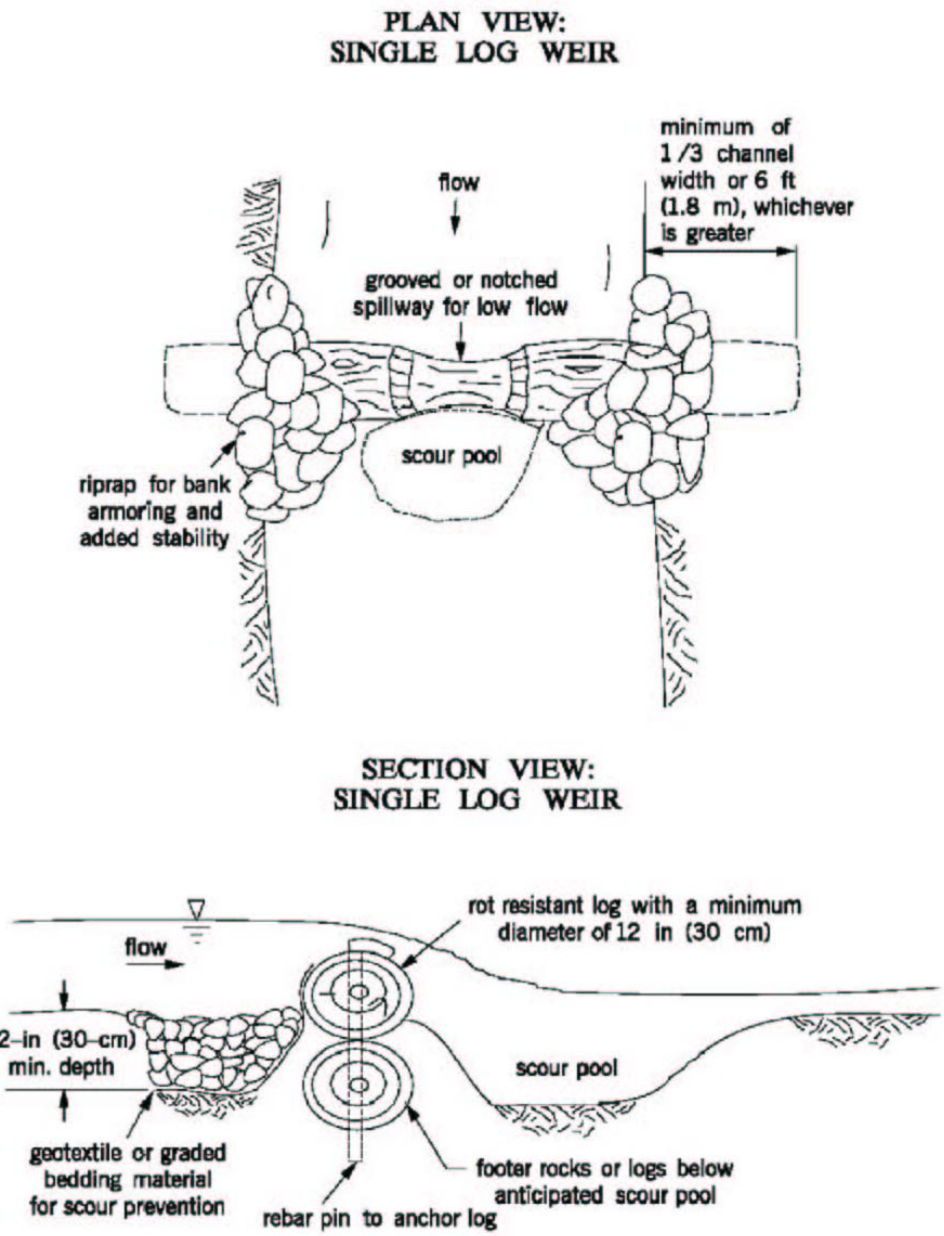
6. All check dams should be monitored to determine if

- 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.

DETAIL 63 - LOG AND ROCK CHECK DAMS



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.6-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

30.7 STANDARDS AND SPECIFICATIONS

FOR

WEIRS

Definition

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 S&S 29.1:Riprap.

Design Criteria

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 Watershed

Protection Division. The recommended construction weirs should proceed as follows (refer to Detail 59):

1. The stream should be diverted according to a Watershed Protection Division 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 S&S 30.9: 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 Watershed Protection Division.

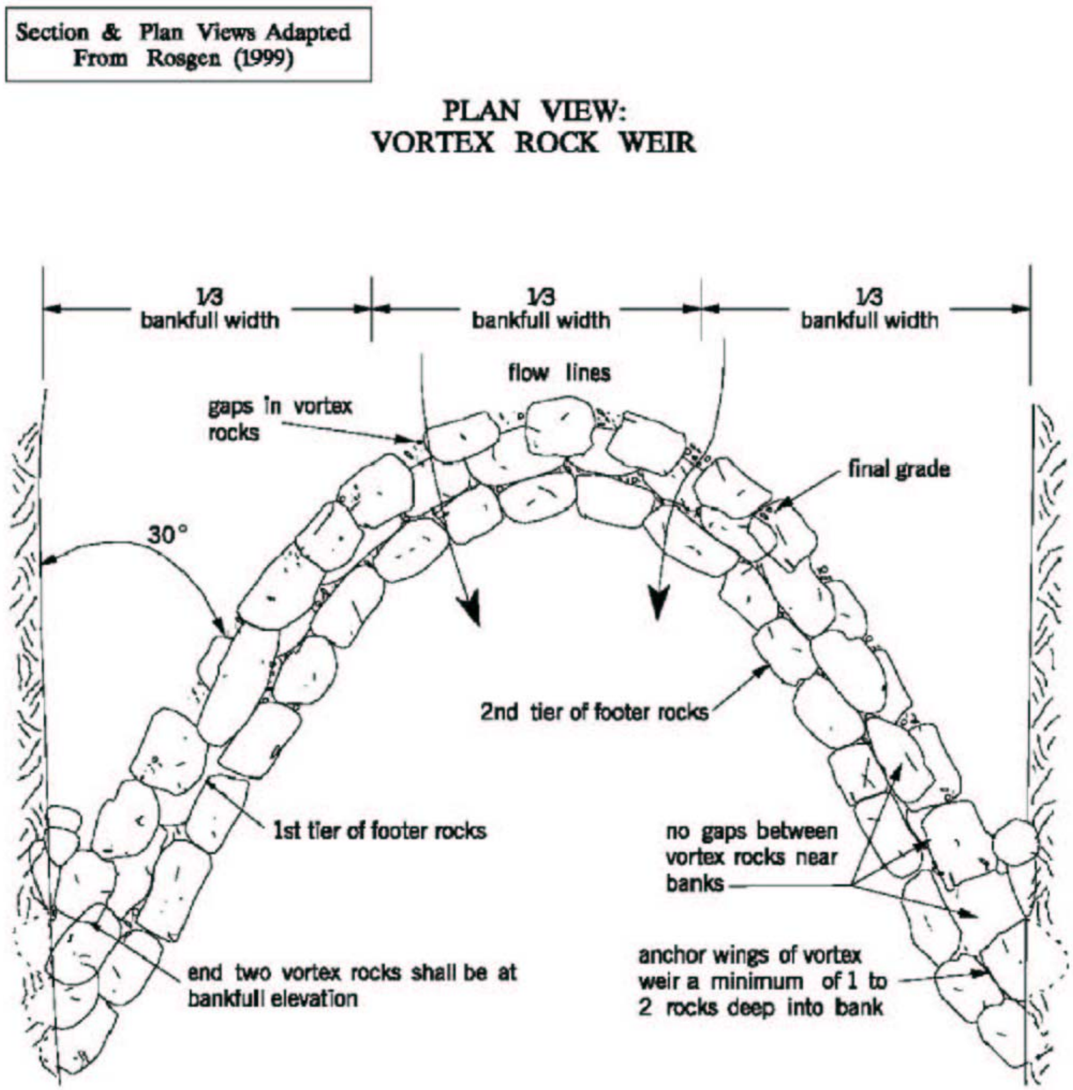
6. All weirs should be monitored to determine if:

    - 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 64A - WEIRS

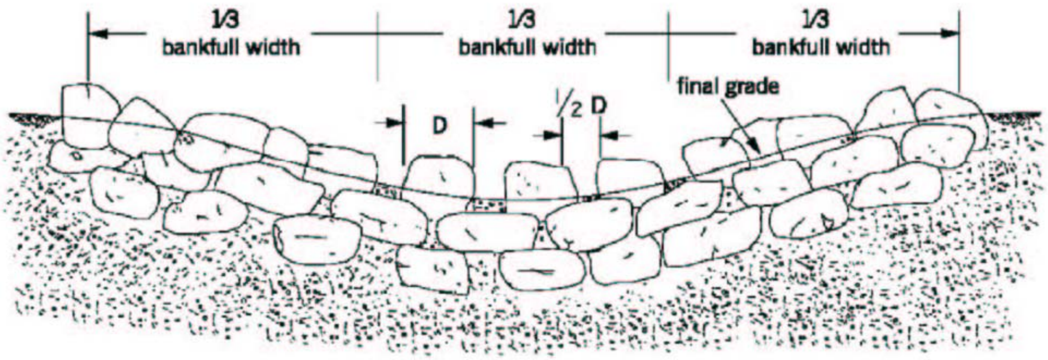


U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.7-3	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

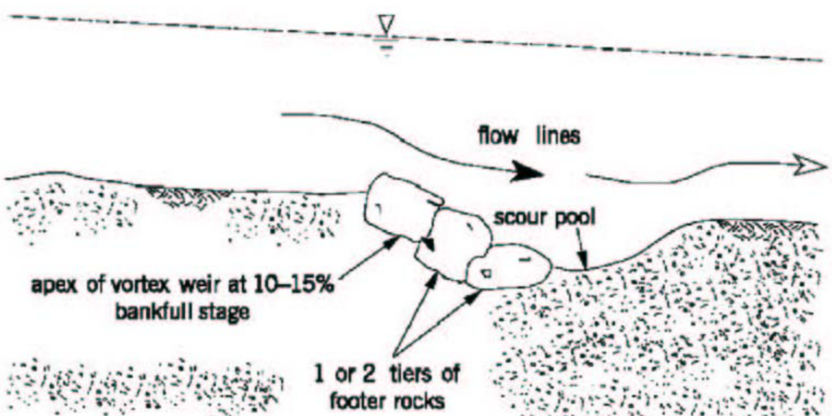
DETAIL 64B – WEIRS

Section & Plan Views Adapted From Rosgen (1999)

SECTION VIEW: VORTEX ROCK WEIR

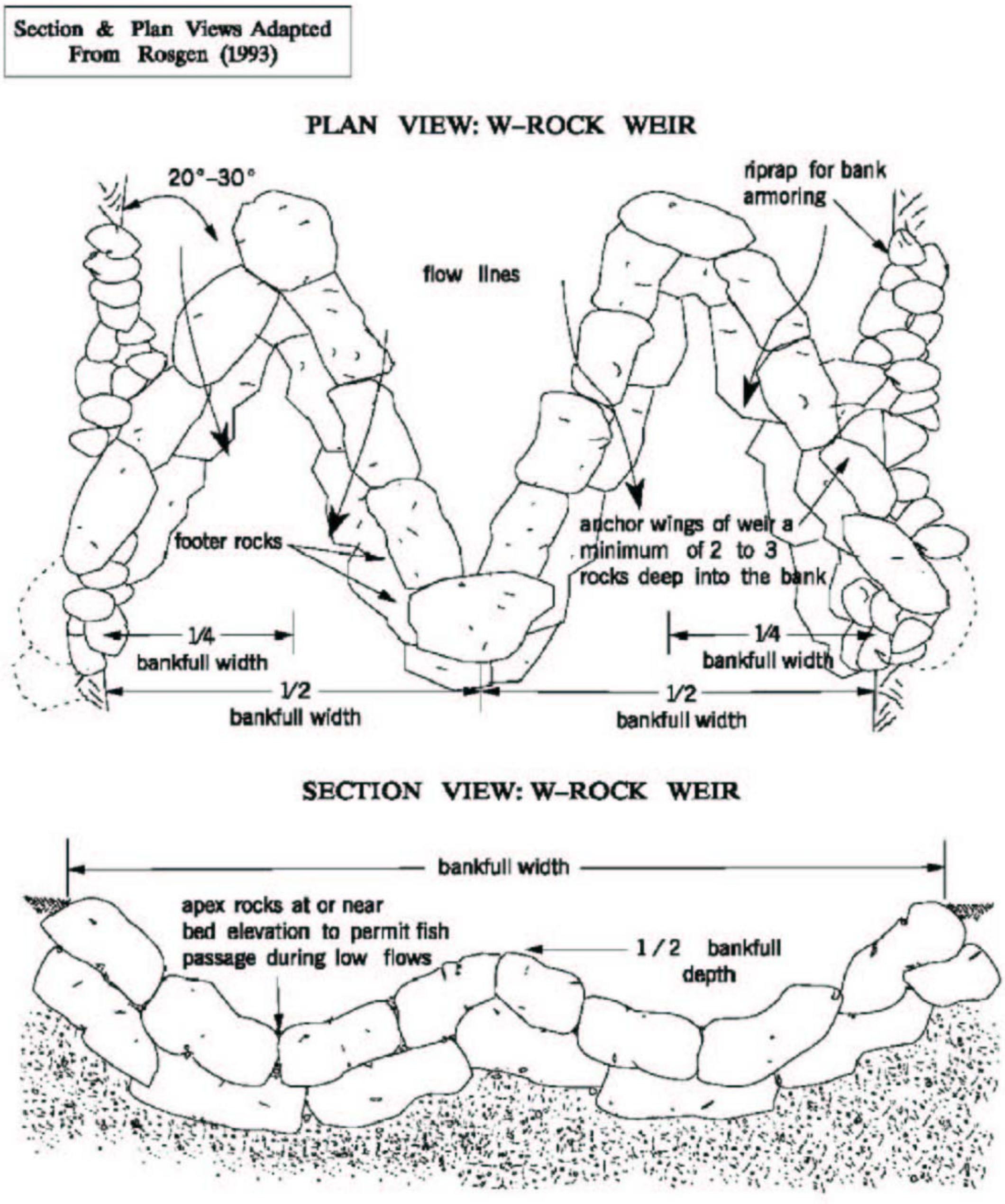


PROFILE VIEW: VORTEX ROCK WEIR



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.7-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

DETAIL 64C - W-WEIRS



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.7-5	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

30.8 STANDARDS AND SPECIFICATIONS

FOR

CROSS VANES

Definition

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 S&S 29.1: Riprap.

Design Criteria

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 Watershed Protection Division. The recommended construction procedure for both cross vanes and weirs should proceed as follows (refer to Detail 60):

1. The stream should be diverted according to a Watershed Protection Division 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 S&S 30.9: 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 Watershed Protection Division.

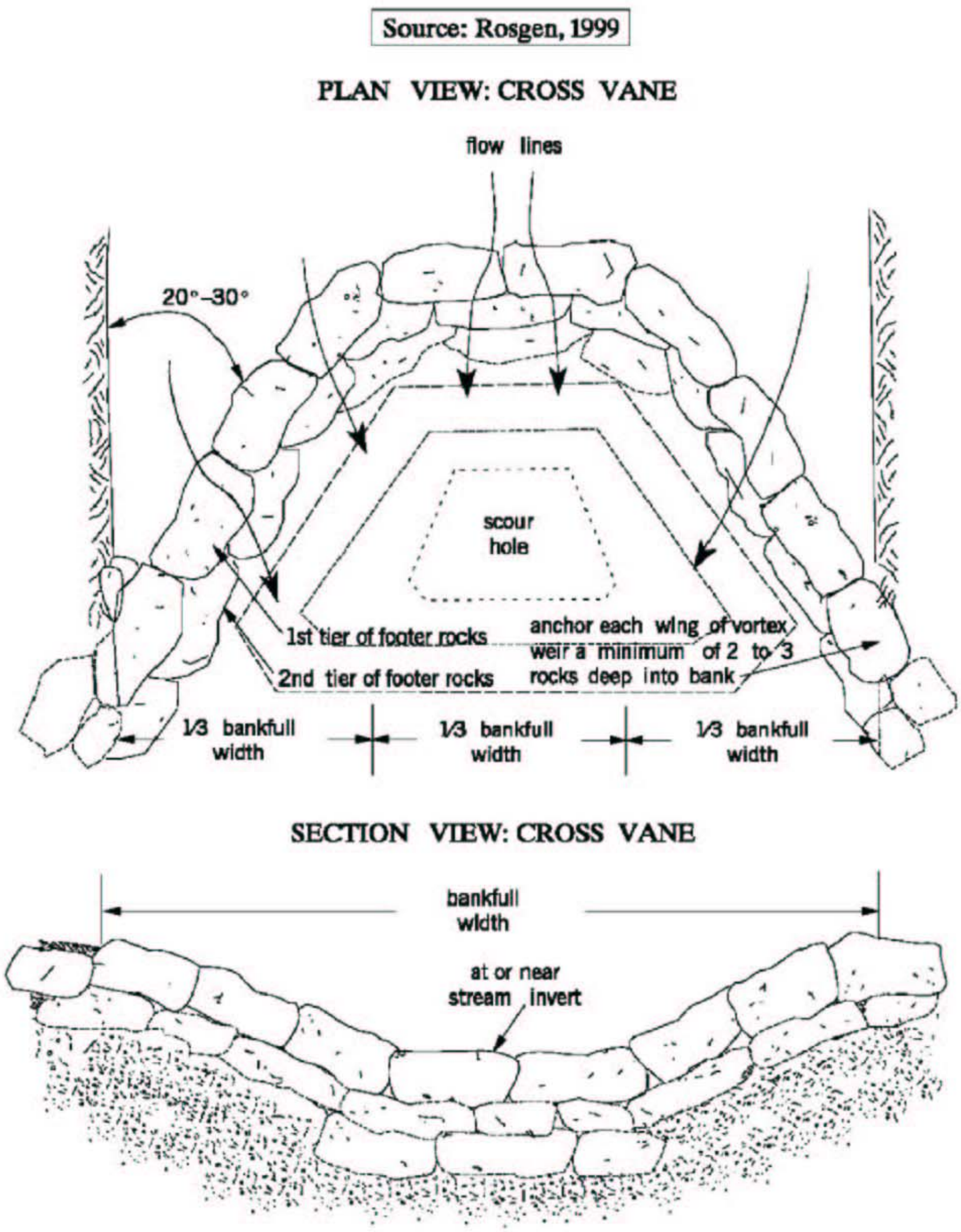
5. All cross vanes should be monitored to determine if:

    - 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.

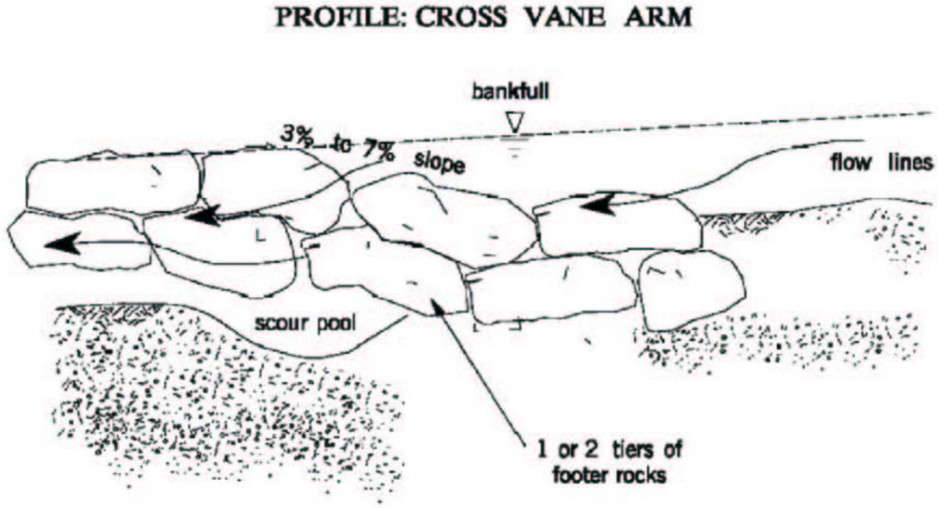
DETAIL 65A – CROSS VANES

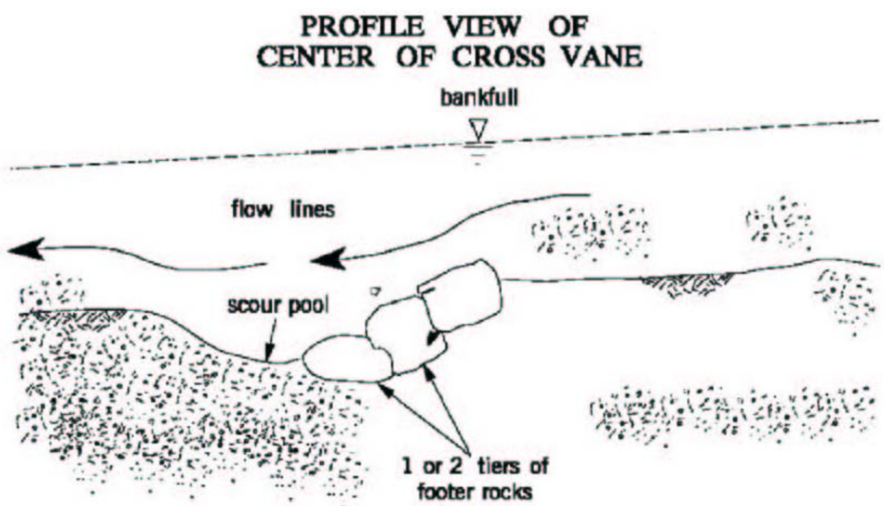


U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.8-3	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

DETAIL 65B - CROSS VANES

Source: Rosgen, 1999





U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.8-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

30.9 STANDARDS AND SPECIFICATIONS

FOR

STEP POOLS

Definition

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 S&S 29.1: Riprap as a guide.

Design Criteria

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 Watershed Protection Division. The proposed construction sequence for step pools is as follows (refer to Detail 61):

1. The stream should be redirected by an approved temporary stream diversion (See *Section 28: Temporary Instream Construction Measures*), 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 62, 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 62(b) relating to alluvial channel morphologies.

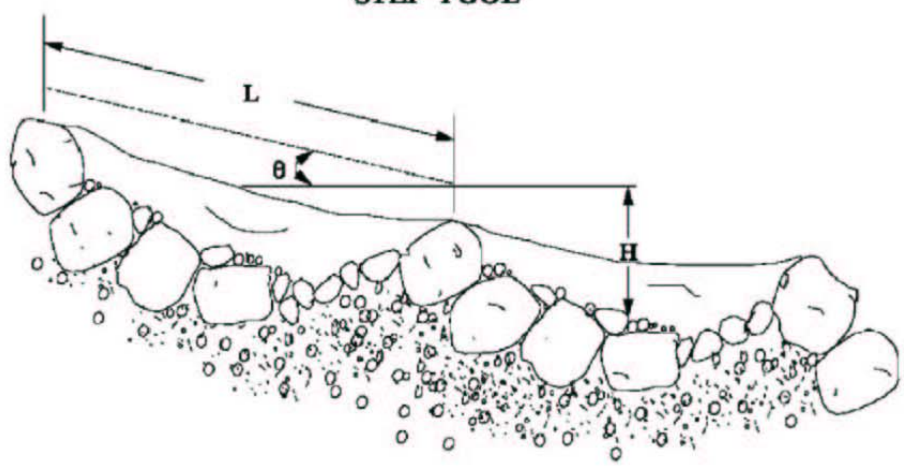
5. Whenever practical, a reference reach with similar flow rates, bed and bank material characteristics, type and density of riparian vegetation, and channel gradient should be surveyed at low flows to determine appropriate values of H and L. At high discharges, step-pool characteristics may be obscured.

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 66A - STEP POOLS

Adapted From Abrahams et al. (1995)

DEFINITION SKETCH: STEP POOL



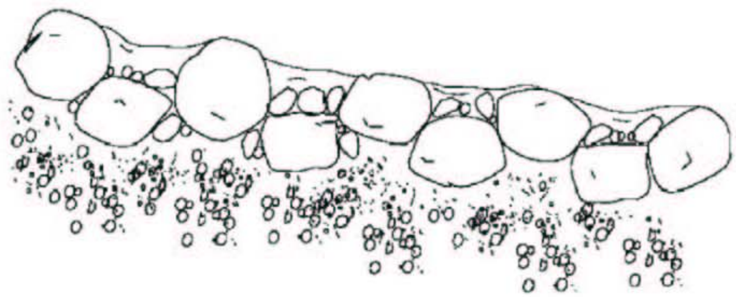
Note: L is measured parallel to the bed slope (tan θ)
H is measured perpendicular to the horizontal

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.9-3	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

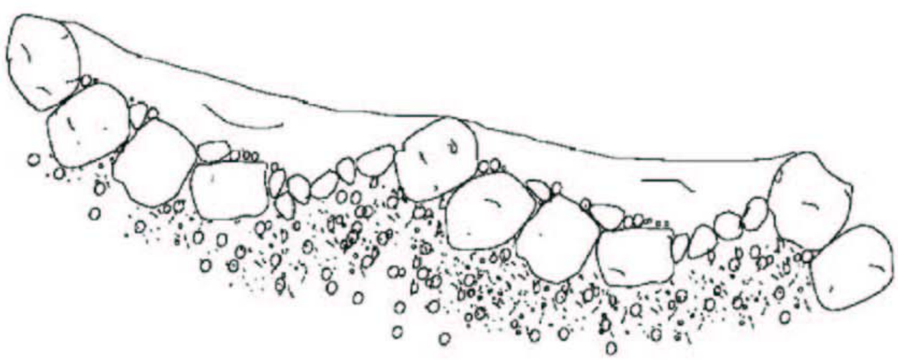
DETAIL 66B – STEP POOLS

Adapted From Montgomery and Buffington (1997)

PROFILE VIEW: CASCADE & STEP POOL MORPHOLOGIES



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



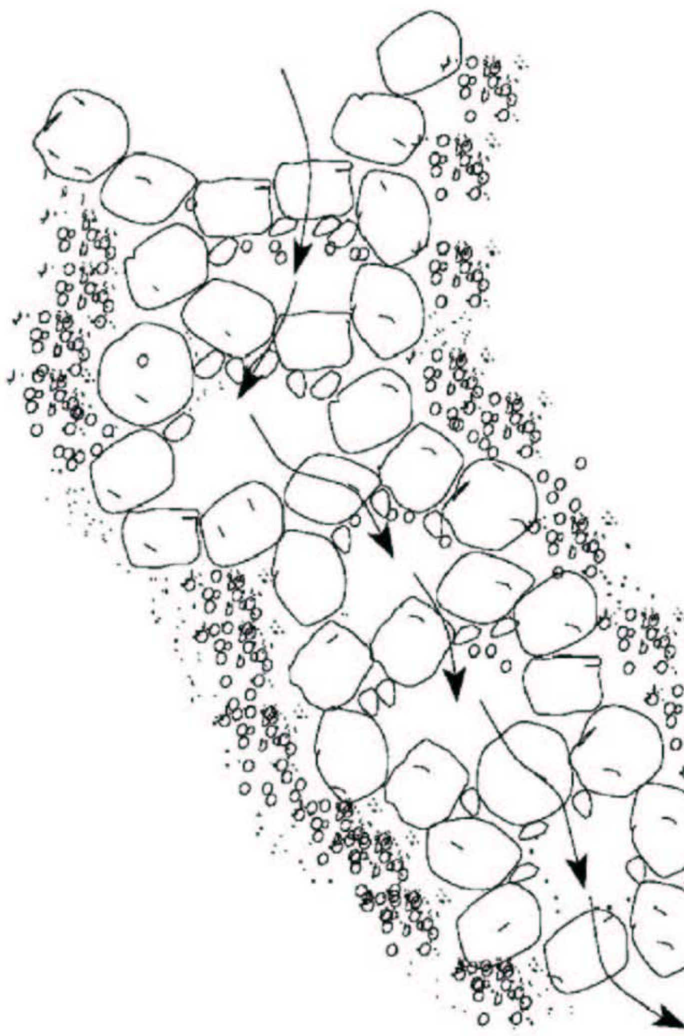
Approximate channel slope: 0.030–0.065	**Typical pool spacing:** 1–4 channel widths	**Average step height** (Abrahams et al., 1995) $1 \leq \{(H/L)_{AVE}/S\} \leq 2$

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33.9–4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

DETAIL 66C -- STEP POOLS

Section & Plan Views Adapted
From Rosgen (1996)

PLAN VIEW: STEP POOL



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H33/9-5	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

31.1 STANDARDS AND SPECIFICATIONS

FOR

UTILITY CROSSING

Definition

Temporary in-stream construction

Description

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

Design Criteria

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 Watershed Protection Division. The proposed construction sequence is as follows (refer to Detail 62):

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 S&S 28.3: Diversion Pipe or other measure should be installed and sandbag or stone barriers as shown in S&S 28.4: Sandbag/Stone Diversion should be constructed according to specifications to divert the streamflow.

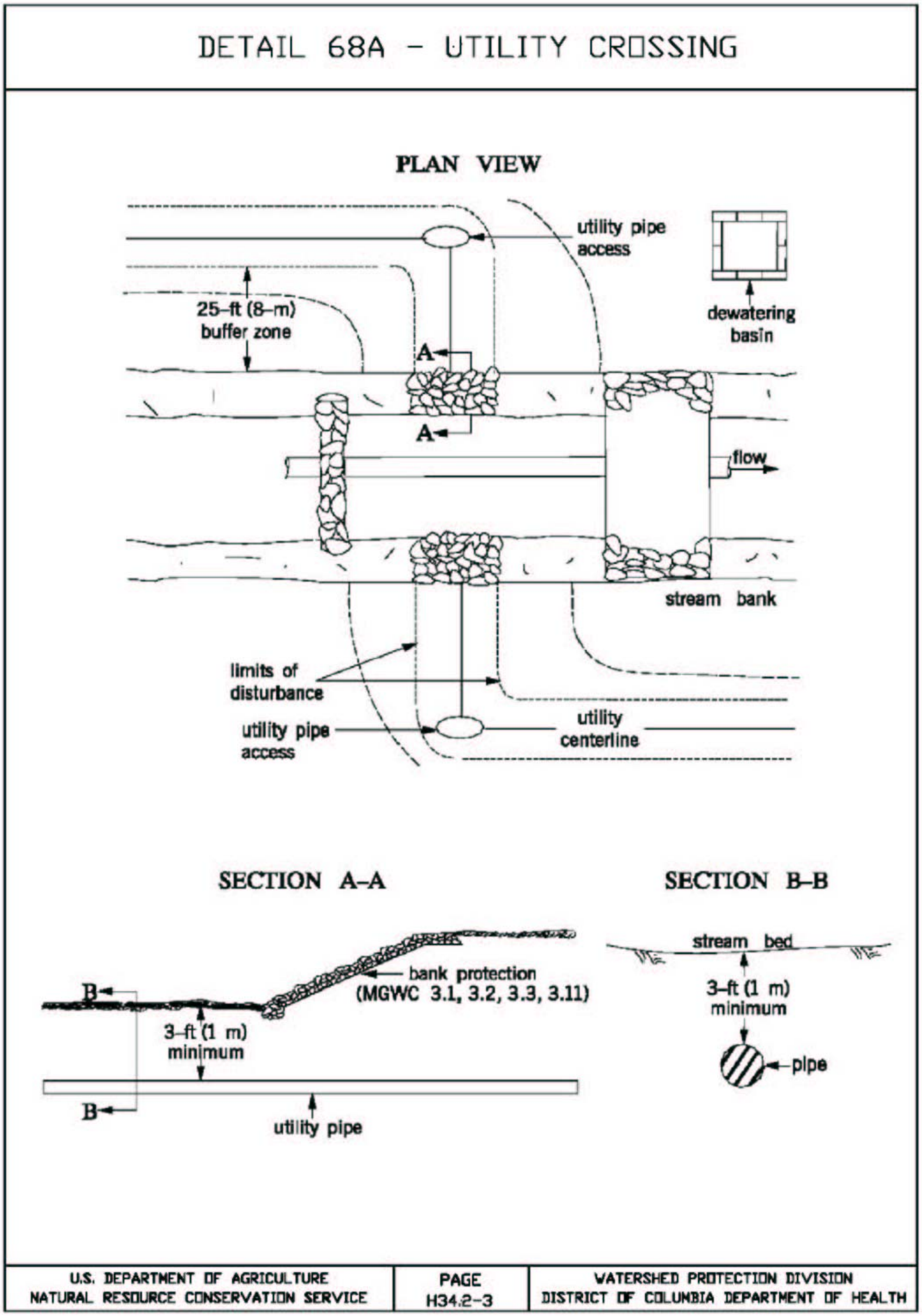
2. Excavated topsoil and subsoil should be kept separate, placed on the upland side of the excavation, and replaced in their natural order.

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 theWatershed Protection Division. For instances where a 3-foot cover is not viable, two alternate stabilization options are given in the Detail 62. A low flow channel shall be constructed through all riprap placements across the stream bed.

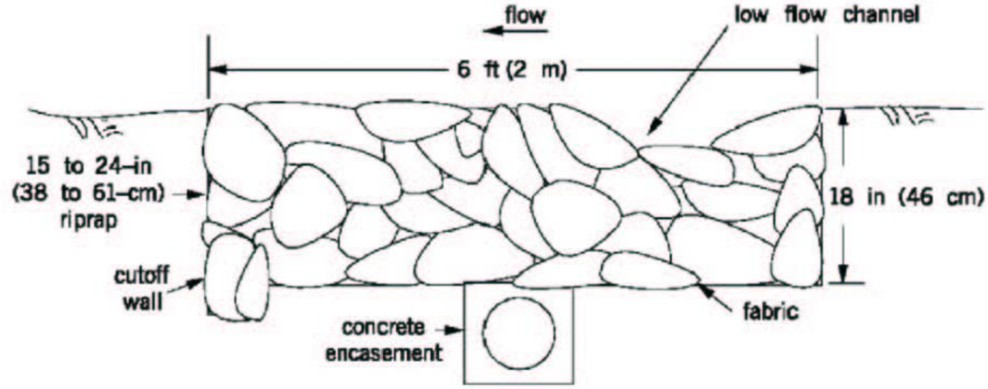
5. The stream should be diverted by an approved temporary stream diversion, the construction area should be dewatered, and any disturbed banks should be stabilized. The contractor may elect to construct the utility crossing in two stages. In this case, a Watershed Protection Division approved flow barrier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

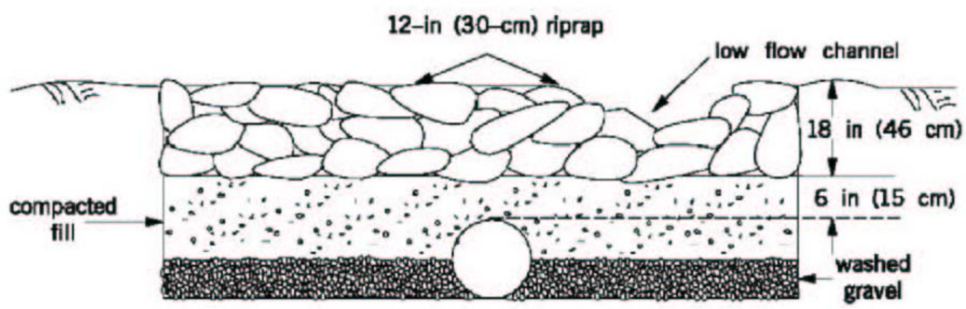

DETAIL 68A - UTILITY CROSSING
PLAN VIEW
utility pipe access
dewatering basin
25-ft (8-m) buffer zone
A
A
flow
stream bank
limits of disturbance
utility pipe access
utility centerline
SECTION A-A
SECTION B-B
bank protection (MGWC 3.1, 3.2, 3.3, 3.11)
B
B
3-ft (1 m) minimum
utility pipe
stream bed
3-ft (1 m) minimum
pipe
U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCE CONSERVATION SERVICE
PAGE
H34.2-3
WATERSHED PROTECTION DIVISION
DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

DETAIL 68B - UTILITY CROSSING

SECTION VIEW: ALTERNATE OPTION 1



SECTION VIEW: ALTERNATE OPTION 2



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H34.2-4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

31.2 STANDARDS AND SPECIFICATIONS

FOR

MULTI-CELL CULVERTS

Definition

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.

Design Criteria

Construction of multi-celled or single barrel culverts should proceed the same as for standard culverts as detailed in S&S 35.0: Individual Practices. The following are general guidelines for design and installation of single or multicell 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 S&S 35.0 Individual Practices. 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 Watershed Protection Division.

31.3 STANDARDS AND SPECIFICATIONS

FOR

CULVERT BAFFLES

Definition

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.

Design Criteria

The following are some general specifications for culvert baffles (refer to Detail 63):

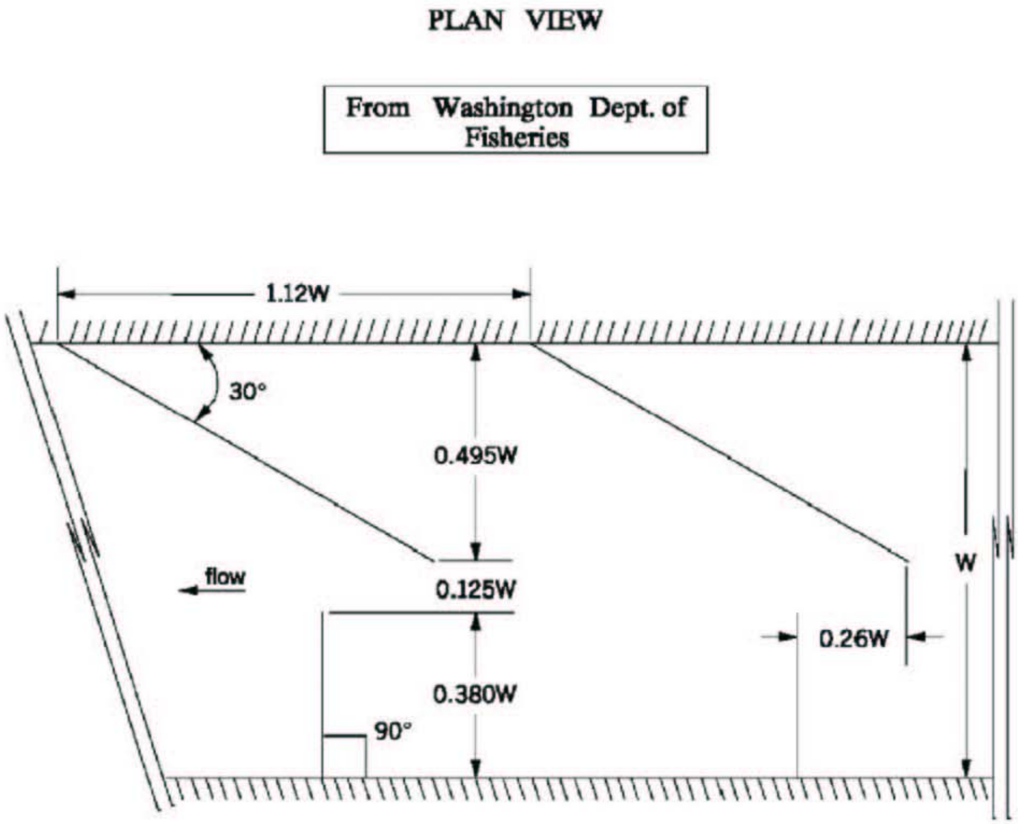
1. Baffles should be installed upon recommendation of a biologist if all possible alternatives to improved fish passage have been thoroughly explored.

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 71 - CULVERT BAFFLES



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

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H34:6-2	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

31.4 STANDARDS AND SPECIFICATIONS

FOR

SMALL BRIDGE INSTALLATION

Definition

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.).

Design Criteria

All erosion and sediment control devices, should be implemented as the first order of business according to a plan approved by the Watershed Protection Division . 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 Watershed Protection Division.

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.

32.0 STANDARDS AND SPECIFICATIONS

FOR

LINED WATERWAY OR OUTLET

Definition

A waterway or outlet with a lining of concrete, stone, or other permanent material. The lined section extends up the side slopes to the designed depth. The earth above the permanent lining may be vegetated or otherwise protected.

Purpose

To provide for the disposal of concentrated runoff without damage from erosion or flooding where grassed waterways would be inadequate due to high velocities.

Scope

This standard applies to waterways or outlets with linings of cast-in-place concrete, flagstone mortared in place, rock rip-rap, gabions, or similar permanent linings. It does not apply to irrigation ditch and canal linings, grassed waterways with stone centers, or small lined sections to carry prolonged low flows, or to reinforced concrete channels. The maximum capacity of the waterway flowing at design depth shall not exceed 100 cubic feet per second.

Conditions Where Practice applies

This practice applies where the following or similar conditions exist:

1. Concentrated runoff is such that a lining is required to control erosion.

2. Steep grades, wetness, prolonged base flow, seepage, or piping would cause erosion.

3. The location is such that damage from use by people or animals precludes use of vegetated waterways or outlets.

4. Soils are highly erosive or other soil and climate conditions preclude using vegetation.

5. High-value property or adjacent facilities warrant the extra cost to contain design runoff in a limited space.

Design criteria

1. Capacity

   a. The minimum capacity shall be adequate to carry the peak rate of runoff from a 10-year, 24-hour storm. Velocity shall be computed using Manning's equation with a coefficient of roughness "n" as follows:

Lined Material	"n"
Concrete (Type):	
Trowel Finish	0.015
Float Finish	0.019
Gunite	0.019
Flagstone	0.022
Rip-rap	Determine from Table 34
Gabion	0.030
Permanent Soil Stab. Mattings	0.030

Table 34: Manning's "n" values for riprap

Dia. (in)	"n"
3	0.0314
6	0.0352
9	0.0377
12	0.0395
18	0.0423

   b. Rip-rap and filter (bedding) shall be designed in accordance with criteria set forth in the National Cooperative Highway Research Program Report 108, available from the University Microfilm International, 300 N. Ree Road, Ann Arbor, Michigan 48016, Publication No. PB-00839; or Publication No. FHWA-IP-89-016, dated March 1989, available from Federal Highway Admin., 4009 7th Street, S. W ., Washington, Service's Engineering Field Manual, Chapter 16.

2. Velocity

   a. Maximum design velocity shall be as shown below. Except for short transition sections, flow with a channel gradient within the range of 0.7 to 1.3 of this flow's critical slope must be avoided unless the channel is straight. Velocities exceeding critical will be restricted to straight reaches.

Design Flow Depth (ft.)	Maximum Velocity (ft./sec.)
0.0- 0.5	25
0.5 - 1.0	15
Greater than 1.0	10

b. Waterways or outlets with velocities exceeding critical shall discharge into an energy dissipator to reduce velocity to less than critical, or to a velocity the downstream soil and vegetative conditions will allow.

3. Cross Section

The cross section shall be triangular, parabolic, or trapezoidal. Monolithic concrete or gabions may be rectangular.

4. Freeboard

The minimum freeboard for lined waterways or outlets shall be 0.25 feet above design high water in areas where erosion resistant vegetation cannot be grown adjacent to the paved side slopes. No freeboard is required where good vegetation can be grown and is maintained.

5. Side Slope

Steepest permissible side slopes, horizontal to vertical, will be as follows:

a. Non-Reinforced Concrete

i. Hand-placed, formed concrete
Height of lining, 1.5 ft. or less .... Vertical

ii. Hand-placed screened concrete or mortared in place flagstone
Height of lining, less than 2 ft.........l to 1
Height of lining, more than 2 ft.......2 to 1

b. Slip form concrete:
i. Height of lining, less than 3 ft................l to 1

c. Rock rip-rap......……….................……...........2 to 1
i. Gabions................Per specifications for gabions

6. Lining Thickness

a. Concrete..............4 in. (In most problem areas, minimum thickness shall be 5 in. with welded wire fabric reinforcing.)

b. Rock rip-rap........1.5 x maximum stone size plus thickness of filter or bedding

c. Flagstone..….......4 in. including mortar bed

7. Related Structures

Side inlets, drop structures, and energy dissipators shall meet the hydraulic and structural requirements of the site.

8. Filters or Bedding

Filters or bedding to prevent piping, reduce uplift pressure, and collect water will be used as required and will be designed in accordance with sound engineering principles. Weep holes and drains will be provided as needed.

9. Concrete

a. Concrete used for lining shall be so proportioned that it is plastic enough for thorough consolidation and stiff enough to stay in place on side slopes. A dense durable product will be required. A mix that can be certified as suitable to produce a minimum strength of at least 3,000 pounds per square inch will be required. Cement used shall be Portland Cement, Type I, II, IV, or V. Aggregate used shall have a maximum diameter of one and one half inches.

b. Weep holes should be provided in concrete footings and retaining walls to allow free drainage of water. Pipe used for weep holes shall be non-corrosive.

10. Mortar

Mortar used for mortared in-place flagstone shall consist of a mix of cement, sand, and water with a water-cement ratio of not more than 6 gallons of water per bag of cement.

11. Contraction Joints

Contraction joints in concrete linings, where required, shall be formed transversely to a depth of about one-third the thickness of the lining at a uniform spacing in the range of 10 to 15 feet.

12. Rock Rip-rap or Flagstone

Stone used for rip-rap or gabions shall be dense and hard enough to withstand exposure to air, water, freezing, and thawing. Flagstone shall be flat for ease of placement and have the strength to resist exposure and breaking.

13. Cutoff

Cutoff walls shall be used at the beginning and ending of concrete lining, and for rock rip-rap lining, shall be keyed into the channel bottom at both ends of the lining.

14. Gabion Baskets

Gabions shall be fabricated in such a manner that the sides, ends, and lid can be assembled at the site into a rectangular basket of similar size. Gabion baskets shall be installed according to the manufacturers specifications.

15. Geotextile fabric

Geotextile Class SE[29] shall be placed beneath all rip-rap and gabions. The geotextile fabric shall consist of either woven or non-woven monofilament fiber and shall conform to ASTM D 1777, ASTM D 1682, having a thickness of 20-60 mils, and a grab strength of 90-120 lbs.

Construction Specifications

1. The foundation area shall be cleared of trees, stumps, roots, sod, loose rock, or other objectionable material.

2. The cross-section shall be excavated to the neat lines and grades as shown on the plans. Overexcavated areas shall be backfilled with moist soil compacted to the density of the surrounding material.

3. No abrupt deviations from design grade or horizontal alignment shall be permitted.

4. Concrete linings shall be placed to the thickness shown on the plans and finished in a workmanlike manner. Adequate precautions shall be taken to protect freshly placed concrete from freezing or extremely high temperatures, to insure proper curing.

[29] Refer to Table 44 (located on page L-53-1)

5. Filter, bedding, and rock rip-rap shall be placed to line and grade and in the manner specified.

6. Construction operations shall be done in such a manner that erosion, air, and water pollution will be minimized and held within legal limits. The completed job shall present a workmanlike appearance. All disturbed areas shall be vegetated or otherwise protected against soil erosion.

Maintenance

1. Pavement or lining should be maintained as built to prevent undermining and deterioration. Trees should be removed next to pavements, as roots can cause uplift damage.

2. Vegetation next to pavement should be maintained in good condition to prevent scouring if the pavement is overtopped. See Standard and Specifications for Critical Area Stabilization for vegetative details.

33.0 STANDARDS AND SPECIFICATIONS

FOR

GRASSED WATERWAY

Definition

A permanent, designed waterway, shaped, sized, and lined with appropriate vegetation or structural material used to safely convey stormwater runoff within or away from a developing area.

Purpose

To provide for the conveyance of concentrated surface runoff water to a receiving channel or system without damage from erosion.

Conditions Where Practice Applies

Generally applicable to man-made channels, including roadside ditches and intermittent natural channels, that are constructed or are modified to accommodate flows generated by land development. The implementation of this control should come only after a channel adequacy analysis for capacity and velocity has been performed. The measure should be installed and stabilized prior to the introduction of post-development flows. This practice is not generally applicable to continuous flowing natural streams. Major streams need full design considerations and calculations. Provisions for protecting the banks of such streams are described in 30.0 Channel Stabilization and Rehabilitation Techniques.

Planning Considerations

The design of a channel cross-section and lining is based primarily upon the volume and velocity of flow expected in the channel. If conditions are appropriate, grass or riprap channels are preferred over concrete. While concrete channels are efficient and easy to maintain, they remove runoff so quickly that channel erosion and flooding often result downstream. Grass or riprap channels reduce this problem by more closely duplicating a natural system.

Besides the primary design considerations of capacity and velocity, a number of other important factors should be taken into account when selecting a cross-section and lining. These factors include land availability, compatibility with land use and surrounding environment, safety, maintenance requirements, outlet conditions, and soil erodibility factor. If the riprap design is chosen, filter fabric must be used to act as a separator and stabilizer between the stone and the earth.

Cross-section design:

Vee-shaped ditches are generally used where the quantity of water to be handled is relatively small, such as roadside ditches. A grass or sod lining will suffice where velocities in the ditch are low. For steeper slopes where high velocities are encountered, a riprap, concrete or bituminous concrete lining may be appropriate.

Parabolic channels are often used where the quantity of water to be handled is larger and where space is available for a wide, shallow channel with low velocity flow. Riprap should be used where higher velocities are expected and where some dissipation of energy (velocity) is desired. Combinations of grass and riprap are also useful where there is a continuous low flow in the channel.

Trapezoidal channels are often used where the quantity of water to be carried is large and conditions require that it be carried at a relatively high velocity. Trapezoidal ditches are generally lined with concrete or riprap.

Details 64A and 64B illustrate the various types of cross-sections and channel linings.

Outlet design:

Outlet conditions for all channels must be considered. This is particularly important for the transition from a man-made lining, such as concrete and riprap, to a vegetated or nonvegetated lining. Appropriate measures must be taken to dissipate the energy of the flow to prevent scour of the receiving channel. (See 22.0 Rock Outlet Protection).

Capacity

If channel modifications are necessary, the capacity of the channel must be sufficient to convey the 15-year frequency design storm (24-hour duration) without overtopping the banks. If pre-development flooding problems exist, the consequences of flooding are severe, or drainage systems which convey larger storms converge with the channel in question, consideration should be given to increasing the capacity beyond the 15-year frequency storm capacity.

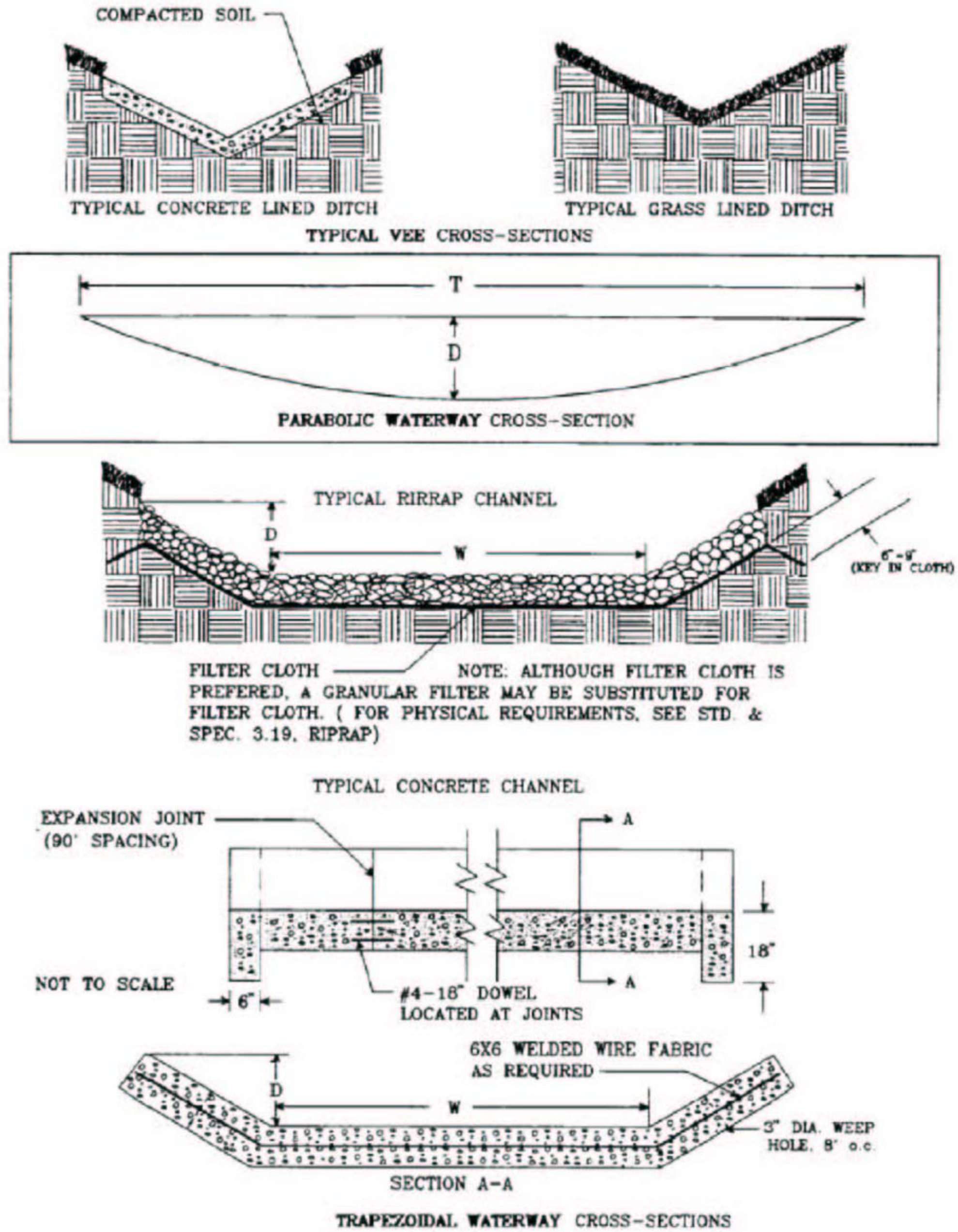
Velocity

Channels should be designed so that the velocity of flow expected from a 2-year frequency storm shall not exceed the permissible velocity for the type of lining used.

While concrete-lined channels can usually be smaller than grass-lined channels, the increased velocity will produce more erosion and flooding downstream.

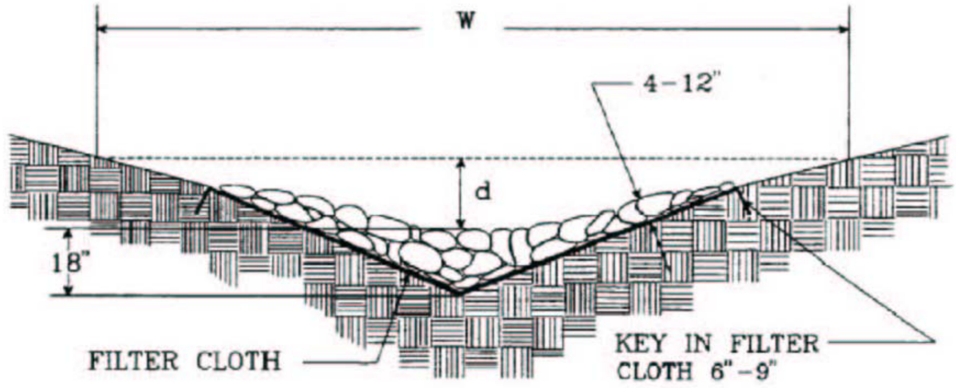
Grass-lined channels provide good protection against erosion, while they provide an aesthetic setting for conveyance of runoff. However, the velocities that grass linings can handle are much lower than those which can be withstood by riprap or concrete-lined channels. For grass linings, the type of vegetation chosen shall be appropriate for the site conditions: i.e., drainage tolerance, shade tolerance, maintenance requirements, etc. (See 42.0 Vegetative Stabilization). Where there will be a base flow in grass-lined channels, a stone center, a subsurface drain, or other suitable means to handle the base flow shall be provided. Detail 64B shows typical cross-sections for stone center channels. Refer to 22.0 Rock Outlet Protection to choose the correct stone size and for filter fabric specifications. Permissible velocities for grass-lined channels are shown in Table 35.

DETAIL 73A -TYPICAL WATERWAY CROSS-SECTIONS



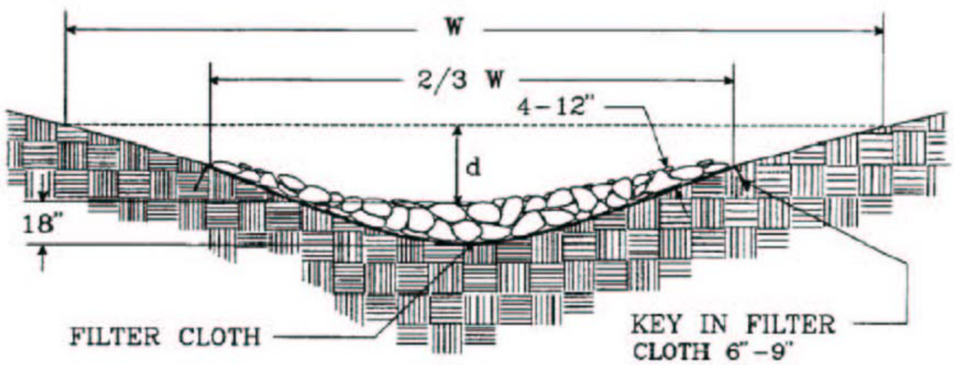
U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H - 36 - 4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

DETAIL 73B - STONE-LINED WATERWAY



V-SHAPED WATERWAY WITH STONE CENTER DRAIN

NOTE: A GRANULAR FILTER MAY BE SUBSTITUTED FOR FILTER CLOTH



PARABOLIC WATERWAY WITH STONE CENTER DRAIN

NOTE: A GRANULAR FILTER MAY BE SUBSTITUTED FOR FILTER CLOTH.

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H - 36 - 5	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

TABLE 35

PERMISSIBLE VELOCITIES FOR GRASS-LINED CHANNELS

CHANNEL SLOPE	LINING	PERMISSIBLE VELOCITY[a]
0 - 5%	Bermudagrass	6 ft./second
	Reed canarygrass Tall fescue Kentucky bluegrass	5 ft./second
	Grass-legume mixture	4 ft./second
	Red fescue Redtop Sericea lespedeza Annual lespedeza Small grains (temporary)	2.5 ft./second
5 - 10%	Bermudagrass	5 ft./second
	Reed canarygrass Tall fescue Kentucky bluegrass	4 ft./second
	Grass-legume mixture	3 ft./second
Greater than 10%	Bermudagrass	4 ft./second
	Reed canarygrass Tall fescue Kentucky bluegrass	3 ft./second

[a] For highly erodible soils, permissible velocities should be decreased by 25%. An erodibility factor (K) greater than 0.35 would indicate a highly erodible soil. Erodibility factors (K-factors) for many Virginia soils are listed in Chapter 6.

Riprap-lined channels can be designed to withstand most flow velocities by choosing a stable stone size. The procedures for selecting a stable stone size for channels and installation is contained in 22.0 Rock Outlet Protection. All riprap must be installed with a filter fabric or gravel (granular) underlining. Transition from a riprap lining to grass and earth linings must be carefully designed to meet the allowable velocities of each type of lining.

Concrete-lined channels are not usually limited in the velocity they can carry; however, it should be kept in mind that the flow velocity at the outlet of the paved section must not exceed the permissible velocity of the receiving channel. See 22.0 Rock Outlet Protection. Concrete channels shall be at least 4 inches thick and meet all applicable criteria found in the District of Columbia's DPW Standard Specifications for Highways and Structures.

Depth

The design water surface elevation of a channel receiving water from diversions or other tributary channels shall be equal to or less than the design water surface elevation of the diversion or other tributary channel at the point of intersection.

The top width of parabolic and vee-shaped, grass-lined channels shall not exceed 30 feet, and the bottom width of trapezoidal, grass-lined channels shall not exceed 15 feet unless multiple or divided waterways, riprap center, or other means are provided to control meandering of low flows.

Outlet

The outlets of all channels shall be protected from erosion (see 22.0 Rock Outlet Protection).

Calculations

1. Channel dimensions for roadside ditches and median channels shall be determined in accordance with applicable design procedures

2. Channel dimensions for parabolic, grass-lined channels may be determined from table 36.

3. There are various computer programs available to assist a designer in designing channels.

Construction Specifications

General

1. All trees, brush, stumps, roots, obstructions and other unsuitable material shall be removed and disposed of properly.

2. The channel shall be excavated or shaped to the proper grade and cross-section.

3. Any fills shall be well compacted to prevent unequal settlement.

4. Any excess soil shall be removed and disposed of properly.

Grass-lined Channels

The method used to establish grass in the ditch or channel will depend upon the severity of the conditions encountered. The methods available for grass establishment are set forth in 42.0 Vegetative Stabilization.

Riprap-lined Channels

Riprap shall be installed in accordance with 22.0 Rock Outlet Protection.

Concrete-lined Channels

Concrete-lined channels must be constructed in accordance with the following specifications:

1. The subgrade should be moist at the time the concrete is poured.

2. Traverse joints for crack control should be provided at approximately 20-foot intervals and when more than 45 minutes elapses between the times of consecutive concrete placements. All sections should be at least 6 feet long. Crack control joints may be formed by using a 1/8-inch thick removable template, by scoring or sawing to a depth of at least 3/4 inch or by an approved "leave in"-type insert.

3. Expansion joints shall be installed every 100 feet.

Maintenance

Grass-lined Channels

During the initial establishment, grass-lined channels should be repaired immediately and grass re-established if necessary. After grass has become established, the channel should be checked periodically to determine if the grass is withstanding flow velocities without damage. If the channel is to be mowed, it should be done in a manner that will not damage the grass.

Riprap-lined Channels

Riprap-lined channels should be checked periodically to ensure that scour is not occurring beneath fabric underlining of the riprap layer. The channel should also be checked to determine that the stones are not dislodged by large flows.

Concrete-lined Channels

Concrete-lined channels should be checked periodically to ensure that there is no undermining of the channel. Particular attention should be paid to the outlet of the channel. If scour is occurring at the outlet, appropriate outlet protection shall be installed. See 22.0 Rock Outlet Protection.

Sediment Deposition

If the channel is below a high sediment-producing area, sediment should be trapped before it enters the channel. Field experience has demonstrated that many newly constructed conveyance channels become damaged and require costly repairs as a result of improper up slope controls. If sediment is deposited in a grass-lined channel, it should be removed promptly to prevent damage to the grass. Sediment deposited in riprap and concrete-lined channels should be removed when it reduces the capacity of the channel.

DESIGN OF PARABOLIC GRASS-LINED CHANNELS

The channel must be designed for capacity and erosion resistance. Capacity will be a minimum when the grass is long and unmowed. This condition corresponds to V_2 in Table 36. Erosion will be most likely to occur when the grass is short. This condition will correspond to V_1 in Table 36. A design based upon Table 36 will result in a channel which will have adequate capacity when the vegetation in the channel is long and thick, which will remain stable when the vegetation is short or recently mowed, and which will have adequate freeboard for the design flow.

Use the following procedure to design a grass-lined parabolic channel based upon Tables 35 and 36:

1. Determine the required channel capacity, O. (Peak rate of runoff for the selected design storm).

2. Select an appropriate grass lining and note the maximum permissible velocity (V_1) from Table 35.

3. Choose the appropriate sheet of Table 36 for the channel slope. Using the maximum permissible velocity (V_1) and the required flow capacity (Q), read the top width (T) and the depth (D) for the correct parabolic section.

Example Problem

Design a parabolic waterway to be lined with Kentucky 31-Tall Fescue which will carry 50 cfs on a 3% slope.

Solution:

1. Q = 50 cfs (given)

2. V_1 = 5 ft./sec. for Kentucky 31-Tall Fescue (from Table 35)

3. From page H-33-20 of Table 36 (for 3% slope): Read the top width (T) and depth (D) for Q = 50 cfs and V_1 = 5.0 fps

   T = 16.3 feet

   D = 1.45 feet

Table 36

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 0.25 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15																											
20																											
25	11.3	3.27	1.00																								
30	13.2	3.09	1.09																								
35	15.2	3.01	1.13																								
40	17.3	2.99	1.15	12.1	3.61	1.36																					
45	19.3	2.94	1.18	13.4	3.49	1.42																					
50	21.4	2.93	1.18	14.7	3.41	1.48																					
55	23.5	2.92	1.19	16.1	3.38	1.50																					
60	25.5	2.89	1.21	17.5	3.35	1.52																					
65	27.6	2.89	1.21	18.8	3.30	1.56																					
70	29.7	2.89	1.21	20.2	3.28	1.57	14.4	3.98	1.81																		
75	31.7	2.87	1.23	21.6	3.27	1.58	15.3	3.91	1.86																		
80	33.8	2.87	1.23	23.0	3.26	1.58	16.3	3.90	1.87																		
90	38.0	2.87	1.23	25.8	3.25	1.60	18.1	3.80	1.94																		
100	42.1	2.85	1.24	28.6	3.23	1.61	20.0	3.76	1.98																		
110	46.3	2.85	1.24	31.4	3.22	1.62	21.9	3.73	2.01																		
120	50.4	2.84	1.25	34.1	3.20	1.64	23.9	3.73	2.00	17.0	4.47	2.34															
130	54.6	2.85	1.24	36.9	3.19	1.64	25.8	3.70	2.02	18.3	4.42	2.39															
140	58.7	2.84	1.25	39.7	3.19	1.65	27.7	3.68	2.04	19.6	4.37	2.43															
150	62.9	2.85	1.25	42.5	3.19	1.65	29.6	3.67	2.06	20.9	4.33	2.47															
160	67.0	2.84	1.25	45.3	3.18	1.65	31.6	3.68	2.05	22.2	4.30	2.50															
170	71.1	2.84	1.26	48.1	3.18	1.65	33.5	3.66	2.07	23.5	4.27	2.53	18.5	4.95	2.76												
180	75.3	2.84	1.25	50.9	3.18	1.66	35.4	3.65	2.08	24.8	4.24	2.55	19.5	4.90	2.80												
190	79.4	2.84	1.26	53.7	3.18	1.66	37.4	3.66	2.07	26.1	4.22	2.57	20.5	4.87	2.84												
200	83.5	2.84	1.26	56.5	3.18	1.66	39.3	3.65	2.08	27.5	4.23	2.56	21.5	4.83	2.87												
220	91.8	2.84	1.26	62.1	3.18	1.66	43.2	3.65	2.08	30.1	4.19	2.60	23.5	4.77	2.92												
240	100.0	2.83	1.26	67.6	3.17	1.67	47.0	3.63	2.10	32.7	4.15	2.64	25.5	4.72	2.97												
260	108.3	2.84	1.26	73.2	3.17	1.67	50.9	3.63	2.10	35.4	4.15	2.64	27.5	4.68	3.01	21.4	5.50	3.29									
280	116.6	2.84	1.26	78.8	3.17	1.67	54.8	3.63	2.10	38.1	4.14	2.64	29.5	4.64	3.05	22.9	5.44	3.35									
300	124.8	2.84	1.26	84.4	3.17	1.67	58.6	3.62	2.11	40.8	4.14	2.65	31.5	4.61	3.08	24.5	5.42	3.37									

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 2.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	24.7	1.14	0.79	15.0	1.25	1.18	11.0	1.40	1.43	7.8	1.56	1.81															
20	32.8	1.14	0.79	20.0	1.25	1.18	14.5	1.37	1.49	10.3	1.53	1.88	7.5	1.71	2.29	6.3	1.91	2.44									
25	41.0	1.14	0.79	24.9	1.24	1.20	18.1	1.37	1.50	12.7	1.48	1.96	9.3	1.68	2.36	7.7	1.82	2.62									
30	49.0	1.14	0.80	29.8	1.24	1.20	21.6	1.35	1.52	15.2	1.48	1.98	11.0	1.63	2.47	9.1	1.77	2.76	7.6	1.97	2.95						
35	57.1	1.14	0.80	34.7	1.24	1.21	25.1	1.35	1.54	17.7	1.47	1.99	12.8	1.62	2.50	10.5	1.73	2.86	8.8	1.94	3.03						
40	65.1	1.14	0.80	39.6	1.24	1.21	28.7	1.35	1.53	20.2	1.47	2.00	14.6	1.62	2.51	12.0	1.73	2.86	9.9	1.88	3.18	8.2	2.13	3.38			
45	73.1	1.14	0.80	44.5	1.24	1.21	32.2	1.35	1.54	22.6	1.46	2.03	16.4	1.61	2.52	13.5	1.73	2.86	11.1	1.87	3.21	9.1	2.08	3.52			
50	81.0	1.14	0.81	49.3	1.24	1.22	35.7	1.35	1.55	25.1	1.46	2.03	18.1	1.59	2.57	14.9	1.71	2.92	12.3	1.86	3.24	10.0	2.03	3.64	8.6	2.29	3.76
55	88.9	1.14	0.81	54.2	1.24	1.21	39.2	1.34	1.55	27.6	1.46	2.03	19.9	1.60	2.57	16.4	1.71	2.91	13.5	1.85	3.26	11.0	2.03	3.65	9.3	2.21	3.96
60	96.8	1.14	0.81	59.0	1.24	1.22	42.7	1.34	1.55	30.0	1.45	2.05	21.7	1.60	2.57	17.8	1.69	2.95	14.7	1.85	3.28	11.9	2.00	3.74	10.1	2.19	4.01
65	104.6	1.14	0.81	63.8	1.24	1.22	46.2	1.35	1.55	32.5	1.46	2.04	23.4	1.58	2.60	19.3	1.70	2.94	15.8	1.82	3.36	12.9	2.00	3.73	10.9	2.18	4.06
70	112.4	1.14	0.81	68.6	1.24	1.22	49.7	1.35	1.56	34.9	1.45	2.05	25.2	1.59	2.60	20.7	1.69	2.98	17.0	1.82	3.36	13.8	1.98	3.81	11.7	2.16	4.10
75	120.2	1.14	0.81	73.4	1.24	1.22	53.1	1.34	1.56	37.3	1.45	2.06	27.0	1.59	2.60	22.2	1.69	2.96	18.2	1.82	3.37	14.8	1.98	3.79	12.5	2.15	4.14
80	127.9	1.14	0.82	78.1	1.24	1.23	56.6	1.35	1.56	39.8	1.45	2.06	28.7	1.58	2.62	23.6	1.69	2.99	19.4	1.82	3.37	15.8	1.99	3.78	13.3	2.14	4.17
90	143.6	1.14	0.82	87.8	1.24	1.23	63.5	1.34	1.57	44.7	1.45	2.06	32.3	1.59	2.61	26.5	1.68	3.00	21.8	1.82	3.38	17.7	1.97	3.83	14.9	2.12	4.22
100	159.2	1.14	0.82	97.4	1.24	1.23	70.5	1.34	1.57	49.6	1.45	2.07	35.8	1.58	2.63	29.4	1.68	3.01	24.1	1.80	3.43	19.6	1.96	3.87	16.5	2.11	4.26
110	174.8	1.14	0.82	106.9	1.24	1.23	77.4	1.34	1.57	54.5	1.45	2.07	39.3	1.58	2.64	32.3	1.68	3.02	26.5	1.80	3.43	21.5	1.95	3.90	18.1	2.10	4.30
120	190.3	1.14	0.82	116.5	1.24	1.23	84.3	1.34	1.58	59.4	1.45	2.07	42.8	1.58	2.65	35.2	1.68	3.02	28.9	1.80	3.43	23.4	1.94	3.92	19.7	2.09	4.33
130	205.7	1.14	0.82	126.0	1.24	1.23	91.2	1.34	1.58	64.2	1.45	2.08	46.4	1.58	2.64	38.1	1.68	3.03	31.3	1.80	3.43	25.4	1.95	3.90	21.3	2.09	4.35
140	221.0	1.14	0.82	135.4	1.24	1.24	98.0	1.34	1.58	69.1	1.45	2.08	49.9	1.58	2.64	41.0	1.68	3.03	33.6	1.80	3.46	27.3	1.95	3.92	22.9	2.08	4.37
150	236.3	1.14	0.83	144.9	1.25	1.24	104.9	1.34	1.58	73.9	1.45	2.08	53.4	1.58	2.65	43.9	1.68	3.03	36.0	1.80	3.45	29.2	1.95	3.93	24.5	2.08	4.38
160	251.5	1.14	0.83	154.3	1.25	1.24	111.7	1.34	1.59	78.7	1.45	2.09	56.9	1.58	2.65	46.7	1.67	3.05	38.3	1.79	3.47	31.1	1.94	3.94	26.1	2.08	4.40
170	266.6	1.14	0.83	163.7	1.25	1.24	118.5	1.34	1.59	83.6	1.45	2.08	60.3	1.58	2.66	49.6	1.68	3.05	40.7	1.80	3.46	33.0	1.94	3.95	27.7	2.07	4.41
180	281.7	1.14	0.83	173.0	1.25	1.24	125.2	1.34	1.59	88.4	1.45	2.09	63.8	1.58	2.66	52.5	1.68	3.04	43.0	1.79	3.48	34.9	1.94	3.96	29.3	2.07	4.41
190	296.7	1.14	0.83	182.3	1.25	1.24	132.0	1.34	1.59	93.2	1.45	2.09	67.3	1.58	2.66	55.3	1.68	3.06	45.4	1.80	3.47	36.8	1.94	3.97	30.8	2.06	4.46
200	311.7	1.14	0.83	191.6	1.25	1.24	138.7	1.34	1.60	97.9	1.45	2.10	70.7	1.58	2.67	58.2	1.68	3.05	47.7	1.79	3.49	38.7	1.94	3.97	32.4	2.06	4.47
220	342.1	1.14	0.83	210.4	1.25	1.25	152.4	1.35	1.60	107.6	1.45	2.10	77.7	1.58	2.67	63.9	1.68	3.06	52.5	1.80	3.47	42.5	1.93	3.99	35.6	2.06	4.48
240	372.4	1.14	0.84	229.2	1.25	1.25	165.9	1.34	1.60	117.2	1.45	2.10	84.7	1.58	2.67	69.7	1.68	3.06	57.2	1.80	3.48	46.4	1.94	3.97	38.8	2.06	4.49
260	402.5	1.14	0.84	247.9	1.25	1.25	179.5	1.34	1.60	126.8	1.45	2.10	91.7	1.58	2.67	75.4	1.68	3.07	61.9	1.80	3.49	50.2	1.94	3.99	42.0	2.06	4.49
280	432.6	1.14	0.84	266.5	1.25	1.25	193.0	1.34	1.61	136.4	1.45	2.10	98.6	1.58	2.68	81.1	1.68	3.07	66.6	1.80	3.49	54.0	1.94	3.99	45.2	2.06	4.49
300	462.5	1.14	0.84	285.1	1.25	1.25	206.5	1.35	1.61	146.0	1.46	2.10	105.5	1.58	2.69	86.8	1.68	3.07	71.2	1.79	3.51	57.8	1.94	4.00	48.4	2.06	4.50

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 0.50 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	10.2	2.28	0.95																								
20	13.3	2.18	1.02																								
25	16.5	2.15	1.05	10.5	2.60	1.35																					
30	19.7	2.12	1.06	12.4	2.51	1.42	9.5	2.91	1.60																		
35	22.8	2.09	1.09	14.3	2.45	1.48	10.9	2.81	1.69																		
40	26.0	2.08	1.09	16.3	2.44	1.49	12.3	2.74	1.76																		
45	29.2	2.08	1.10	18.2	2.41	1.52	13.7	2.69	1.81																		
50	32.4	2.08	1.10	20.2	2.40	1.53	15.1	2.64	1.86	11.1	3.22	2.07															
55	35.6	2.08	1.11	22.1	2.38	1.55	16.6	2.64	1.86	12.0	3.11	2.18															
60	38.8	2.08	1.11	24.1	2.38	1.55	18.0	2.61	1.90	13.0	3.07	2.23															
65	42.0	2.08	1.11	26.0	2.36	1.57	19.5	2.61	1.89	14.0	3.03	2.27															
70	45.2	2.08	1.11	28.0	2.36	1.57	20.9	2.59	1.92	15.0	3.01	2.31															
75	48.4	2.08	1.11	29.9	2.35	1.59	22.4	2.59	1.92	16.0	2.98	2.34	12.7	3.48	2.52												
80	51.6	2.08	1.11	31.9	2.36	1.58	23.8	2.58	1.94	17.0	2.96	2.36	13.4	3.41	2.60												
90	57.9	2.07	1.12	35.8	2.35	1.59	26.7	2.56	1.96	19.1	2.95	2.37	15.0	3.37	2.64												
100	64.3	2.07	1.11	39.7	2.34	1.60	29.6	2.55	1.97	21.1	2.92	2.42	16.5	3.31	2.72	13.3	3.77	2.96									
110	70.7	2.08	1.11	43.6	2.34	1.61	32.6	2.56	1.96	23.2	2.92	2.42	18.1	3.29	2.75	14.5	3.70	3.05									
120	77.0	2.07	1.12	47.5	2.33	1.61	35.5	2.56	1.97	25.2	2.89	2.45	19.6	3.24	2.81	15.7	3.64	3.12									
130	83.4	2.08	1.12	51.5	2.34	1.61	38.4	2.55	1.98	27.3	2.90	2.45	21.2	3.23	2.82	16.9	3.60	3.18									
140	89.7	2.08	1.12	55.4	2.34	1.61	41.3	2.55	1.98	29.3	2.88	2.47	22.8	3.22	2.84	18.1	3.56	3.23									
150	96.0	2.08	1.12	59.3	2.34	1.61	44.2	2.55	1.99	31.4	2.88	2.47	24.3	3.19	2.88	19.4	3.56	3.23	15.5	4.09	3.52						
160	102.3	2.08	1.12	63.2	2.34	1.61	47.1	2.54	1.99	33.5	2.89	2.47	25.9	3.19	2.88	20.6	3.53	3.27	16.4	4.02	3.60						
170	108.6	2.08	1.12	67.1	2.34	1.62	50.0	2.54	1.99	35.5	2.87	2.48	27.5	3.19	2.89	21.9	3.54	3.27	17.4	4.01	3.62						
180	114.9	2.08	1.12	70.9	2.33	1.62	52.9	2.54	1.99	37.6	2.88	2.48	29.1	3.19	2.89	23.1	3.51	3.30	18.3	3.96	3.69						
190	121.2	2.08	1.12	74.8	2.33	1.62	55.8	2.54	2.00	39.6	2.87	2.49	30.6	3.16	2.92	24.3	3.49	3.34	19.3	3.96	3.70						
200	127.4	2.08	1.13	78.7	2.33	1.62	58.7	2.54	2.00	41.7	2.87	2.49	32.2	3.16	2.93	25.6	3.50	3.33	20.2	3.91	3.77	16.8	4.48	3.96			
220	140.0	2.08	1.13	86.5	2.33	1.62	64.5	2.54	2.00	45.8	2.87	2.50	35.4	3.16	2.93	28.1	3.49	3.35	22.1	3.87	3.83	18.3	4.39	4.08			
240	152.6	2.08	1.13	94.3	2.33	1.63	70.3	2.54	2.01	49.9	2.86	2.51	38.6	3.16	2.93	30.6	3.48	3.36	24.1	3.87	3.84	19.9	4.36	4.12			
260	165.2	2.08	1.13	102.1	2.33	1.63	76.1	2.54	2.01	54.0	2.86	2.51	41.7	3.15	2.95	33.1	3.47	3.38	26.0	3.84	3.88	21.5	4.34	4.15			
280	177.7	2.08	1.13	109.8	2.33	1.63	81.9	2.54	2.01	58.2	2.87	2.50	44.9	3.15	2.95	35.6	3.46	3.39	28.0	3.84	3.88	23.0	4.28	4.24	19.0	4.88	4.50
300	190.3	2.08	1.13	117.6	2.33	1.63	87.7	2.54	2.01	62.3	2.86	2.51	48.0	3.14	2.97	38.1	3.45	3.40	29.9	3.82	3.92	24.6	4.27	4.26	20.2	4.80	4.61

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 0.75 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	13.7	1.76	0.92	8.0	2.22	1.24									
20	18.2	1.75	0.93	10.4	2.10	1.35									
25	22.6	1.73	0.95	12.8	2.03	1.42	9.5	2.33	1.66						
30	27.1	1.73	0.95	15.3	2.02	1.44	11.2	2.25	1.76	8.9	2.56	1.94			
35	31.5	1.72	0.96	17.8	2.01	1.45	13.0	2.23	1.79	10.2	2.47	2.05			
40	36.0	1.72	0.96	20.2	1.98	1.48	14.8	2.21	1.81	11.6	2.44	2.09			
45	40.4	1.71	0.96	22.7	1.98	1.49	16.5	2.17	1.86	12.9	2.39	2.16			
50	44.9	1.72	0.96	25.2	1.98	1.49	18.3	2.16	1.87	14.3	2.38	2.18	10.6	2.82	2.47
55	49.3	1.72	0.96	27.6	1.96	1.51	20.1	2.16	1.88	15.7	2.37	2.19	11.6	2.80	2.51
60	53.7	1.72	0.97	30.1	1.96	1.51	21.9	2.16	1.89	17.1	2.36	2.20	12.5	2.73	2.61
65	58.1	1.72	0.97	32.5	1.95	1.52	23.6	2.14	1.92	18.4	2.33	2.25	13.5	2.71	2.63
70	62.5	1.72	0.97	35.0	1.96	1.52	25.4	2.14	1.92	19.8	2.33	2.25	14.4	2.66	2.71
75	66.9	1.72	0.97	37.4	1.95	1.53	27.2	2.14	1.92	21.2	2.33	2.26	15.4	2.65	2.73
80	71.2	1.71	0.97	39.9	1.95	1.53	29.0	2.14	1.92	22.5	2.31	2.29	16.4	2.65	2.74
90	80.0	1.71	0.97	44.8	1.95	1.53	32.5	2.12	1.94	25.3	2.31	2.29	18.4	2.63	2.76
100	88.8	1.72	0.98	49.7	1.95	1.54	36.1	2.13	1.94	28.1	2.31	2.29	20.4	2.62	2.78
110	97.6	1.72	0.98	54.7	1.95	1.53	39.7	2.13	1.94	30.8	2.30	2.31	22.4	2.61	2.79
120	106.3	1.72	0.98	59.6	1.95	1.54	43.2	2.12	1.95	33.6	2.30	2.31	24.4	2.61	2.81
130	115.0	1.72	0.98	64.5	1.95	1.54	46.8	2.12	1.95	36.4	2.30	2.31	26.3	2.58	2.85
140	123.7	1.72	0.98	69.4	1.95	1.54	50.3	2.12	1.96	39.1	2.29	2.33	28.3	2.58	2.85
150	132.4	1.72	0.98	74.2	1.95	1.55	53.9	2.12	1.95	41.9	2.30	2.32	30.3	2.58	2.86
160	141.1	1.72	0.98	79.1	1.95	1.55	57.4	2.12	1.96	44.6	2.29	2.33	32.3	2.58	2.86
170	149.7	1.72	0.98	84.0	1.95	1.55	60.9	2.12	1.97	47.4	2.30	2.33	34.3	2.58	2.86
180	158.3	1.72	0.98	88.8	1.95	1.55	64.5	2.12	1.96	50.1	2.29	2.34	36.3	2.58	2.86
190	166.9	1.72	0.98	93.7	1.95	1.55	68.0	2.12	1.97	52.8	2.29	2.34	38.3	2.58	2.86
200	175.5	1.72	0.99	98.5	1.95	1.55	71.5	2.12	1.97	55.6	2.29	2.34	40.2	2.57	2.89
220	192.8	1.72	0.99	108.3	1.95	1.55	78.6	2.12	1.97	61.1	2.29	2.34	44.2	2.57	2.89
240	210.1	1.72	0.99	118.0	1.95	1.56	85.6	2.12	1.98	66.6	2.29	2.35	48.2	2.57	2.89
260	227.3	1.72	0.99	127.7	1.95	1.56	92.7	2.12	1.98	72.1	2.29	2.35	52.2	2.57	2.89
280	244.5	1.72	0.99	137.4	1.95	1.56	99.7	2.12	1.98	77.6	2.29	2.35	56.2	2.57	2.89
300	261.7	1.72	0.99	147.1	1.95	1.56	106.8	2.12	1.98	83.0	2.29	2.36	60.1	2.57	2.90

Q cfs	V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15												
20												
25												
30												
35												
40												
45												
50												
55												
60												
65	11.2	3.04	2.83									
70	12.0	3.01	2.87									
75	12.8	2.99	2.91									
80	13.5	2.92	3.01									
90	15.1	2.89	3.07	12.4	3.26	3.30						
100	16.7	2.86	3.11	13.7	3.22	3.36						
110	18.3	2.84	3.15	14.9	3.15	3.48						
120	19.9	2.82	3.18	16.2	3.13	3.52	13.4	3.49	3.81			
130	21.5	2.81	3.20	17.5	3.11	3.55	14.5	3.49	3.82			
140	23.1	2.80	3.22	18.7	3.07	3.63	15.5	3.44	3.91			
150	24.7	2.79	3.24	20.0	3.06	3.65	16.5	3.39	3.98			
160	26.3	2.78	3.26	21.3	3.05	3.67	17.6	3.39	3.98	14.4	3.77	4.37
170	28.0	2.80	3.24	22.6	3.04	3.68	18.6	3.36	4.05	15.3	3.77	4.38
180	29.6	2.79	3.25	23.9	3.04	3.69	19.6	3.33	4.11	16.1	3.73	4.46
190	31.2	2.78	3.26	25.2	3.03	3.70	20.7	3.33	4.10	17.0	3.73	4.45
200	32.8	2.78	3.27	26.5	3.03	3.71	21.7	3.31	4.15	17.8	3.70	4.52
220	36.0	2.77	3.29	29.1	3.02	3.73	23.8	3.29	4.18	19.5	3.67	4.58
240	39.2	2.76	3.31	31.7	3.01	3.75	25.9	3.28	4.22	21.2	3.64	4.63
260	42.5	2.77	3.30	34.3	3.01	3.76	28.0	3.26	4.24	22.9	3.62	4.67
280	45.7	2.76	3.31	36.9	3.00	3.77	30.1	3.25	4.26	24.7	3.63	4.65
300	48.9	2.76	3.32	39.5	3.00	3.78	32.2	3.25	4.28	26.4	3.62	4.68

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 0.75 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	13.7	1.76	0.92	8.0	2.22	1.24																					
20	18.2	1.75	0.93	10.4	2.10	1.35																					
25	22.6	1.73	0.95	12.8	2.03	1.42	9.5	2.33	1.66																		
30	27.1	1.73	0.95	15.3	2.02	1.44	11.2	2.25	1.76	8.9	2.56	1.94															
35	31.5	1.72	0.96	17.8	2.01	1.45	13.0	2.23	1.79	10.2	2.47	2.05															
40	36.0	1.72	0.96	20.2	1.98	1.48	14.8	2.21	1.81	11.6	2.44	2.09															
45	40.4	1.71	0.96	22.7	1.98	1.49	16.5	2.17	1.86	12.9	2.39	2.16															
50	44.9	1.72	0.96	25.2	1.98	1.49	18.3	2.16	1.87	14.3	2.38	2.18	10.6	2.82	2.47												
55	49.3	1.72	0.96	27.6	1.96	1.51	20.1	2.16	1.88	15.7	2.37	2.19	11.6	2.80	2.51												
60	53.7	1.72	0.97	30.1	1.96	1.51	21.9	2.16	1.89	17.1	2.36	2.20	12.5	2.73	2.61												
65	58.1	1.72	0.97	32.5	1.95	1.52	23.6	2.14	1.92	18.4	2.33	2.25	13.5	2.71	2.63	11.2	3.04	2.83									
70	62.5	1.72	0.97	35.0	1.96	1.52	25.4	2.14	1.92	19.8	2.33	2.25	14.4	2.66	2.71	12.0	3.01	2.87									
75	66.9	1.72	0.97	37.4	1.95	1.53	27.2	2.14	1.92	21.2	2.33	2.26	15.4	2.65	2.73	12.8	2.99	2.91									
80	71.2	1.71	0.97	39.9	1.95	1.53	29.0	2.14	1.92	22.5	2.31	2.29	16.4	2.65	2.74	13.5	2.92	3.01									
90	80.0	1.71	0.97	44.8	1.95	1.53	32.5	2.12	1.94	25.3	2.31	2.29	18.4	2.63	2.76	15.1	2.89	3.07	12.4	3.26	3.30						
100	88.8	1.72	0.98	49.7	1.95	1.54	36.1	2.13	1.94	28.1	2.31	2.29	20.4	2.62	2.78	16.7	2.86	3.11	13.7	3.22	3.36						
110	97.6	1.72	0.98	54.7	1.95	1.53	39.7	2.13	1.94	30.8	2.30	2.31	22.4	2.61	2.79	18.3	2.84	3.15	14.9	3.15	3.48						
120	106.3	1.72	0.98	59.6	1.95	1.54	43.2	2.12	1.95	33.6	2.30	2.31	24.4	2.61	2.81	19.9	2.82	3.18	16.2	3.13	3.52	13.4	3.49	3.81			
130	115.0	1.72	0.98	64.5	1.95	1.54	46.8	2.12	1.95	36.4	2.30	2.31	26.3	2.58	2.85	21.5	2.81	3.20	17.5	3.11	3.55	14.5	3.49	3.82			
140	123.7	1.72	0.98	69.4	1.95	1.54	50.3	2.12	1.96	39.1	2.29	2.33	28.3	2.58	2.85	23.1	2.80	3.22	18.7	3.07	3.63	15.5	3.44	3.91			
150	132.4	1.72	0.98	74.2	1.95	1.55	53.9	2.12	1.95	41.9	2.30	2.32	30.3	2.58	2.86	24.7	2.79	3.24	20.0	3.06	3.65	16.5	3.39	3.98			
160	141.1	1.72	0.98	79.1	1.95	1.55	57.4	2.12	1.96	44.6	2.29	2.33	32.3	2.58	2.86	26.3	2.78	3.26	21.3	3.05	3.67	17.6	3.39	3.98	14.4	3.77	4.37
170	149.7	1.72	0.98	84.0	1.95	1.55	60.9	2.12	1.97	47.4	2.30	2.33	34.3	2.58	2.86	28.0	2.80	3.24	22.6	3.04	3.68	18.6	3.36	4.05	15.3	3.77	4.38
180	158.3	1.72	0.98	88.8	1.95	1.55	64.5	2.12	1.96	50.1	2.29	2.34	36.3	2.58	2.86	29.6	2.79	3.25	23.9	3.04	3.69	19.6	3.33	4.11	16.1	3.73	4.46
190	166.9	1.72	0.98	93.7	1.95	1.55	68.0	2.12	1.97	52.8	2.29	2.34	38.3	2.58	2.86	31.2	2.78	3.26	25.2	3.03	3.70	20.7	3.33	4.10	17.0	3.73	4.45
200	175.5	1.72	0.99	98.5	1.95	1.55	71.5	2.12	1.97	55.6	2.29	2.34	40.2	2.57	2.89	32.8	2.78	3.27	26.5	3.03	3.71	21.7	3.31	4.15	17.8	3.70	4.52
220	192.8	1.72	0.99	108.3	1.95	1.55	78.6	2.12	1.97	61.1	2.29	2.34	44.2	2.57	2.89	36.0	2.77	3.29	29.1	3.02	3.73	23.8	3.29	4.18	19.5	3.67	4.58
240	210.1	1.72	0.99	118.0	1.95	1.56	85.6	2.12	1.98	66.6	2.29	2.35	48.2	2.57	2.89	39.2	2.76	3.31	31.7	3.01	3.75	25.9	3.28	4.22	21.2	3.64	4.63
260	227.3	1.72	0.99	127.7	1.95	1.56	92.7	2.12	1.98	72.1	2.29	2.35	52.2	2.57	2.89	42.5	2.77	3.30	34.3	3.01	3.76	28.0	3.26	4.24	22.9	3.62	4.67
280	244.5	1.72	0.99	137.4	1.95	1.56	99.7	2.12	1.98	77.6	2.29	2.35	56.2	2.57	2.89	45.7	2.76	3.31	36.9	3.00	3.77	30.1	3.25	4.26	24.7	3.63	4.65
300	261.7	1.72	0.99	147.1	1.95	1.56	106.8	2.12	1.98	83.0	2.29	2.36	60.1	2.57	2.90	48.9	2.76	3.32	39.5	3.00	3.78	32.2	3.25	4.28	26.4	3.62	4.68

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 1.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	15.7	1.55	0.91	9.9	1.80	1.24																					
20	20.9	1.54	0.92	13.0	1.74	1.31	8.8	2.04	1.65																		
25	26.0	1.53	0.93	16.2	1.73	1.32	10.9	1.99	1.70	8.9	2.21	1.87															
30	31.1	1.52	0.94	19.3	1.70	1.35	12.9	1.94	1.78	10.5	2.14	1.98															
35	36.2	1.52	0.94	22.5	1.70	1.36	15.0	1.93	1.80	12.1	2.08	2.06	9.2	2.37	2.37												
40	41.3	1.52	0.95	25.7	1.70	1.36	17.1	1.92	1.81	13.7	2.04	2.12	10.4	2.32	2.45												
45	46.4	1.52	0.95	28.8	1.69	1.37	19.2	1.91	1.82	15.4	2.04	2.12	11.7	2.32	2.46												
50	51.5	1.52	0.95	32.0	1.70	1.37	21.2	1.89	1.85	17.0	2.02	2.16	12.9	2.28	2.52	9.9	2.61	2.86									
55	56.5	1.51	0.95	35.1	1.69	1.38	23.3	1.89	1.86	18.7	2.02	2.16	14.1	2.25	2.57	10.8	2.57	2.93									
60	61.6	1.52	0.95	38.3	1.69	1.37	25.4	1.89	1.86	20.3	2.00	2.19	15.3	2.23	2.61	11.7	2.54	3.00									
65	66.6	1.52	0.96	41.4	1.69	1.38	27.5	1.89	1.86	22.0	2.01	2.19	16.6	2.24	2.60	12.7	2.55	2.98	10.6	2.88	3.16						
70	71.6	1.51	0.96	44.6	1.70	1.38	29.5	1.88	1.88	23.6	1.99	2.21	17.8	2.22	2.63	13.6	2.52	3.03	11.3	2.82	3.26						
75	76.6	1.51	0.96	47.7	1.69	1.38	31.6	1.88	1.88	25.3	2.00	2.21	19.0	2.21	2.66	14.5	2.50	3.08	12.0	2.77	3.35						
80	81.6	1.52	0.96	50.8	1.69	1.38	33.7	1.88	1.88	26.9	1.99	2.22	20.3	2.22	2.64	15.4	2.48	3.11	12.7	2.73	3.43						
90	91.7	1.52	0.96	57.1	1.69	1.39	37.8	1.88	1.89	30.2	1.98	2.24	22.8	2.21	2.65	17.3	2.47	3.13	14.2	2.69	3.49	11.8	2.99	3.78			
100	101.7	1.52	0.96	63.4	1.69	1.39	42.0	1.88	1.89	33.5	1.98	2.24	25.2	2.19	2.69	19.2	2.47	3.14	15.7	2.67	3.55	13.0	2.94	3.88			
110	111.7	1.52	0.97	69.6	1.69	1.39	46.1	1.87	1.90	36.8	1.98	2.25	27.7	2.19	2.70	21.0	2.44	3.20	17.3	2.68	3.53	14.3	2.94	3.88	12.4	3.23	4.07
120	121.7	1.52	0.97	75.8	1.69	1.39	50.2	1.87	1.90	40.1	1.98	2.26	30.2	2.19	2.70	22.9	2.44	3.20	18.8	2.66	3.57	15.5	2.91	3.96	13.4	3.17	4.19
130	131.6	1.51	0.97	82.1	1.69	1.39	54.4	1.87	1.90	43.4	1.97	2.26	32.7	2.19	2.70	24.8	2.44	3.20	20.3	2.64	3.61	16.7	2.88	4.03	14.4	3.12	4.30
140	141.5	1.51	0.97	88.3	1.69	1.39	58.5	1.87	1.90	46.7	1.97	2.26	35.2	2.19	2.70	26.6	2.42	3.24	21.8	2.63	3.64	17.9	2.85	4.08	15.5	3.12	4.31
150	151.4	1.52	0.97	94.5	1.69	1.40	62.6	1.87	1.91	50.0	1.98	2.26	37.6	2.18	2.72	28.5	2.42	3.23	23.3	2.62	3.66	19.2	2.86	4.07	16.5	3.08	4.39
160	161.3	1.52	0.97	100.7	1.69	1.40	66.7	1.87	1.91	53.3	1.98	2.26	40.1	2.18	2.72	30.4	2.43	3.23	24.8	2.61	3.68	20.4	2.84	4.11	17.6	3.08	4.39
170	171.1	1.52	0.97	106.8	1.69	1.40	70.8	1.87	1.91	56.5	1.97	2.28	42.6	2.19	2.72	32.2	2.41	3.26	26.3	2.60	3.70	21.7	2.85	4.10	18.6	3.05	4.46
180	180.9	1.52	0.98	113.0	1.69	1.40	74.9	1.87	1.91	59.8	1.97	2.27	45.0	2.18	2.73	34.1	2.42	3.25	27.9	2.61	3.68	22.9	2.83	4.14	19.6	3.02	4.52
190	190.6	1.52	0.98	119.1	1.69	1.40	79.0	1.87	1.91	63.1	1.98	2.27	47.5	2.18	2.73	35.9	2.41	3.27	29.4	2.61	3.69	24.1	2.81	4.17	20.7	3.03	4.51
200	200.4	1.52	0.98	125.3	1.69	1.40	83.0	1.87	1.92	66.3	1.97	2.28	49.9	2.18	2.74	37.8	2.41	3.27	30.9	2.60	3.71	25.4	2.82	4.15	21.7	3.00	4.57
220	220.1	1.52	0.98	137.6	1.69	1.41	91.2	1.87	1.92	72.9	1.97	2.28	54.9	2.18	2.74	41.5	2.41	3.28	33.9	2.59	3.73	27.9	2.82	4.17	23.8	2.99	4.61
240	239.8	1.52	0.98	150.0	1.69	1.41	99.4	1.87	1.93	79.5	1.98	2.28	59.8	2.18	2.75	45.3	2.41	3.28	37.0	2.60	3.72	30.4	2.81	4.18	25.9	2.97	4.64
260	259.4	1.52	0.98	162.3	1.69	1.41	107.6	1.87	1.93	86.0	1.97	2.28	64.8	2.18	2.74	49.0	2.41	3.29	40.0	2.59	3.75	32.9	2.81	4.20	28.0	2.96	4.67
280	279.0	1.52	0.98	174.6	1.70	1.41	115.8	1.87	1.93	92.5	1.97	2.29	69.7	2.18	2.75	52.7	2.40	3.30	43.0	2.58	3.76	35.3	2.79	4.24	30.2	2.97	4.65
300	298.5	1.52	0.98	186.9	1.70	1.41	123.9	1.87	1.93	99.1	1.98	2.29	74.6	2.18	2.75	56.4	2.40	3.30	46.1	2.59	3.75	37.8	2.79	4.24	32.3	2.97	4.67

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 1.25 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	18.1	1.40	0.88	11.5	1.59	1.21	7.7	1.85	1.55																		
20	24.0	1.38	0.89	15.2	1.56	1.25	10.1	1.79	1.64	7.7	2.03	1.89															
25	30.0	1.38	0.89	19.0	1.56	1.25	12.5	1.75	1.69	9.5	1.97	1.97	7.8	2.19	2.16												
30	35.9	1.38	0.90	22.7	1.55	1.27	14.9	1.73	1.73	11.2	1.90	2.09	9.2	2.11	2.28												
35	41.8	1.38	0.90	26.4	1.54	1.28	17.3	1.71	1.75	13.0	1.88	2.12	10.5	2.02	2.44	8.3	2.36	2.64									
40	47.7	1.38	0.90	30.1	1.54	1.28	19.7	1.70	1.77	14.8	1.87	2.15	12.0	2.02	2.44	9.4	2.32	2.72									
45	53.6	1.38	0.90	33.9	1.54	1.28	22.1	1.69	1.78	16.6	1.86	2.17	13.4	1.99	2.50	10.5	2.28	2.78									
50	59.4	1.38	0.91	37.6	1.54	1.28	24.5	1.69	1.79	18.4	1.85	2.18	14.9	1.99	2.50	11.5	2.22	2.90	9.4	2.49	3.16						
55	65.3	1.38	0.91	41.3	1.54	1.28	26.9	1.69	1.80	20.2	1.84	2.19	16.3	1.97	2.54	12.6	2.20	2.94	10.3	2.47	3.20						
60	71.1	1.38	0.91	44.9	1.53	1.29	29.3	1.68	1.81	22.0	1.84	2.20	17.7	1.96	2.57	13.7	2.19	2.97	11.2	2.45	3.23						
65	76.9	1.38	0.91	48.6	1.54	1.29	31.7	1.68	1.81	23.7	1.82	2.24	19.2	1.97	2.56	14.8	2.18	2.99	12.0	2.40	3.34	9.8	2.76	3.55			
70	82.7	1.38	0.91	52.3	1.54	1.29	34.1	1.68	1.81	25.5	1.82	2.24	20.6	1.95	2.58	15.9	2.17	3.01	12.9	2.39	3.36	10.5	2.74	3.61			
75	88.4	1.38	0.91	55.9	1.53	1.30	36.5	1.68	1.82	27.3	1.82	2.24	22.1	1.96	2.57	17.0	2.16	3.03	13.8	2.39	3.38	11.1	2.67	3.76			
80	94.2	1.38	0.91	59.6	1.54	1.30	38.9	1.68	1.82	29.1	1.82	2.24	23.5	1.95	2.59	18.1	2.16	3.05	14.7	2.38	3.39	11.8	2.65	3.80	10.3	2.92	3.94
90	105.8	1.38	0.91	66.9	1.53	1.30	43.7	1.68	1.82	32.7	1.82	2.25	26.4	1.95	2.60	20.3	2.14	3.07	16.4	2.34	3.48	13.2	2.62	3.87	11.4	2.83	4.14
100	117.3	1.38	0.92	74.3	1.54	1.30	48.5	1.68	1.83	36.3	1.82	2.25	29.3	1.95	2.61	22.5	2.14	3.10	18.2	2.34	3.49	14.6	2.59	3.92	12.6	2.80	4.21
110	128.9	1.38	0.92	91.6	1.54	1.31	53.3	1.68	1.83	39.8	1.81	2.27	32.2	1.95	2.61	24.7	2.13	3.11	20.0	2.34	3.50	16.0	2.58	3.97	13.8	2.77	4.27
120	140.4	1.38	0.92	88.9	1.54	1.31	58.1	1.68	1.83	43.4	1.81	2.27	35.0	1.94	2.64	26.9	2.12	3.13	21.7	2.31	3.56	17.4	2.56	4.00	15.0	2.75	4.32
130	151.8	1.38	0.92	96.1	1.53	1.31	62.9	1.68	1.83	47.0	1.82	2.27	37.9	1.94	2.64	29.1	2.12	3.14	23.5	2.31	3.56	18.8	2.55	4.04	16.2	2.74	4.36
140	163.2	1.38	0.92	103.4	1.54	1.31	67.6	1.68	1.84	50.5	1.81	2.28	40.8	1.94	2.64	31.3	2.12	3.14	25.3	2.31	3.56	20.2	2.54	4.06	17.4	2.72	4.39
150	174.6	1.38	0.92	110.6	1.53	1.31	72.4	1.68	1.83	54.1	1.81	2.28	43.7	1.94	2.64	33.5	2.12	3.15	27.0	2.30	3.60	21.6	2.53	4.08	18.6	2.71	4.42
160	186.0	1.38	0.92	117.8	1.53	1.32	77.1	1.68	1.84	57.6	1.81	2.29	46.5	1.93	2.65	35.7	2.12	3.16	28.8	2.30	3.60	22.9	2.50	4.16	19.8	2.70	4.45
170	197.3	1.39	0.92	125.0	1.54	1.32	81.9	1.68	1.84	61.2	1.81	2.28	49.4	1.94	2.65	37.9	2.12	3.16	30.6	2.30	3.59	24.3	2.50	4.17	21.0	2.69	4.47
180	208.5	1.38	0.93	132.2	1.54	1.32	86.6	1.68	1.84	64.7	1.81	2.29	52.2	1.93	2.66	40.1	2.12	3.16	32.3	2.29	3.62	25.7	2.49	4.18	22.2	2.69	4.49
190	219.8	1.39	0.93	139.3	1.54	1.32	91.3	1.68	1.84	68.2	1.81	2.29	55.1	1.94	2.65	42.3	2.12	3.16	34.1	2.30	3.62	27.1	2.49	4.19	23.4	2.68	4.51
200	231.0	1.39	0.93	146.5	1.54	1.32	96.0	1.68	1.84	71.8	1.82	2.29	57.9	1.93	2.66	44.5	2.12	3.17	35.8	2.29	3.64	28.5	2.49	4.20	24.6	2.68	4.52
220	253.7	1.39	0.93	160.9	1.54	1.32	105.5	1.68	1.84	78.9	1.82	2.29	63.7	1.94	2.66	48.9	2.12	3.17	39.4	2.29	3.63	31.3	2.48	4.22	27.0	2.67	4.55
240	276.3	1.39	0.93	175.3	1.54	1.33	115.0	1.69	1.84	85.9	1.81	2.30	69.4	1.94	2.66	53.3	2.11	3.18	42.9	2.29	3.65	34.1	2.48	4.23	29.4	2.66	4.57
260	298.9	1.39	0.93	189.7	1.54	1.33	124.4	1.68	1.85	93.0	1.81	2.30	75.1	1.93	2.67	57.6	2.11	3.19	46.5	2.29	3.64	36.9	2.48	4.24	31.8	2.65	4.59
280	321.3	1.39	0.93	204.0	1.54	1.33	133.9	1.69	1.85	100.1	1.82	2.30	80.8	1.93	2.67	62.0	2.11	3.19	50.0	2.29	3.65	39.7	2.47	4.25	34.2	2.65	4.61
300	343.7	1.39	0.93	218.2	1.54	1.33	143.3	1.69	1.85	107.1	1.81	2.30	86.5	1.94	2.67	66.4	2.11	3.19	53.5	2.28	3.66	42.5	2.47	4.26	36.6	2.65	4.62

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 1.50 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	20.1	1.29	0.86	13.2	1.43	1.17	8.9	1.65	1.51						
20	26.8	1.29	0.86	17.5	1.42	1.19	11.7	1.60	1.58	8.1	1.86	1.95	6.7	2.09	2.10
25	33.4	1.28	0.86	21.8	1.41	1.21	14.5	1.57	1.63	9.9	1.78	2.10	8.1	1.95	2.34
30	40.0	1.28	0.87	26.2	1.42	1.20	17.4	1.57	1.63	11.8	1.75	2.15	9.6	1.90	2.43
35	46.5	1.28	0.87	30.5	1.41	1.21	20.2	1.56	1.65	13.7	1.74	2.18	11.1	1.86	2.50
40	53.1	1.28	0.87	34.8	1.41	1.21	23.0	1.55	1.67	15.6	1.73	2.20	12.6	1.84	2.56
45	59.6	1.28	0.88	39.0	1.40	1.22	25.9	1.55	1.66	17.5	1.72	2.22	14.2	1.85	2.55
50	66.1	1.28	0.88	43.3	1.41	1.22	28.7	1.55	1.67	19.4	1.71	2.24	15.7	1.83	2.58
55	72.6	1.28	0.88	47.6	1.41	1.22	31.5	1.55	1.68	21.3	1.71	2.25	17.2	1.82	2.61
60	79.0	1.28	0.88	51.8	1.41	1.22	34.3	1.54	1.69	23.2	1.70	2.25	18.8	1.82	2.60
65	85.5	1.28	0.88	56.0	1.40	1.23	37.1	1.54	1.69	25.1	1.70	2.26	20.3	1.82	2.62
70	91.9	1.28	0.88	60.3	1.41	1.22	39.9	1.54	1.69	27.0	1.70	2.26	21.8	1.81	2.64
75	98.2	1.28	0.89	64.5	1.41	1.23	42.7	1.54	1.69	28.9	1.70	2.27	23.3	1.80	2.66
80	104.6	1.28	0.89	68.7	1.41	1.23	45.5	1.54	1.70	30.8	1.70	2.27	24.9	1.81	2.64
90	117.5	1.28	0.89	77.1	1.41	1.23	51.1	1.54	1.70	34.6	1.70	2.28	27.9	1.80	2.67
100	130.3	1.28	0.89	85.6	1.41	1.23	56.7	1.54	1.70	38.3	1.69	2.30	31.0	1.80	2.66
110	143.0	1.28	0.89	94.0	1.41	1.24	62.3	1.54	1.71	42.1	1.69	2.30	34.0	1.79	2.68
120	155.8	1.28	0.89	102.4	1.41	1.24	67.9	1.54	1.71	45.9	1.69	2.30	37.1	1.80	2.68
130	168.4	1.28	0.90	110.7	1.41	1.24	73.4	1.54	1.71	49.7	1.69	2.30	40.1	1.79	2.69
140	181.0	1.28	0.90	119.1	1.41	1.24	79.0	1.54	1.71	53.4	1.69	2.31	43.2	1.80	2.68
150	193.6	1.28	0.90	127.4	1.41	1.24	84.5	1.54	1.72	57.2	1.69	2.31	46.2	1.79	2.70
160	206.2	1.28	0.90	135.7	1.41	1.24	90.0	1.54	1.72	60.9	1.69	2.32	49.3	1.80	2.69
170	218.6	1.28	0.90	144.0	1.41	1.24	95.6	1.54	1.72	64.7	1.69	2.31	52.3	1.80	2.69
180	231.1	1.28	0.90	152.2	1.41	1.25	101.0	1.54	1.72	68.4	1.69	2.32	55.3	1.80	2.70
190	243.5	1.28	0.90	160.4	1.41	1.25	106.5	1.54	1.72	72.1	1.69	2.32	58.3	1.80	2.71
200	255.8	1.28	0.91	168.6	1.41	1.25	112.0	1.54	1.72	75.9	1.69	2.32	61.3	1.79	2.71
220	280.9	1.28	0.91	185.2	1.41	1.25	123.0	1.54	1.73	83.4	1.69	2.32	67.4	1.80	2.71
240	305.8	1.28	0.91	201.7	1.41	1.25	134.1	1.54	1.73	90.9	1.69	2.32	73.5	1.80	2.71
260	330.7	1.28	0.91	218.2	1.41	1.26	145.1	1.54	1.73	98.3	1.69	2.33	79.5	1.80	2.72
280	355.5	1.28	0.91	234.7	1.41	1.26	156.0	1.54	1.73	105.8	1.69	2.33	85.5	1.79	2.72
300	380.2	1.28	0.91	251.1	1.41	1.26	167.0	1.54	1.73	113.2	1.69	2.33	91.6	1.80	2.72

Q cfs	V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15												
20												
25												
30	8.0	2.13	2.60									
35	9.2	2.06	2.72									
40	10.4	2.02	2.82	8.2	2.38	3.03						
45	11.7	2.02	2.82	9.1	2.31	3.16						
50	12.9	1.99	2.89	10.0	2.26	3.27						
55	14.2	1.99	2.89	10.9	2.22	3.36	9.3	2.47	3.54			
60	15.4	1.97	2.94	11.9	2.22	3.36	10.1	2.45	3.59			
65	16.6	1.95	2.98	12.8	2.19	3.43	10.8	2.39	3.73			
70	17.9	1.96	2.96	13.8	2.20	3.42	11.6	2.38	3.76	9.8	2.62	4.03
75	19.1	1.95	3.00	14.7	2.18	3.48	12.4	2.37	3.79	10.5	2.62	4.04
80	20.4	1.95	2.98	15.7	2.18	3.46	13.2	2.36	3.81	11.1	2.58	4.15
90	22.9	1.95	3.00	17.6	2.17	3.50	14.7	2.31	3.93	12.4	2.54	4.24
100	25.4	1.94	3.02	19.5	2.16	3.53	16.3	2.30	3.96	13.7	2.51	4.32
110	27.9	1.94	3.03	21.4	2.15	3.56	17.9	2.30	3.98	15.0	2.49	4.38
120	30.4	1.94	3.03	23.3	2.14	3.57	19.5	2.29	3.99	16.3	2.47	4.43
130	32.9	1.94	3.04	25.2	2.14	3.59	21.1	2.29	4.01	17.6	2.45	4.48
140	35.3	1.93	3.07	27.1	2.14	3.60	22.7	2.29	4.02	18.9	2.44	4.51
150	37.8	1.93	3.07	29.0	2.13	3.61	24.2	2.27	4.07	20.2	2.43	4.54
160	40.3	1.93	3.07	30.9	2.13	3.62	25.8	2.27	4.08	21.6	2.45	4.51
170	42.8	1.93	3.07	32.8	2.13	3.62	27.4	2.27	4.08	22.9	2.44	4.53
180	45.3	1.93	3.07	34.7	2.13	3.63	29.0	2.27	4.08	24.2	2.43	4.56
190	47.7	1.92	3.08	36.5	2.12	3.66	30.6	2.27	4.08	25.5	2.42	4.58
200	50.2	1.93	3.08	38.4	2.12	3.66	32.1	2.26	4.12	26.8	2.42	4.60
220	55.2	1.93	3.08	42.2	2.12	3.67	35.3	2.26	4.12	29.5	2.42	4.58
240	60.1	1.92	3.09	46.0	2.12	3.67	38.5	2.26	4.12	32.1	2.41	4.62
260	65.1	1.93	3.09	49.8	2.12	3.68	41.7	2.26	4.12	34.7	2.41	4.64
280	70.0	1.93	3.10	53.6	2.12	3.68	44.8	2.25	4.14	37.4	2.41	4.63
300	74.9	1.92	3.11	57.4	2.12	3.68	48.0	2.25	4.14	40.0	2.41	4.65

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B"

Grade 1.75 Percent

Q cfs	V_1 = 2.0 T	D	V_2	V_1 = 2.5 T	D	V_2	V_1 = 3.0 T	D	V_2	V_1 = 3.5 T	D	V_2	V_1 = 4.0 T	D	V_2
15	21.8	1.21	0.84	14.2	1.33	1.17	10.0	1.50	1.48	6.9	1.74	1.84			
20	29.0	1.20	0.85	18.9	1.33	1.18	13.2	1.46	1.53	9.0	1.66	1.98	7.6	1.83	2.12
25	36.2	1.20	0.85	23.5	1.32	1.20	16.4	1.45	1.56	11.2	1.64	2.01	9.3	1.75	2.27
30	43.4	1.21	0.85	28.2	1.32	1.20	19.6	1.44	1.58	13.3	1.60	2.08	11.1	1.72	2.32
35	50.5	1.20	0.85	32.8	1.31	1.21	22.8	1.43	1.59	15.5	1.60	2.09	12.8	1.68	2.40
40	57.6	1.20	0.85	37.4	1.31	1.21	26.0	1.43	1.60	17.6	1.58	2.13	14.6	1.68	2.42
45	64.6	1.20	0.86	42.0	1.31	1.21	29.2	1.43	1.61	19.8	1.58	2.13	16.4	1.68	2.43
50	71.6	1.20	0.86	46.6	1.31	1.21	32.4	1.43	1.61	21.9	1.57	2.16	18.2	1.67	2.44
55	78.6	1.20	0.86	51.2	1.31	1.22	35.6	1.43	1.61	24.1	1.58	2.15	19.9	1.66	2.48
60	85.6	1.20	0.87	55.8	1.31	1.22	38.8	1.43	1.61	26.2	1.57	2.17	21.7	1.66	2.48
65	92.6	1.20	0.87	60.3	1.31	1.22	41.9	1.42	1.62	28.4	1.57	2.16	23.5	1.66	2.48
70	99.5	1.20	0.87	64.9	1.32	1.22	45.1	1.42	1.62	30.5	1.57	2.18	25.2	1.65	2.50
75	106.4	1.20	0.87	69.4	1.31	1.22	48.2	1.42	1.63	32.7	1.57	2.17	27.0	1.65	2.50
80	113.3	1.20	0.87	73.9	1.31	1.22	51.4	1.43	1.62	34.8	1.57	2.18	28.8	1.66	2.50
90	127.2	1.20	0.87	83.0	1.31	1.23	57.7	1.42	1.63	39.1	1.57	2.18	32.3	1.65	2.52
100	141.0	1.20	0.87	92.1	1.32	1.23	64.0	1.42	1.64	43.4	1.57	2.18	35.8	1.64	2.53
110	154.9	1.21	0.87	101.2	1.32	1.23	70.4	1.43	1.63	47.7	1.57	2.19	39.4	1.65	2.52
120	168.6	1.20	0.88	110.2	1.32	1.23	76.6	1.42	1.64	51.9	1.57	2.20	42.9	1.64	2.53
130	182.3	1.21	0.88	119.2	1.32	1.23	82.9	1.42	1.64	56.2	1.57	2.20	46.4	1.64	2.54
140	196.0	1.21	0.88	128.1	1.32	1.23	89.2	1.43	1.64	60.4	1.57	2.21	49.9	1.64	2.55
150	209.6	1.21	0.88	137.1	1.32	1.23	95.4	1.42	1.64	64.7	1.57	2.20	53.4	1.64	2.55
160	223.1	1.21	0.88	146.0	1.32	1.24	101.6	1.42	1.65	68.9	1.57	2.21	56.9	1.64	2.55
170	236.6	1.21	0.88	154.9	1.32	1.24	107.9	1.43	1.64	73.1	1.57	2.21	60.4	1.64	2.55
180	250.0	1.21	0.89	163.7	1.32	1.24	114.0	1.43	1.65	77.4	1.57	2.21	63.9	1.64	2.55
190	263.4	1.21	0.89	172.6	1.32	1.24	120.2	1.43	1.65	81.6	1.57	2.21	67.4	1.64	2.55
200	276.7	1.21	0.89	181.4	1.32	1.24	126.4	1.43	1.65	85.7	1.57	2.22	70.8	1.64	2.56
220	303.8	1.21	0.89	199.2	1.32	1.24	138.8	1.43	1.65	94.2	1.57	2.22	77.8	1.64	2.57
240	330.8	1.21	0.89	217.0	1.32	1.24	151.2	1.43	1.66	102.7	1.57	2.22	84.8	1.64	2.57
260	357.7	1.21	0.89	234.7	1.32	1.25	163.6	1.43	1.66	111.1	1.57	2.22	91.8	1.64	2.57
280	384.5	1.21	0.89	252.3	1.32	1.25	176.0	1.43	1.66	119.5	1.57	2.23	98.7	1.64	2.58
300	411.2	1.21	0.90	269.9	1.32	1.25	188.3	1.43	1.66	127.9	1.57	2.23	105.7	1.64	2.57

Q cfs	V_1 = 4.5 T	D	V_2	V_1 = 5.0 T	D	V_2	V_1 = 5.5 T	D	V_2	V_1 = 6.0 T	D	V_2
15												
20												
25	7.6	1.93	2.51									
30	9.0	1.88	2.62									
35	10.4	1.84	2.70	8.2	2.11	2.98						
40	11.8	1.81	2.77	9.3	2.08	3.06						
45	13.2	1.79	2.82	10.3	2.01	3.21	8.6	2.26	3.41			
50	14.7	1.80	2.80	11.4	2.00	3.25	9.5	2.24	3.48			
55	16.1	1.79	2.83	12.5	1.99	3.28	10.3	2.17	3.64	8.6	2.51	3.77
60	17.5	1.78	2.86	13.6	1.98	3.31	11.2	2.16	3.67	9.2	2.41	4.00
65	18.9	1.77	2.88	14.7	1.97	3.33	12.1	2.15	3.70	9.9	2.38	4.08
70	20.3	1.76	2.90	15.8	1.96	3.35	13.0	2.14	3.73	10.6	2.35	4.15
75	21.8	1.78	2.88	16.9	1.96	3.36	13.9	2.13	3.75	11.4	2.37	4.11
80	23.2	1.77	2.90	17.9	1.94	3.43	14.8	2.13	3.77	12.1	2.35	4.17
90	26.0	1.76	2.93	20.1	1.93	3.45	16.6	2.12	3.81	13.5	2.31	4.28
100	28.9	1.76	2.92	22.3	1.93	3.46	18.4	2.11	3.83	14.9	2.28	4.37
110	31.7	1.76	2.94	24.5	1.92	3.47	20.1	2.08	3.91	16.4	2.29	4.36
120	34.6	1.76	2.93	26.7	1.92	3.48	21.9	2.08	3.93	17.8	2.26	4.43
130	37.4	1.76	2.95	28.9	1.92	3.49	23.7	2.07	3.93	19.2	2.25	4.48
140	40.2	1.75	2.96	31.1	1.92	3.49	25.5	2.07	3.94	20.7	2.25	4.47
150	43.1	1.76	2.95	33.3	1.92	3.49	27.3	2.07	3.95	22.1	2.24	4.51
160	45.9	1.76	2.96	35.4	1.91	3.52	29.1	2.07	3.95	23.6	2.25	4.49
170	48.7	1.76	2.96	37.6	1.91	3.52	30.9	2.07	3.95	25.0	2.24	4.53
180	51.5	1.75	2.97	39.8	1.92	3.52	32.6	2.06	3.99	26.4	2.23	4.56
190	54.3	1.75	2.97	42.0	1.92	3.52	34.4	2.06	3.99	27.9	2.23	4.54
200	57.1	1.75	2.98	44.1	1.91	3.54	36.2	2.06	3.99	29.3	2.23	4.57
220	62.8	1.76	2.97	48.5	1.91	3.53	39.8	2.07	3.99	32.2	2.22	4.58
240	68.4	1.75	2.98	52.9	1.92	3.53	43.3	2.06	4.02	35.1	2.22	4.58
260	74.1	1.76	2.98	57.2	1.91	3.54	46.9	2.06	4.01	38.0	2.22	4.59
280	79.7	1.76	2.98	61.6	1.92	3.54	50.5	2.06	4.01	40.9	2.22	4.59
300	85.3	1.76	2.99	65.9	1.91	3.55	54.0	2.06	4.03	43.7	2.21	4.62

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 3.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	28.1	0.98	0.80	19.2	1.05	1.10	13.4	1.15	1.44	10.3	1.24	1.74	7.6	1.37	2.12	5.8	1.56	2.44									
20	37.4	0.98	0.80	25.6	1.05	1.10	17.8	1.14	1.46	13.7	1.23	1.76	10.0	1.33	2.22	7.6	1.50	2.59	6.8	1.58	2.74						
25	46.7	0.99	0.80	31.9	1.05	1.11	22.2	1.14	1.47	17.0	1.21	1.80	12.5	1.33	2.23	9.4	1.46	2.69	8.4	1.54	2.85	6.9	1.68	3.18			
30	55.9	0.99	0.81	38.2	1.05	1.11	26.6	1.14	1.47	20.3	1.20	1.82	14.9	1.31	2.27	11.2	1.44	2.75	9.9	1.48	3.02	8.2	1.64	3.28	6.7	1.88	3.50
35	65.0	0.99	0.81	44.4	1.04	1.12	31.0	1.14	1.47	23.7	1.21	1.81	17.3	1.30	2.30	13.0	1.43	2.80	11.5	1.47	3.07	9.5	1.62	3.36	7.7	1.82	3.68
40	74.1	0.99	0.81	50.6	1.04	1.12	35.3	1.14	1.48	27.0	1.20	1.83	19.7	1.29	2.33	14.8	1.42	2.83	13.1	1.46	3.10	10.8	1.60	3.42	8.7	1.78	3.82
45	83.2	0.99	0.81	56.8	1.04	1.13	39.7	1.14	1.48	30.3	1.20	1.84	22.1	1.29	2.34	16.6	1.41	2.85	14.7	1.45	3.12	12.1	1.59	3.46	9.7	1.75	3.92
50	92.2	0.99	0.81	63.0	1.04	1.13	44.0	1.14	1.48	33.6	1.20	1.84	24.6	1.30	2.32	18.4	1.40	2.87	16.3	1.45	3.14	13.4	1.58	3.50	10.7	1.72	4.01
55	101.1	0.99	0.82	69.1	1.04	1.13	48.3	1.14	1.49	36.9	1.20	1.84	27.0	1.30	2.34	20.2	1.40	2.88	17.9	1.45	3.15	14.7	1.57	3.53	11.7	1.70	4.09
60	110.1	0.99	0.82	75.3	1.05	1.13	52.6	1.14	1.49	40.2	1.20	1.85	29.4	1.29	2.34	22.0	1.40	2.89	19.5	1.45	3.16	16.0	1.57	3.55	12.7	1.69	4.15
65	118.9	0.99	0.82	81.4	1.05	1.13	56.9	1.14	1.49	43.4	1.20	1.86	31.8	1.29	2.35	23.8	1.40	2.90	21.1	1.45	3.16	17.3	1.57	3.56	13.8	1.70	4.11
70	127.8	0.99	0.82	87.4	1.04	1.14	61.1	1.14	1.50	46.7	1.20	1.86	34.2	1.29	2.35	25.6	1.40	2.90	22.7	1.45	3.17	18.5	1.55	3.63	14.8	1.69	4.16
75	136.6	0.99	0.82	93.5	1.05	1.14	65.4	1.14	1.50	49.9	1.20	1.87	36.6	1.29	2.35	27.4	1.40	2.91	24.2	1.44	3.21	19.8	1.55	3.64	15.8	1.68	4.20
80	145.3	0.99	0.83	99.5	1.05	1.14	69.6	1.14	1.50	53.1	1.20	1.87	38.9	1.29	2.37	29.2	1.40	2.91	25.8	1.44	3.21	21.1	1.55	3.64	16.9	1.69	4.16
90	163.1	0.99	0.83	111.7	1.05	1.14	78.2	1.14	1.50	59.7	1.20	1.87	43.7	1.29	2.38	32.7	1.39	2.94	29.0	1.44	3.21	23.7	1.54	3.66	18.9	1.67	4.23
100	180.8	0.99	0.83	123.8	1.05	1.15	86.7	1.14	1.51	66.2	1.20	1.88	48.5	1.29	2.38	36.3	1.39	2.95	32.2	1.44	3.21	26.3	1.54	3.67	21.0	1.67	4.23
110	198.3	0.99	0.83	135.9	1.05	1.15	95.2	1.14	1.51	72.7	1.20	1.88	53.3	1.29	2.38	39.9	1.39	2.95	35.4	1.44	3.21	28.9	1.54	3.67	23.1	1.68	4.22
120	215.8	0.99	0.83	148.0	1.05	1.15	103.7	1.14	1.51	79.2	1.20	1.88	58.1	1.29	2.38	43.5	1.39	2.95	38.5	1.43	3.23	31.5	1.54	3.68	25.1	1.67	4.27
130	233.3	0.99	0.83	160.0	1.05	1.15	112.1	1.14	1.51	85.7	1.20	1.88	62.8	1.29	2.39	47.0	1.39	2.96	41.7	1.44	3.23	34.1	1.54	3.68	27.2	1.67	4.26
140	250.6	0.99	0.84	171.9	1.05	1.15	120.5	1.14	1.52	92.1	1.20	1.89	67.6	1.29	2.38	50.6	1.39	2.96	44.8	1.43	3.24	36.7	1.54	3.68	29.3	1.67	4.25
150	267.8	0.99	0.84	183.8	1.05	1.16	128.9	1.14	1.52	98.5	1.20	1.89	72.3	1.29	2.39	54.1	1.39	2.97	48.0	1.44	3.24	39.3	1.55	3.68	31.3	1.67	4.28
160	285.0	0.99	0.84	195.7	1.05	1.16	137.2	1.14	1.52	104.9	1.20	1.89	77.0	1.29	2.39	57.7	1.39	2.96	51.1	1.44	3.25	41.8	1.54	3.70	33.4	1.67	4.27
170	302.0	0.99	0.84	207.5	1.05	1.16	145.5	1.14	1.52	111.3	1.20	1.89	81.7	1.29	2.40	61.2	1.39	2.97	54.3	1.44	3.24	44.4	1.54	3.70	35.4	1.67	4.29
180	319.0	0.99	0.84	219.2	1.05	1.16	153.8	1.14	1.53	117.7	1.20	1.89	86.4	1.29	2.40	64.7	1.39	2.98	57.4	1.44	3.25	47.0	1.55	3.69	37.5	1.67	4.28
190	335.9	0.99	0.85	231.0	1.05	1.16	162.1	1.14	1.53	124.0	1.20	1.90	91.1	1.30	2.40	68.2	1.39	2.98	60.5	1.44	3.25	49.5	1.54	3.71	39.5	1.67	4.30
200	352.7	0.99	0.85	242.6	1.05	1.16	170.3	1.14	1.53	130.3	1.20	1.90	95.7	1.29	2.40	71.7	1.39	2.99	63.6	1.44	3.26	52.1	1.55	3.70	41.6	1.67	4.28
220	387.1	0.99	0.85	266.3	1.05	1.17	187.0	1.14	1.53	143.1	1.20	1.90	105.1	1.29	2.41	78.8	1.39	2.99	69.9	1.44	3.26	57.2	1.54	3.71	45.7	1.67	4.29
240	421.2	0.99	0.85	289.9	1.05	1.17	203.6	1.14	1.53	155.9	1.20	1.90	114.5	1.29	2.41	85.9	1.39	2.99	76.2	1.44	3.26	62.3	1.54	3.72	49.8	1.67	4.30
260	455.2	0.99	0.85	313.4	1.05	1.17	220.2	1.14	1.54	168.6	1.20	1.91	123.9	1.30	2.41	92.9	1.39	2.99	82.4	1.44	3.27	67.5	1.55	3.72	53.9	1.67	4.31
280	489.0	0.99	0.85	336.9	1.05	1.17	236.7	1.14	1.54	181.3	1.20	1.91	133.3	1.30	2.41	99.9	1.39	3.00	88.6	1.44	3.27	72.6	1.55	3.72	58.0	1.67	4.31
300	522.6	0.99	0.86	360.2	1.05	1.17	253.2	1.15	1.54	193.9	1.20	1.91	142.6	1.30	2.42	106.9	1.39	3.00	94.9	1.44	3.27	77.7	1.55	3.73	62.0	1.67	4.33

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 4.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5			V_1 = 4.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	33.1	0.87	0.77	23.6	0.93	1.01	16.3	1.00	1.36	12.1	1.08	1.69	9.2	1.15	2.08
20	44.0	0.87	0.77	31.4	0.93	1.01	21.7	1.00	1.37	16.1	1.08	1.70	12.3	1.16	2.08
25	54.9	0.87	0.77	39.1	0.93	1.02	27.1	1.00	1.37	20.1	1.08	1.71	15.3	1.15	2.11
30	65.7	0.87	0.78	46.8	0.93	1.02	32.4	0.99	1.38	24.0	1.07	1.73	18.3	1.14	2.13
35	76.4	0.87	0.78	54.5	0.93	1.02	37.7	0.99	1.39	27.9	1.07	1.74	21.3	1.14	2.14
40	87.1	0.87	0.78	62.1	0.93	1.03	43.0	0.99	1.39	31.9	1.07	1.74	24.3	1.14	2.15
45	97.7	0.87	0.78	69.7	0.93	1.03	48.3	0.99	1.39	35.8	1.07	1.74	27.2	1.13	2.17
50	108.3	0.87	0.78	77.3	0.93	1.03	53.5	0.99	1.40	39.7	1.07	1.75	30.2	1.13	2.17
55	118.8	0.87	0.78	84.7	0.93	1.04	58.7	0.99	1.40	43.6	1.07	1.75	33.2	1.13	2.17
60	129.2	0.87	0.79	92.2	0.93	1.04	63.9	0.99	1.40	47.4	1.07	1.76	36.1	1.13	2.18
65	139.6	0.87	0.79	99.6	0.93	1.04	69.1	0.99	1.41	51.3	1.07	1.76	39.0	1.13	2.19
70	149.9	0.88	0.79	107.0	0.93	1.04	74.2	0.99	1.41	55.1	1.07	1.77	42.0	1.13	2.19
75	160.2	0.88	0.79	114.3	0.93	1.05	79.3	0.99	1.42	58.9	1.07	1.77	44.9	1.13	2.19
80	170.4	0.88	0.79	121.6	0.93	1.05	84.4	0.99	1.42	62.7	1.07	1.77	47.8	1.13	2.20
90	191.1	0.88	0.80	136.5	0.93	1.05	94.8	0.99	1.42	70.4	1.07	1.78	53.7	1.13	2.20
100	211.8	0.88	0.80	151.2	0.93	1.05	105.1	0.99	1.42	78.1	1.07	1.78	59.6	1.13	2.20
110	232.3	0.88	0.80	165.9	0.93	1.06	115.3	0.99	1.43	85.8	1.07	1.78	65.4	1.13	2.21
120	252.7	0.88	0.80	180.5	0.93	1.06	125.5	0.99	1.43	93.4	1.07	1.78	71.2	1.13	2.22
130	273.0	0.88	0.80	195.1	0.93	1.06	135.6	0.99	1.43	101.0	1.07	1.79	77.0	1.13	2.22
140	293.2	0.88	0.80	209.5	0.93	1.06	145.7	0.99	1.44	108.5	1.07	1.79	82.8	1.13	2.22
150	313.3	0.88	0.81	223.9	0.93	1.07	155.8	0.99	1.44	116.0	1.07	1.80	88.6	1.13	2.22
160	333.2	0.88	0.81	238.2	0.93	1.07	165.8	1.00	1.44	123.5	1.07	1.80	94.3	1.13	2.23
170	353.1	0.88	0.81	252.4	0.93	1.07	175.8	1.00	1.44	131.0	1.07	1.80	100.0	1.13	2.23
180	372.8	0.88	0.81	266.5	0.93	1.07	185.7	1.00	1.45	138.4	1.07	1.80	105.7	1.13	2.24
190	392.4	0.88	0.81	280.6	0.93	1.08	195.6	1.00	1.45	145.8	1.07	1.81	111.4	1.13	2.24
200	411.9	0.88	0.82	294.6	0.93	1.08	205.4	1.00	1.45	153.2	1.07	1.81	117.1	1.14	2.24
220	451.9	0.88	0.82	323.2	0.93	1.08	225.4	1.00	1.46	168.2	1.07	1.81	128.6	1.14	2.24
240	491.5	0.88	0.82	351.6	0.93	1.09	245.3	1.00	1.46	183.2	1.07	1.81	140.0	1.14	2.25
260	531.0	0.88	0.82	379.9	0.93	1.09	265.2	1.00	1.46	198.0	1.07	1.82	151.5	1.14	2.25
280	570.3	0.88	0.82	408.0	0.93	1.09	284.9	1.00	1.47	212.9	1.08	1.82	162.8	1.14	2.25
300	609.3	0.88	0.83	436.0	0.93	1.09	304.6	1.00	1.47	227.6	1.08	1.83	174.2	1.14	2.25

Q cfs	V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	7.4	1.27	2.34	5.7	1.43	2.69						
20	9.7	1.23	2.48	7.4	1.35	2.94	6.4	1.47	3.12			
25	12.1	1.22	2.50	9.2	1.33	3.01	7.9	1.43	3.26	6.5	1.56	3.62
30	14.4	1.20	2.57	11.0	1.32	3.05	9.3	1.38	3.46	7.7	1.52	3.78
35	16.8	1.20	2.57	12.7	1.30	3.14	10.9	1.39	3.42	8.9	1.49	3.90
40	19.2	1.21	2.56	14.5	1.30	3.15	12.4	1.38	3.47	10.2	1.50	3.87
45	21.5	1.20	2.59	16.3	1.30	3.16	13.9	1.37	3.51	11.4	1.48	3.95
50	23.9	1.20	2.58	18.1	1.30	3.16	15.4	1.36	3.54	12.6	1.46	4.01
55	26.2	1.20	2.60	19.8	1.29	3.21	16.9	1.36	3.56	13.8	1.45	4.06
60	28.5	1.19	2.62	21.6	1.29	3.20	18.4	1.36	3.57	15.1	1.46	4.02
65	30.9	1.20	2.61	23.4	1.29	3.19	19.9	1.35	3.58	16.3	1.46	4.06
70	33.2	1.20	2.62	25.1	1.28	3.23	21.4	1.35	3.59	17.5	1.45	4.09
75	35.5	1.20	2.62	26.9	1.29	3.22	22.9	1.35	3.60	18.7	1.45	4.12
80	37.8	1.20	2.63	28.6	1.28	3.24	24.4	1.35	3.60	20.0	1.46	4.08
90	42.4	1.19	2.65	32.1	1.28	3.26	27.4	1.35	3.62	22.4	1.45	4.13
100	47.1	1.20	2.64	35.7	1.29	3.24	30.4	1.35	3.63	24.9	1.45	4.12
110	51.7	1.19	2.65	39.2	1.29	3.25	33.4	1.35	3.63	27.3	1.44	4.16
120	56.3	1.19	2.66	42.7	1.28	3.26	36.3	1.34	3.66	29.8	1.45	4.14
130	60.9	1.19	2.66	46.2	1.29	3.26	39.3	1.34	3.66	32.2	1.44	4.16
140	65.5	1.20	2.66	49.6	1.28	3.28	42.3	1.35	3.66	34.6	1.44	4.18
150	70.1	1.20	2.66	53.1	1.28	3.28	45.3	1.35	3.66	37.1	1.45	4.17
160	74.6	1.20	2.67	56.6	1.28	3.28	48.2	1.35	3.67	39.5	1.44	4.18
170	79.2	1.20	2.67	60.0	1.28	3.29	51.2	1.35	3.67	41.9	1.44	4.19
180	83.7	1.20	2.68	63.5	1.28	3.29	54.1	1.35	3.68	44.3	1.44	4.20
190	88.2	1.20	2.68	66.9	1.28	3.30	57.0	1.34	3.69	46.7	1.44	4.21
200	92.7	1.20	2.68	70.3	1.28	3.30	60.0	1.35	3.68	49.1	1.44	4.21
220	101.9	1.20	2.68	77.2	1.28	3.31	65.9	1.35	3.69	54.0	1.44	4.21
240	110.9	1.20	2.69	84.1	1.28	3.32	71.8	1.35	3.70	58.8	1.44	4.22
260	120.0	1.20	2.69	91.0	1.28	3.32	77.7	1.35	3.70	63.7	1.44	4.21
280	129.0	1.20	2.70	97.9	1.28	3.32	83.5	1.35	3.71	68.5	1.44	4.22
300	138.1	1.20	2.69	104.8	1.29	3.32	89.4	1.35	3.71	73.3	1.44	4.23

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 5.0 Percent

Q cfs	V_1 = 2.0 T	D	V_2	V_1 = 2.5 T	D	V_2	V_1 = 3.0 T	D	V_2	V_1 = 3.5 T	D	V_2	V_1 = 4.0 T	D	V_2
15	34.8	0.80	0.79	25.2	0.86	1.02	17.7	0.92	1.36	14.3	0.96	1.61	10.6	1.04	2.00
20	46.3	0.80	0.79	33.5	0.86	1.02	23.5	0.92	1.37	19.0	0.96	1.62	14.1	1.04	2.02
25	57.7	0.80	0.80	41.7	0.86	1.03	29.3	0.92	1.38	23.7	0.96	1.63	17.5	1.03	2.06
30	69.0	0.80	0.80	49.9	0.86	1.04	35.0	0.91	1.39	28.3	0.95	1.65	21.0	1.03	2.06
35	80.3	0.80	0.80	58.1	0.86	1.04	40.8	0.91	1.39	33.0	0.95	1.65	24.4	1.02	2.08
40	91.5	0.81	0.80	66.2	0.86	1.04	46.5	0.91	1.40	37.6	0.95	1.66	27.8	1.02	2.09
45	102.6	0.81	0.81	74.2	0.86	1.05	52.2	0.91	1.40	42.2	0.95	1.66	31.3	1.03	2.08
50	113.7	0.81	0.81	82.3	0.86	1.05	57.9	0.92	1.40	46.8	0.95	1.66	34.7	1.03	2.08
55	124.7	0.81	0.81	90.2	0.86	1.05	63.5	0.91	1.41	51.4	0.96	1.66	38.0	1.02	2.11
60	135.7	0.81	0.81	98.2	0.86	1.05	69.1	0.91	1.41	56.0	0.96	1.66	41.4	1.02	2.11
65	146.5	0.81	0.81	106.1	0.86	1.05	74.7	0.92	1.41	60.5	0.96	1.67	44.8	1.02	2.10
70	157.3	0.81	0.82	113.9	0.86	1.06	80.2	0.91	1.42	65.0	0.96	1.67	48.1	1.02	2.11
75	168.1	0.81	0.82	121.7	0.86	1.06	85.8	0.92	1.42	69.5	0.96	1.67	51.4	1.02	2.12
80	178.8	0.81	0.82	129.4	0.86	1.06	91.3	0.92	1.42	74.0	0.96	1.67	54.8	1.02	2.12
90	200.5	0.81	0.82	145.2	0.86	1.07	102.4	0.92	1.43	83.0	0.96	1.68	61.5	1.02	2.12
100	222.2	0.81	0.82	160.9	0.86	1.07	113.5	0.92	1.43	92.1	0.96	1.68	68.2	1.02	2.13
110	243.7	0.81	0.82	176.5	0.86	1.07	124.6	0.92	1.43	101.0	0.96	1.69	74.8	1.02	2.14
120	265.0	0.81	0.83	192.0	0.86	1.07	135.6	0.92	1.43	110.0	0.96	1.69	81.4	1.02	2.15
130	286.3	0.81	0.83	207.5	0.86	1.08	146.6	0.92	1.43	118.9	0.96	1.69	88.1	1.02	2.14
140	307.4	0.81	0.83	222.8	0.86	1.08	157.5	0.92	1.44	127.8	0.96	1.69	94.6	1.02	2.15
150	328.4	0.81	0.83	238.1	0.87	1.08	168.3	0.92	1.44	136.[illegible]	0.96	1.7[illegible]	101.2	1.02	2.15
160	349.3	0.81	0.83	253.2	0.86	1.08	179.1	0.92	1.44	145.4	0.96	1.70	107.7	1.02	2.16
170	370.0	0.81	0.84	268.3	0.87	1.09	189.9	0.92	1.45	154.1	0.96	1.70	114.2	1.02	2.16
180	390.7	0.82	0.84	283.3	0.87	1.09	200.6	0.92	1.45	162.9	0.96	1.70	120.7	1.02	2.17
190	411.2	0.82	0.84	298.2	0.87	1.09	211.2	0.92	1.45	171.5	0.96	1.71	127.1	1.02	2.17
200	431.6	0.82	0.84	313.0	0.87	1.09	221.8	0.92	1.4[illegible]	180.2	0.96	1.71	133.5	1.02	2.18
220	473.3	0.82	0.84	343.4	0.87	1.10	243.4	0.92	1.46	197.8	0.97	1.71	146.6	1.02	2.18
240	514.8	0.82	0.84	373.6	0.87	1.10	264.9	0.92	1.46	215.3	0.97	1.72	159.6	1.02	2.18
260	556.1	0.82	0.85	403.6	0.87	1.10	286.3	0.92	1.46	232.7	0.97	1.72	172.6	1.03	2.19
280	597.1	0.82	0.85	433.5	0.87	1.10	307.6	0.92	1.47	250.1	0.97	1.72	185.5	1.03	2.19
300	638.0	0.82	0.85	463.1	0.87	1.11	328.7	0.92	1.47	267.4	0.97	1.73	198.4	1.03	2.19

Q cfs	V_1 = 4.5 T	D	V_2	V_1 = 5.0 T	D	V_2	V_1 = 5.5 T	D	V_2	V_1 = 6.0 T	D	V_2
15	8.4	1.12	2.34	6.7	1.23	2.67	5.4	1.36	3.00			
20	11.1	1.10	2.41	8.8	1.19	2.81	7.0	1.28	3.29	6.1	1.40	3.44
25	13.8	1.09	2.46	10.9	1.17	2.90	8.7	1.26	3.37	7.5	1.35	3.64
30	16.6	1.10	2.44	13.0	1.15	2.96	10.4	1.25	3.41	8.9	1.32	3.78
35	19.3	1.09	2.46	15.2	1.16	2.94	12.1	1.24	3.45	10.3	1.30	3.87
40	22.0	1.09	2.47	17.3	1.15	2.97	13.8	1.24	3.47	11.8	1.30	3.85
45	24.7	1.09	2.48	19.4	1.15	2.99	15.4	1.22	3.55	13.2	1.29	3.91
50	27.3	1.08	2.51	21.5	1.15	3.01	17.1	1.22	3.55	14.7	1.30	3.88
55	30.0	1.08	2.51	23.7	1.15	2.98	18.8	1.22	3.55	16.1	1.29	3.93
60	32.7	1.08	2.51	25.8	1.15	3.00	20.5	1.22	3.55	17.5	1.28	3.97
65	35.3	1.08	2.53	27.9	1.15	3.00	22.1	1.22	3.59	18.9	1.28	4.00
70	38.0	1.08	2.53	30.0	1.15	3.01	23.8	1.22	3.58	20.4	1.29	3.96
75	40.6	1.08	2.54	32.0	1.15	3.04	25.4	1.21	3.62	21.8	1.28	3.98
80	43.3	1.09	2.53	34.1	1.15	3.04	27.1	1.22	3.61	23.2	1.28	4.00
90	48.6	1.08	2.54	38.3	1.15	3.05	30.4	1.21	3.63	26.1	1.28	4.00
100	53.9	1.08	2.54	42.5	1.15	3.05	33.8	1.22	3.61	28.9	1.28	4.03
110	59.2	1.09	2.55	46.7	1.15	3.05	37.1	1.22	3.63	31.8	1.28	4.02
120	64.4	1.08	2.56	50.8	1.15	3.07	40.4	1.21	3.64	34.6	1.28	4.04
130	69.7	1.09	2.56	55.0	1.15	3.06	43.7	1.21	3.65	37.5	1.28	4.03
140	74.9	1.08	2.57	59.1	1.15	3.07	47.0	1.21	3.65	40.3	1.28	4.04
150	80.1	1.08	2.57	63.2	1.15	3.08	50.2	1.21	3.67	43.1	1.28	4.05
160	85.3	1.09	2.57	67.3	1.15	3.09	53.5	1.21	3.67	45.9	1.28	4.06
170	90.4	1.08	2.58	71.4	1.15	3.09	56.8	1.21	3.67	48.7	1.28	4.07
180	95.6	1.09	2.58	75.5	1.15	3.09	60.0	1.21	3.69	51.5	1.28	4.07
190	100.7	1.08	2.59	79.6	1.15	3.09	63.3	1.21	3.68	54.3	1.28	4.07
200	105.8	1.09	2.59	83.6	1.15	3.10	66.5	1.21	3.69	57.1	1.28	4.08
220	116.2	1.09	2.60	91.9	1.15	3.10	73.1	1.22	3.69	62.7	1.28	4.09
240	126.5	1.09	2.60	100.1	1.15	3.10	79.6	1.21	3.70	68.3	1.28	4.09
260	136.8	1.09	2.61	108.2	1.15	3.11	86.1	1.21	3.71	73.9	1.28	4.10
280	147.1	1.09	2.61	116.4	1.15	3.11	92.6	1.21	3.71	79.5	1.28	4.10
300	157.3	1.09	2.61	124.5	1.15	3.12	99.1	1.22	3.71	85.1	1.28	4.10

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 6.0 Percent

Q cfs	V_1 = 2.0 T	D	V_2	V_1 = 2.5 T	D	V_2	V_1 = 3.0 T	D	V_2
15	40.5	0.72	0.76	26.9	0.81	1.02	19.6	0.85	1.34
20	53.9	0.72	0.76	35.7	0.81	1.03	26.1	0.85	1.34
25	67.1	0.72	0.76	44.5	0.81	1.03	32.5	0.85	1.35
30	80.3	0.72	0.76	53.2	0.80	1.04	38.9	0.85	1.35
35	93.4	0.72	0.76	61.9	0.81	1.04	45.3	0.85	1.35
40	106.4	0.73	0.77	70.6	0.81	1.04	51.6	0.85	1.36
45	119.3	0.73	0.77	79.2	0.81	1.04	57.9	0.85	1.36
50	132.1	0.73	0.77	87.7	0.81	1.05	64.1	0.84	1.37
55	144.9	0.73	0.77	96.2	0.81	1.05	70.4	0.85	1.37
60	157.5	0.73	0.77	104.6	0.81	1.05	76.5	0.84	1.38
65	170.1	0.73	0.78	113.0	0.81	1.06	82.7	0.85	1.38
70	182.6	0.73	0.78	121.3	0.81	1.06	88.8	0.85	1.38
75	195.1	0.73	0.78	129.6	0.81	1.06	94.9	0.85	1.39
80	207.4	0.73	0.78	137.8	0.81	1.06	100.9	0.85	1.39
90	232.6	0.73	0.78	154.5	1.81	1.07	113.2	0.85	1.40
100	257.7	0.73	0.78	171.2	0.81	1.07	125.5	0.85	1.40
110	282.6	0.74	0.78	187.8	0.81	1.07	137.7	0.85	1.40
120	307.3	0.74	0.79	204.2	0.81	1.08	149.8	0.85	1.40
130	331.9	0.74	0.79	220.6	0.81	1.08	161.9	0.85	1.41
140	356.3	0.74	0.79	236.8	0.81	1.08	173.9	0.85	1.41
150	380.5	0.74	0.79	253.0	0.81	1.09	185.8	0.85	1.41
160	404.6	0.74	0.79	269.0	0.81	1.09	197.7	0.85	1.42
170	428.6	0.74	0.79	285.0	0.81	1.09	209.5	0.85	1.42
180	452.4	0.74	0.79	300.8	0.81	1.09	221.3	0.85	1.42
190	476.1	0.74	0.80	316.6	0.81	1.10	233.0	0.85	1.42
200	499.6	0.74	0.80	332.3	0.81	1.10	244.6	0.85	1.43
220	547.7	0.74	0.80	364.5	0.81	1.10	268.4	0.85	1.43
240	595.6	0.74	0.80	396.5	0.81	1.11	292.1	0.85	1.43
260	643.2	0.74	0.80	428.3	0.81	1.11	315.7	0.85	1.43
280	690.5	0.75	0.81	459.9	0.81	1.11	339.1	0.85	1.44
300	737.5	0.75	0.81	491.4	0.81	1.11	362.4	0.85	1.44

Q cfs	V_1 = 3.5 T	D	V_2	V_1 = 4.0 T	D	V_2	V_1 = 4.5 T	D	V_2
15	14.8	0.90	1.66	11.7	0.96	1.97	9.4	1.02	2.31
20	19.6	0.89	1.69	15.6	0.96	1.97	12.5	1.01	2.33
25	24.5	0.90	1.69	19.4	0.95	2.00	15.5	1.00	2.39
30	29.3	0.89	1.70	23.3	0.96	1.99	18.6	1.00	2.39
35	34.1	0.89	1.70	27.1	0.96	2.00	21.6	0.99	2.42
40	38.9	0.89	1.71	30.9	0.95	2.01	24.7	1.00	2.41
45	43.7	0.90	1.71	34.6	0.95	2.03	27.7	1.00	2.42
50	48.4	0.89	1.71	38.4	0.95	2.03	30.7	0.99	2.43
55	53.1	0.89	1.72	42.2	0.95	2.03	33.7	0.99	2.44
60	57.8	0.89	1.72	45.9	0.95	2.04	36.7	1.00	2.44
65	62.5	0.90	1.72	49.6	0.95	2.04	39.7	1.00	2.44
70	67.2	0.90	1.72	53.3	0.95	2.05	42.7	1.00	2.44
75	71.8	0.90	1.73	57.0	0.95	2.05	45.6	1.00	2.46
80	76.4	0.90	1.73	60.6	0.95	2.06	48.6	1.00	2.45
90	85.8	0.90	1.73	68.1	0.95	2.06	54.6	1.00	2.45
100	95.1	0.90	1.74	75.5	0.95	2.06	60.5	1.00	2.46
110	104.4	0.90	1.74	82.8	0.95	2.07	66.4	1.00	2.47
120	113.6	0.90	1.74	90.2	0.95	2.07	72.3	1.00	2.47
130	122.8	0.90	1.75	97.5	0.95	2.08	78.2	1.00	2.48
140	131.9	0.90	1.75	104.7	0.95	2.09	84.0	1.00	2.48
150	141.0	0.90	1.75	112.0	0.96	2.09	89.9	1.00	2.48
160	150.1	0.90	1.76	119.2	0.96	2.09	95.7	1.00	2.49
170	159.1	0.90	1.76	126.4	0.96	2.09	101.5	1.00	2.49
180	168.1	0.90	1.76	133.5	0.96	2.10	107.2	1.00	2.50
190	177.0	0.90	1.77	140.6	0.96	2.10	113.0	1.00	2.50
200	185.9	0.90	1.77	147.7	0.96	2.11	118.7	1.00	2.50
220	204.1	0.91	1.77	162.1	0.96	2.11	130.3	1.00	2.51
240	222.1	0.91	1.78	176.5	0.96	2.11	141.9	1.00	2.51
260	240.1	0.91	1.78	190.7	0.96	2.12	153.4	1.00	2.52
280	258.0	0.91	1.78	205.0	0.96	2.12	164.9	1.00	2.52
300	275.8	0.91	1.78	219.1	0.96	2.13	176.3	1.00	2.52

Q cfs	V_1 = 5.0 T	D	V_2	V_1 = 5.5 T	D	V_2	V_1 = 6.0 T	D	V_2
15	7.6	1.09	2.67	6.1	1.18	3.05	5.0	1.32	3.33
20	10.1	1.08	2.71	8.0	1.14	3.23	6.5	1.24	3.63
25	12.5	1.06	2.80	10.0	1.14	3.24	8.1	1.23	3.69
30	15.0	1.06	2.80	11.9	1.12	3.32	9.6	1.20	3.84
35	17.4	1.05	2.84	13.9	1.13	3.31	11.2	1.20	3.84
40	19.9	1.05	2.83	15.8	1.12	3.36	12.7	1.19	3.93
45	22.3	1.05	2.86	17.7	1.11	3.40	14.3	1.19	3.92
50	24.7	1.05	2.87	19.7	1.12	3.38	15.8	1.18	3.98
55	27.1	1.04	2.89	21.6	1.11	3.40	17.4	1.18	3.96
60	29.6	1.05	2.87	23.5	1.11	3.42	18.9	1.18	4.01
65	32.0	1.05	2.88	25.4	1.11	3.43	20.5	1.18	3.98
70	34.4	1.05	2.88	27.4	1.11	3.41	22.0	1.18	4.01
75	36.7	1.04	2.91	29.3	1.11	3.42	23.6	1.18	3.99
80	39.1	1.05	2.91	31.2	1.11	3.42	25.1	1.18	4.02
90	43.9	1.05	2.92	35.0	1.11	3.44	28.2	1.18	4.02
100	48.7	1.05	2.92	38.8	1.11	3.46	31.3	1.18	4.03
110	53.5	1.05	2.92	42.6	1.11	3.47	34.4	1.18	4.03
120	58.3	1.05	2.92	46.4	1.11	3.47	37.4	1.18	4.06
130	63.0	1.05	2.93	50.2	1.11	3.48	40.5	1.18	4.05
140	67.7	1.05	2.94	54.0	1.11	3.48	43.5	1.18	4.07
150	72.5	1.05	2.93	57.8	1.11	3.48	46.6	1.18	4.06
160	77.2	1.05	2.94	61.5	1.11	3.49	49.6	1.18	4.08
170	81.8	1.05	2.95	65.3	1.11	3.49	52.7	1.18	4.07
180	86.5	1.05	2.95	69.0	1.11	3.49	55.7	1.18	4.08
190	91.1	1.05	2.96	72.7	1.11	3.50	58.7	1.18	4.08
200	95.8	1.05	2.96	76.4	1.11	3.51	61.7	1.18	4.09
220	105.2	1.05	2.96	83.9	1.11	3.51	67.8	1.18	4.09
240	114.5	1.05	2.97	91.4	1.11	3.52	73.8	1.18	4.11
260	123.9	1.05	2.97	98.9	1.11	3.52	79.9	1.18	4.10
280	133.2	1.05	2.97	106.3	1.11	3.53	85.9	1.18	4.11
300	142.4	1.05	2.98	113.7	1.11	3.53	91.9	1.18	4.12

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 8.0 Percent

Q cfs	V_1 = 2.0			V_1 = 2.5			V_1 = 3.0			V_1 = 3.5		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	43.1	0.64	0.80	31.6	0.71	0.98	22.2	0.76	1.31	18.0	0.79	1.56
20	57.3	0.64	0.80	42.0	0.71	0.99	29.5	0.76	1.32	24.0	0.79	1.56
25	71.4	0.65	0.80	52.3	0.71	0.99	36.7	0.76	1.33	29.9	0.79	1.57
30	85.4	0.65	0.80	62.6	0.71	0.99	43.9	0.76	1.33	35.8	0.79	1.57
35	99.3	0.65	0.80	72.8	0.72	0.99	51.1	0.76	1.34	41.6	0.79	1.58
40	113.1	0.65	0.81	82.9	0.72	1.00	58.2	0.76	1.34	47.4	0.79	1.59
45	126.8	0.65	0.81	93.0	0.72	1.00	65.3	0.76	1.34	53.2	0.79	1.59
50	140.4	0.65	0.81	102.9	0.72	1.01	72.3	0.76	1.35	59.0	0.79	1.59
55	153.9	0.65	0.81	112.8	0.72	1.01	79.3	0.76	1.35	64.7	0.79	1.60
60	167.3	0.65	0.81	122.7	0.72	1.01	86.2	0.76	1.36	70.4	0.79	1.60
65	180.6	0.65	0.82	132.4	0.72	1.01	93.1	0.76	1.36	76.0	0.79	1.61
70	193.9	0.65	0.82	142.2	0.72	1.01	100.0	0.76	1.37	81.7	0.79	1.61
75	207.0	0.65	0.82	151.8	0.72	1.02	106.8	0.76	1.37	87.2	0.79	1.62
80	220.1	0.66	0.82	161.4	0.72	1.02	113.6	0.76	1.37	92.8	0.79	1.62
90	246.8	0.66	0.82	180.9	0.72	1.02	127.4	0.76	1.38	104.1	0.79	1.62
100	273.3	0.66	0.82	200.3	0.72	1.03	141.1	0.76	1.38	115.4	0.79	1.62
110	299.6	0.66	0.83	219.6	0.72	1.03	154.8	0.76	1.38	126.5	0.79	1.63
120	325.7	0.66	0.83	238.8	0.72	1.03	168.4	0.76	1.39	137.7	0.79	1.63
130	351.7	0.66	0.83	257.9	0.72	1.04	181.9	0.76	1.39	148.7	0.79	1.64
140	377.5	0.66	0.83	276.8	0.72	1.04	195.3	0.76	1.39	159.7	0.79	1.64
150	403.1	0.66	0.83	295.6	0.72	1.04	208.6	0.76	1.40	170.7	0.80	1.64
160	428.5	0.66	0.83	314.2	0.72	1.04	221.9	0.76	1.40	181.5	0.79	1.65
170	453.8	0.66	0.84	332.8	0.72	1.05	235.1	0.76	1.40	192.4	0.80	1.65
180	478.9	0.66	0.84	351.2	0.72	1.05	248.2	0.76	1.41	203.1	0.80	1.65
190	503.9	0.66	0.84	369.5	0.72	1.05	261.2	0.77	1.41	213.8	0.80	1.66
200	528.5	0.67	0.84	387.7	0.73	1.05	274.1	0.77	1.42	224.4	0.80	1.66
220	579.5	0.67	0.84	425.1	0.73	1.06	300.7	0.77	1.42	246.2	0.80	1.66
240	630.1	0.67	0.84	462.2	0.73	1.06	327.0	0.77	1.42	267.9	0.80	1.67
260	680.4	0.67	0.85	499.1	0.73	1.06	353.3	0.77	1.42	289.4	0.80	1.67
280	730.4	0.67	0.85	535.6	0.73	1.07	379.3	0.77	1.43	310.8	0.80	1.68
300	780.0	0.67	0.85	572.1	0.73	1.07	405.2	0.77	1.43	332.1	0.80	1.68

Q cfs	V_1 = 4.0			V_1 = 4.5			V_1 = 5.0			V_1 = 5.5			V_1 = 6.0		
	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2	T	D	V_2
15	13.7	0.84	1.92	11.0	0.89	2.26	9.2	0.95	2.54	7.4	0.99	3.00	6.2	1.09	3.26
20	18.2	0.84	1.94	14.7	0.89	2.25	12.2	0.93	2.59	9.8	0.98	3.08	8.1	1.04	3.49
25	22.7	0.84	1.95	18.3	0.89	2.28	15.2	0.93	2.62	12.2	0.97	3.12	10.1	1.04	3.53
30	27.2	0.84	1.95	21.9	0.89	2.29	18.1	0.92	2.67	14.6	0.97	3.15	12.1	1.03	3.55
35	31.7	0.84	1.95	25.5	0.89	2.30	21.1	0.92	2.67	17.0	0.96	3.16	14.0	1.02	3.64
40	36.1	0.84	1.96	29.0	0.88	2.32	24.1	0.92	2.67	19.4	0.96	3.17	16.0	1.02	3.63
45	40.5	0.84	1.97	32.6	0.88	2.32	27.0	0.92	2.69	21.8	0.97	3.17	18.0	1.02	3.62
50	44.9	0.84	1.97	36.1	0.88	2.33	30.0	0.92	2.68	24.2	0.97	3.17	19.9	1.02	3.67
55	49.3	0.84	1.97	39.6	0.88	2.34	32.9	0.92	2.70	26.5	0.96	3.20	21.9	1.02	3.65
60	53.7	0.84	1.97	43.1	0.88	2.34	35.8	0.92	2.70	28.9	0.97	3.19	23.8	1.02	3.69
65	58.0	0.84	1.98	46.6	0.88	2.35	38.7	0.92	2.71	31.3	0.97	3.18	25.7	1.01	3.71
70	62.3	0.84	1.98	50.1	0.88	2.35	41.6	0.92	2.71	33.6	0.97	3.20	27.7	1.02	3.69
75	66.6	0.84	1.99	53.5	0.88	2.36	44.5	0.92	2.72	35.9	0.96	3.22	29.6	1.02	3.71
80	70.9	0.84	1.99	56.9	0.88	2.37	47.3	0.92	2.73	38.2	0.96	3.23	31.5	1.01	3.72
90	79.5	0.84	2.00	63.9	0.88	2.37	53.1	0.92	2.74	42.9	0.96	3.23	35.4	1.02	3.72
100	88.1	0.84	2.00	70.8	0.88	2.38	58.9	0.92	2.74	47.6	0.97	3.24	39.2	1.01	3.75
110	96.7	0.84	2.01	77.7	0.88	2.38	64.7	0.92	2.74	52.3	0.97	3.23	43.1	1.02	3.74
120	105.3	0.84	2.01	84.6	0.88	2.39	70.4	0.92	2.75	56.9	0.97	3.25	46.9	1.01	3.75
130	113.8	0.84	2.01	91.4	0.88	2.40	76.1	0.92	2.75	61.6	0.97	3.24	50.7	1.01	3.76
140	122.2	0.84	2.02	98.2	0.88	2.40	81.8	0.92	2.76	66.2	0.97	3.25	54.5	1.01	3.77
150	130.6	0.84	2.02	105.0	0.88	2.40	87.4	0.92	2.77	70.8	0.97	3.25	58.3	1.01	3.78
160	139.0	0.85	2.02	111.7	0.88	2.41	93.1	0.92	2.77	75.3	0.97	3.27	62.1	1.01	3.78
170	147.3	0.85	2.03	118.4	0.88	2.42	98.7	0.92	2.77	79.9	0.97	3.27	65.9	1.02	3.78
180	155.6	0.85	2.03	125.1	0.88	2.42	104.3	0.93	2.78	84.4	0.97	3.28	69.6	1.02	3.79
190	163.9	0.85	2.03	131.8	0.89	2.42	109.8	0.92	2.79	89.0	0.97	3.27	73.4	1.02	3.79
200	172.1	0.85	2.04	138.4	0.89	2.43	115.3	0.92	2.79	93.5	0.97	3.28	77.1	1.02	3.80
220	188.8	0.85	2.04	151.8	0.88	2.44	126.6	0.93	2.80	102.6	0.97	3.29	84.7	1.02	3.80
240	205.5	0.85	2.05	165.2	0.89	2.44	137.8	0.93	2.80	111.8	0.97	3.29	92.2	1.02	3.81
260	222.1	0.85	2.05	178.6	0.89	2.45	149.0	0.93	2.80	120.8	0.97	3.30	99.7	1.02	3.82
280	238.6	0.85	2.05	191.9	0.89	2.45	160.1	0.93	2.81	129.9	0.97	3.30	107.2	1.02	3.82
300	255.0	0.85	2.06	205.1	0.89	2.46	171.2	0.93	2.81	138.9	0.97	3.31	114.7	1.02	3.82

Table 36 (Continued)

DESIGN TABLES FOR PARABOLIC GRASS-LINED CHANNELS

V_1 for RETARDANCE "D". Top Width (T), Depth (D) and V_2 for RETARDANCE "B".

Grade 10.0 Percent

Q cfs	V_1 = 2.0 T	D	V_2	V_1 = 2.5 T	D	V_2	V_1 = 3.0 T	D	V_2	V_1 = 3.5 T	D	V_2	V_1 = 4.0 T	D	V_2
15	51.4	0.56	0.77	38.3	0.63	0.92	27.2	0.69	1.18	19.6	0.73	1.56	15.7	0.76	1.86
20	68.2	0.55	0.78	50.9	0.63	0.92	36.2	0.69	1.18	26.1	0.73	1.56	20.9	0.76	1.87
25	85.0	0.56	0.78	63.4	0.63	0.92	45.1	0.69	1.19	32.5	0.73	1.57	26.1	0.76	1.87
30	101.6	0.56	0.78	75.8	0.63	0.92	53.9	0.69	1.20	38.8	0.72	1.58	31.2	0.76	1.88
35	118.1	0.56	0.78	88.1	0.63	0.93	62.7	0.69	1.20	45.2	0.73	1.58	36.3	0.76	1.88
40	134.4	0.56	0.79	100.3	0.64	0.93	71.3	0.69	1.21	51.5	0.73	1.59	41.3	0.76	1.90
45	150.7	0.56	0.79	112.5	0.64	0.93	80.0	0.69	1.21	57.7	0.72	1.60	46.4	0.76	1.90
50	166.8	0.56	0.79	124.5	0.64	0.93	88.5	0.69	1.21	63.9	0.72	1.60	51.3	0.76	1.91
55	182.8	0.56	0.79	136.4	0.64	0.93	97.1	0.69	1.21	70.1	0.73	1.60	56.3	0.76	1.92
60	198.6	0.56	0.79	148.2	0.64	0.94	105.5	0.69	1.22	76.2	0.72	1.61	61.2	0.76	1.92
65	214.3	0.57	0.79	160.0	0.64	0.94	113.9	0.69	1.22	82.3	0.73	1.62	66.2	0.76	1.92
70	229.9	0.57	0.79	171.6	0.64	0.94	122.2	0.69	1.23	88.4	0.73	1.62	71.0	0.76	1.93
75	245.4	0.57	0.80	183.2	0.64	0.94	130.5	0.69	1.23	94.4	0.73	1.62	75.9	0.76	1.94
80	260.7	0.57	0.80	194.6	0.64	0.95	138.6	0.69	1.24	100.3	0.73	1.63	80.7	0.76	1.94
90	292.1	0.57	0.80	218.1	0.64	0.95	155.4	0.69	1.24	112.5	0.73	1.64	90.5	0.76	1.95
100	323.3	0.57	0.80	241.5	0.64	0.95	172.1	0.69	1.24	124.6	0.73	1.64	100.3	0.76	1.95
110	354.3	0.57	0.80	264.6	0.64	0.96	188.6	0.69	1.25	136.7	0.73	1.64	110.0	0.76	1.96
120	385.0	0.57	0.80	287.6	0.64	0.96	205.0	0.69	1.25	148.7	0.73	1.65	119.6	0.76	1.97
130	415.5	0.57	0.81	310.3	0.65	0.96	221.3	0.69	1.26	160.6	0.73	1.65	129.3	0.76	1.97
140	445.7	0.57	0.81	333.0	0.65	0.96	237.5	0.69	1.26	172.5	0.73	1.65	138.8	0.76	1.97
150	475.7	0.58	0.81	355.4	0.65	0.97	253.6	0.69	1.26	184.2	0.73	1.66	148.4	0.76	1.97
160	505.5	0.58	0.81	377.7	0.65	0.97	269.5	0.69	1.27	195.9	0.73	1.66	157.8	0.76	1.98
170	535.0	0.58	0.81	399.7	0.65	0.97	285.3	0.69	1.27	207.6	0.73	1.66	167.2	0.76	1.98
180	564.3	0.58	0.81	421.7	0.65	0.97	301.0	0.70	1.28	219.1	0.73	1.67	176.6	0.76	1.99
190	593.4	0.58	0.82	443.4	0.65	0.98	316.6	0.70	1.28	230.6	0.73	1.67	185.9	0.76	1.99
200	622.2	0.58	0.82	465.0	0.65	0.98	332.1	0.70	1.28	242.1	0.73	1.68	195.2	0.76	1.99
220	681.9	0.58	0.82	509.6	0.65	0.98	364.1	0.70	1.29	265.5	0.73	1.68	214.1	0.76	2.00
240	741.1	0.58	0.82	553.8	0.65	0.99	395.9	0.70	1.29	288.8	0.73	1.68	233.0	0.76	2.00
260	799.9	0.58	0.82	597.7	0.65	0.99	427.4	0.70	1.29	312.0	0.73	1.69	251.7	0.77	2.01
280	858.2	0.58	0.83	641.3	0.65	0.99	458.7	0.70	1.30	335.0	0.73	1.69	270.4	0.77	2.01
300	916.0	0.59	0.83	684.6	0.65	0.99	489.8	0.70	1.30	357.9	0.73	1.69	289.0	0.77	2.01

Q cfs	V_1 = 4.5 T	D	V_2	V_1 = 5.0 T	D	V_2	V_1 = 5.5 T	D	V_2	V_1 = 6.0 T	D	V_2
15	12.6	0.81	2.18	10.6	0.85	2.45	8.7	0.90	2.83	7.2	0.94	3.26
20	16.8	0.81	2.18	14.0	0.84	2.53	11.5	0.88	2.91	9.5	0.92	3.39
25	20.9	0.80	2.20	17.5	0.84	2.52	14.3	0.87	2.96	11.9	0.92	3.37
30	25.0	0.80	2.22	20.9	0.83	2.55	17.1	0.87	2.98	14.2	0.91	3.42
35	29.1	0.80	2.22	24.3	0.83	2.57	19.9	0.87	3.00	16.5	0.91	3.46
40	33.2	0.80	2.22	27.7	0.83	2.58	22.7	0.87	3.00	18.9	0.91	3.43
45	37.2	0.80	2.24	31.1	0.83	2.58	25.5	0.87	3.01	21.2	0.91	3.45
50	41.3	0.80	2.23	34.5	0.83	2.58	28.3	0.87	3.01	23.5	0.91	3.46
55	45.3	0.80	2.24	37.8	0.83	2.60	31.1	0.87	3.00	25.8	0.91	3.47
60	49.3	0.80	2.25	41.1	0.83	2.61	33.8	0.87	3.02	28.1	0.91	3.47
65	53.2	0.80	2.26	44.4	0.83	2.62	36.5	0.87	3.04	30.3	0.91	3.51
70	57.2	0.80	2.26	47.7	0.83	2.63	39.3	0.87	3.03	32.6	0.91	3.50
75	61.1	0.80	2.27	51.0	0.83	2.63	42.0	0.87	3.04	34.9	0.91	3.50
80	65.0	0.80	2.27	54.3	0.83	2.63	44.7	0.87	3.04	37.1	0.91	3.52
90	73.0	0.81	2.27	60.9	0.83	2.64	50.1	0.87	3.06	41.7	0.91	3.52
100	80.9	0.81	2.28	67.5	0.83	2.65	55.6	0.87	3.06	46.2	0.91	3.53
110	88.7	0.81	2.29	74.1	0.83	2.65	61.0	0.87	3.07	50.7	0.91	3.54
120	96.5	0.81	2.29	80.6	0.83	2.66	66.4	0.87	3.08	55.2	0.91	3.55
130	104.3	0.81	2.30	87.1	0.83	2.67	71.8	0.87	3.08	59.7	0.91	3.55
140	112.1	0.81	2.30	93.5	0.83	2.68	77.1	0.87	3.09	64.2	0.91	3.55
150	119.8	0.81	2.30	100.0	0.83	2.68	82.5	0.88	3.09	68.6	0.91	3.57
160	127.4	0.81	2.31	106.4	0.83	2.69	87.8	0.88	3.10	73.0	0.91	3.58
170	135.0	0.81	2.32	112.8	0.83	2.69	93.0	0.87	3.11	77.5	0.91	3.57
180	142.6	0.81	2.32	119.1	0.83	2.70	98.3	0.88	3.11	81.8	0.91	3.59
190	150.1	0.81	2.33	125.4	0.83	2.71	103.5	0.88	3.12	86.2	0.91	3.59
200	157.6	0.81	2.33	131.7	0.83	2.71	108.7	0.88	3.13	90.6	0.92	3.59
220	173.0	0.81	2.33	144.6	0.83	2.71	119.3	0.88	3.13	99.4	0.91	3.60
240	188.2	0.81	2.34	157.4	0.84	2.72	129.9	0.88	3.13	108.3	0.92	3.60
260	203.4	0.81	2.34	170.1	0.84	2.72	140.4	0.88	3.14	117.0	0.92	3.61
280	218.5	0.81	2.35	182.7	0.84	2.73	150.9	0.88	3.15	125.8	0.92	3.62
300	233.5	0.81	2.35	195.4	0.84	2.73	161.3	0.88	3.15	134.5	0.92	3.62

34.0 STANDARDS AND SPECIFICATIONS

FOR

TEMPORARY ACCESS WATERWAY CROSSINGS

Definition

A temporary access waterway crossing is a structure placed across a waterway to provide access for construction purposes for a period of less than one year. Temporary access crossings shall not be utilized to maintain traffic for the general public.

Purpose

The purpose of the temporary access waterway crossing is to provide safe, pollution free access across a waterway for construction equipment by establishing minimum standards and specifications for the design, construction, maintenance, and removal of the structure. Temporary access waterway crossings are necessary to prevent construction equipment from damaging the waterway, blocking fish migration, and tracking sediment and other pollutants into the waterway. These standards and specifications may represent a channel constriction thus the **temporary** nature of waterway access crossings must be stressed. They should be planned to be in service for the shortest practical period of time and removed as soon as their function is completed.

Conditions Where Practice Applies

Any temporary access crossing shall conform to the technical requirements of these Standards and Specifications. The following standards and specifications for temporary access waterway crossings are applicable in non-tidal waterways. These Standards and Specifications provide designs based on waterway geometry rather than the drainage area contributing to the point of crossing. The principal consideration for development of these Standards and Specifications is concern for soil erosion and sediment control. Structural integrity and safety must also be considered when designing temporary access waterway crossings to withstand expected loads. The three types of standard temporary access waterway crossings are bridges, culverts, and fords.

General Requirements

1. In-stream excavation

In-Stream excavation shall be limited to only that necessary to allow installation and removal of the standard methods as presented below in the individual practices section and shall not take place within the restricted time periods.

2. Elimination of Fish Migration Barriers

Of the three basic methods presented below in the individual practices section, bridges pose the least potential for creating barriers to aquatic migration. The construction of any specific crossing method, shall not cause a significant water level difference between the upstream and downstream water surface elevations.

Stream closure dates for fish spawning or migration within waterways are March 15 - June 15.

Therefore, the stream channel must not be disturbed during this period. For more information about the closures based on stream uses contact the Fisheries and Wildlife Division of the Department of Health at 202 535-2260.

3. Crossing Alignment

The temporary waterway crossing shall be at right angles to the stream. Where approach conditions dictate, the crossing may vary 15 degrees from a line drawn perpendicular to the centerline of the stream at the intended crossing location.

4. Road Approaches

The centerline of both roadway approaches shall coincide with the crossing alignment centerline for a minimum distance of 50' from each bank of the waterway being crossed. If physical or right-of-way restraints preclude the 50' minimum, a shorter distance may be provided. All fill materials associated with the roadway approach shall be limited to a maximum height of 2' above the existing floodplain elevation. To the extent possible, the work on the approaches primarily within the floodplain shall be limited to grading to keep the road close to the existing grades.

5. Surface Water Diverting Structure

A water diverting structure such as a swale shall be constructed (across the roadway on both roadway approaches) 50 feet (maximum) on either side of the waterway crossing. This will prevent roadway surface runoff from directly entering the waterway. The 50 feet is measured from the top of the waterway bank. Design criteria for this diverting structure shall be in accordance with the Standards and Specifications for the individual design standard of choice. If the roadway approach is constructed with a reverse grade away from the waterway, a separate diverting structure is not required.

6. Road Width

All crossings shall have one traffic lane. The minimum width shall be 12 feet with a maximum width of 20 feet.

7. Time of Operation

All temporary crossings shall be removed within 14 calendar days after the structure is no longer needed. Unless prior written approval is obtained from the Water Resources Administration, all structures shall be removed within one year from the date of the installation. Removal of the structure shall not take place during the spawning periods for the stream as stated above.

8. Materials:

a. Aggregate - There shall be no earth or soil materials used for construction within the waterway channel. AASHTO designation No. 1 coarse aggregate, (3/4" to 4"), shall be the minimum acceptable aggregate size for temporary crossings. Larger aggregates will be allowed.

b. Geotextile fabric - Geotextile fabric is a fabric consisting of either woven or nonwoven plastic, polypropylene, or nylon used to distribute the load, retain fines, allow increased drainage of the aggregate, and reduce mixing of the aggregate with the subgrade soil. Approved geotextile fabrics shall be used, as required by the specific method.

Temporary Access Waterway Crossing Methods

1. Considerations for Choosing a Specific Method.

The following criteria for soil erosion and sediment control shall be considered when selecting a specific temporary access waterway crossing standard method:

a. Site aesthetics: Select a standard design method that will least disrupt the existing terrain of the stream reach. Consider the effort that will be required to restore the area after the temporary crossing is removed.

b. Site location: Locate the temporary crossing where there will be the least disturbance to the soils of the existing waterway banks. When possible, locate the crossing at a point receiving minimal surface runoff.

c. Physical site constraints: The physical constraints of a site may preclude the selection of some of the standard methods.

d. Time of year: The time of year may preclude the selection of one or more of the standard methods due to fish spawning or migration restrictions.

e. Vehicular loads and traffic patterns: Vehicular loads, traffic patterns, and frequency of crossings should be considered in choosing a specific method.

f. Maintenance of crossing: The standard methods will require various amounts of maintenance. The bridge method should require the least maintenance, whereas the ford method will probably require more intensive maintenance.

g. Removal of the structure: Ease of removal and subsequent damage to the waterway should be primary factors in considering the choice of a standard method.

Temporary Ford

A temporary access ford is a shallow structure placed in the bottom of the waterway over which the water flows while still allowing traffic to cross the waterway.

Considerations

Temporary fords may be used when bridge or culvert crossings are not possible and the streambed is armored with naturally occurring bedrock, or can be protected with an aggregate layer in conforming with these specifications.

Construction Specifications

1. Restrictions - Use or removal of a temporary ford will be prohibited from March 1 through June 15 of each year because fish are spawning during this period.

2. The approaches to the structure shall consist of stone pads.

   The entire ford approach (where banks were cut) shall be covered with geotextile fabric and protected with aggregate to a depth of 4 inches.

3. Fords shall be prohibited when the stream banks are 4 feet or more in height above the invert of the stream and a bridge or culvert crossing can easily be constructed.

4. The approach roads at the cut banks shall be no steeper than 5:1. Spoil material from the banks shall be stored out of the flood plain and stabilized.

5. One layer of geotextile fabric shall be placed on the streambed, streambanks, and road approaches prior to placing the bedding material on the stream channel or

approaches. The geotextile fabric shall extend a minimum of 6 inches and a maximum one foot beyond bedding material.

6. The bedding material shall be coarse aggregate or gabion mattresses filled with coarse aggregate.

7. All fords shall be constructed to minimize the blockage of stream flow and shall allow free flow over the ford. The placing of any material in the waterway bed will cause some upstream ponding. The depth of this ponding will be equivalent to the depth of the material placed within the stream and therefore should be kept to a minimum height. However, in no case will the bedding material be placed deeper than 12 inches or one half (1/2) the height of the existing banks, whichever is smaller.

8. Stabilization - All areas disturbed during ford installation shall be stabilized in accordance with the standards and specifications in this manual.

Ford Removal and Final Clean-Up Requirements

When the temporary structure has served its purpose. Care should be taken so that any aggregate left does not create an impoundment or restrict fish passage. Final clean-up shall consist of removal of excess temporary ford materials from the waterway. All materials shall be stored outside the waterway floodplain.

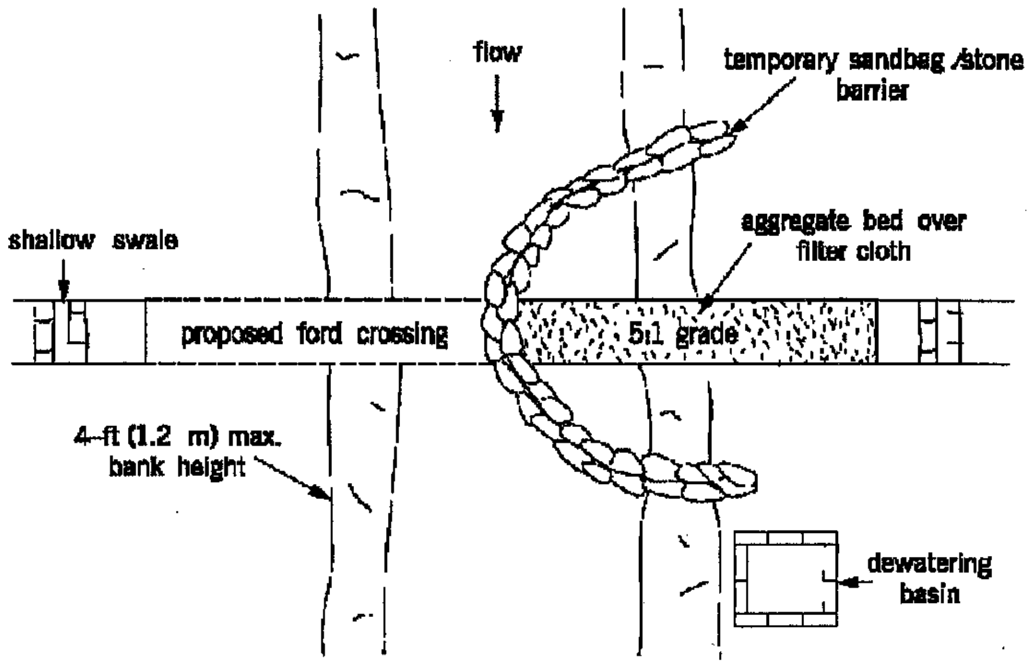
1. Method - Clean up shall be accomplished without construction equipment working in the stream channel.

2. Approach Disposition - The approach slopes of the cut banks shall not be backfilled.

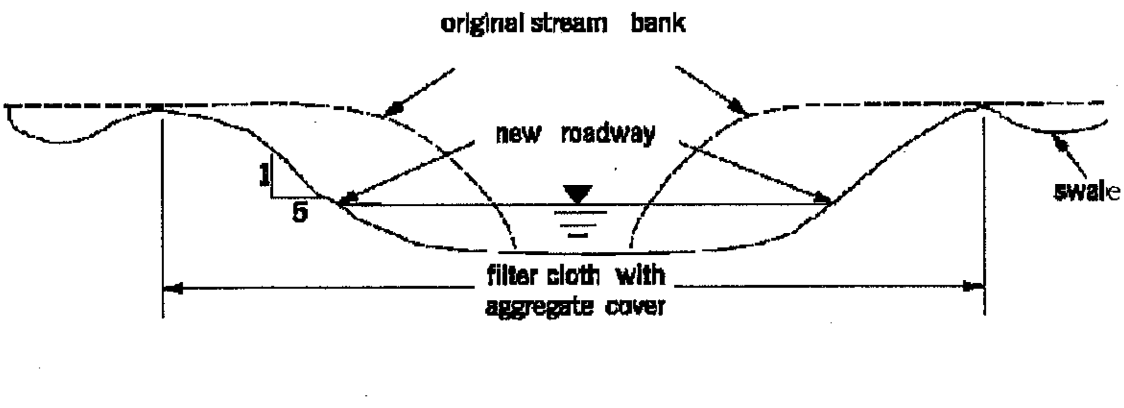
3. Final Stabilization - All areas disturbed during ford installation shall be stabilized in accordance with the standards and specifications in this manual.

DETAIL 65 - TEMPORARY ACCESS FORD

PLAN VIEW



SECTION VIEW



TEMPORARY ACCESS FORD

Construction Specifications

1. Restrictions - Use of removal of a temporary access will not be permitted between October 1 and April 30 for all Class III and Class IV Trout Waters. For other streams, use or removal of a temporary ford will be prohibited from March 1 through June 15 of each year because fish are spawning during this period.

2. The approaches to the structure shall consist of stone pads. The entire ford approach (where banks were cut) shall be covered with filter cloth and protected with aggregate to a depth of 4 inches.

3. Fords shall be prohibited when the stream banks are 4 feet or more in height above the invert of the stream and a bridge or culvert crossing can easily be constructed.

4. The approach roads at the cut banks shall be no steeper than 5:1. Spoil material from the banks shall be stored out of the flood plain and stabilized.

5. One layer of filter cloth shall be placed on the streambed, streambanks, and road approaches prior to placing the bedding material on the stream channel or approaches. The filter cloth shall extend a minimum of 6 inches and a maximum one foot beyond bedding material.

6. The bedding material shall be coarse aggregate or gabion mattresses filled with coarse aggregate.

7. Aggregate used in ford construction shall be Class I (table 45).

8. All fords shall be constructed to minimize the blockage of stream flow and shall allow free flow over the ford. The placing of any material in the waterway bed will cause some upstream ponding. The depth of this ponding will be equivalent to the depth of the material placed within the stream and therefore should be kept to a minimum height. However, in no case will the bedding material be placed deeper than 12" or ½ the height of the existing banks, whichever is smaller.

9. Stabilization - All areas disturbed during the ford installation shall be stabilized within 14-calendar days at that disturbance in accordance with the Standards for Stabilization with Permanent Seeding.

35.0 STANDARDS AND PRACTICES

FOR

INDIVIDUAL PRACTICES

Temporary Access Bridge

A temporary access bridge is a structure made of wood, metal, or other materials, which provides access across a stream or waterway.

Considerations

1. Preferred Method - This is the preferred method for temporary access waterway crossings. Normally, bridge construction causes the least disturbance to the waterway bed and banks when compared to the other access waterway crossings. Disturbance to the stream banks shall be kept to a minimum.

2. Most bridges can be quickly removed and reused.

3. Temporary access bridges pose the least chance for interference with fish migration when compared to the other temporary access waterway crossings.

Construction Specifications

1. Restriction - Construction, use, or removal of a temporary access bridge will not normally have any time of year restrictions since construction, use, or removal should not affect the stream or its banks, unless the bridge is built with a pier(s) in the water.

2. Bridge Placement - A temporary bridge structure shall be constructed at or above the bank elevation to prevent the entrapment of floating materials and debris.

3. Abutments - Abutments shall be placed parallel to, and on, stable banks.

4. Bridge Span - Bridges shall be constructed to span the entire channel. If the channel width exceeds 8 feet, (as measured from top-of-bank to top-of-bank), then a footing, pier, or bridge support may be constructed within the waterway. One additional footing, pier, or bridge support will be permitted for each additional 8-foot width of the channel. However, no footing, pier, or bridge support will be permitted within the channel for waterways less than 8 feet wide.

5. Stringers - Stringers shall either be logs, sawn timber, prestressed concrete beams, metal beams, or other approved materials.

6. Deck Material - Decking materials shall be of sufficient strength to support the anticipated load. All decking members shall be placed perpendicular 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 below.

7. Run Planks (optional) - Run planking shall be securely fastened to the length of the span. One run plank shall be provided for each track of the equipment wheels. Although run planks are optional, they may be necessary to properly distribute loads.

8. Curbs or fenders - Curbs or fenders may be installed along the outer sides of the deck. Curbs or fenders are an option, which will provide additional safety.

9. Bridge Anchors - Bridges shall be securely anchored at only one end using steel cable or chain. Anchoring at only one end will prevent channel obstruction in the event that floodwaters float the bridge. Acceptable anchors are large trees, large boulders, or driven steel anchors. Anchoring shall be sufficient to prevent the bridge from floating downstream and possibly causing an obstruction to the flow.

10. Stabilization - All areas disturbed during ford installation shall be stabilized in accordance with the standards and specifications in this manual.

11. All temporary access bridges installed on public right of way must be approved by DC DPW-DOT.

Bridge Maintenance Requirements

1. Inspection - Periodic inspection shall be performed by the user to ensure that the bridge, streambed, and stream banks are maintained and not damaged.

2. Maintenance - Maintenance shall be performed, as needed to ensure that the structure complies with the standard and specifications. This shall include removal and disposal of any trapped sediment or debris. Sediment shall be disposed of outside of the flood plain and stabilized.

Bridge Removal and Clean-Up Requirements

1. Removal - When the temporary bridge is no longer needed, all structures including abutments and other bridging materials shall be removed within 14 calendar days. In all cases, the bridge materials shall be removed within one year of installation.

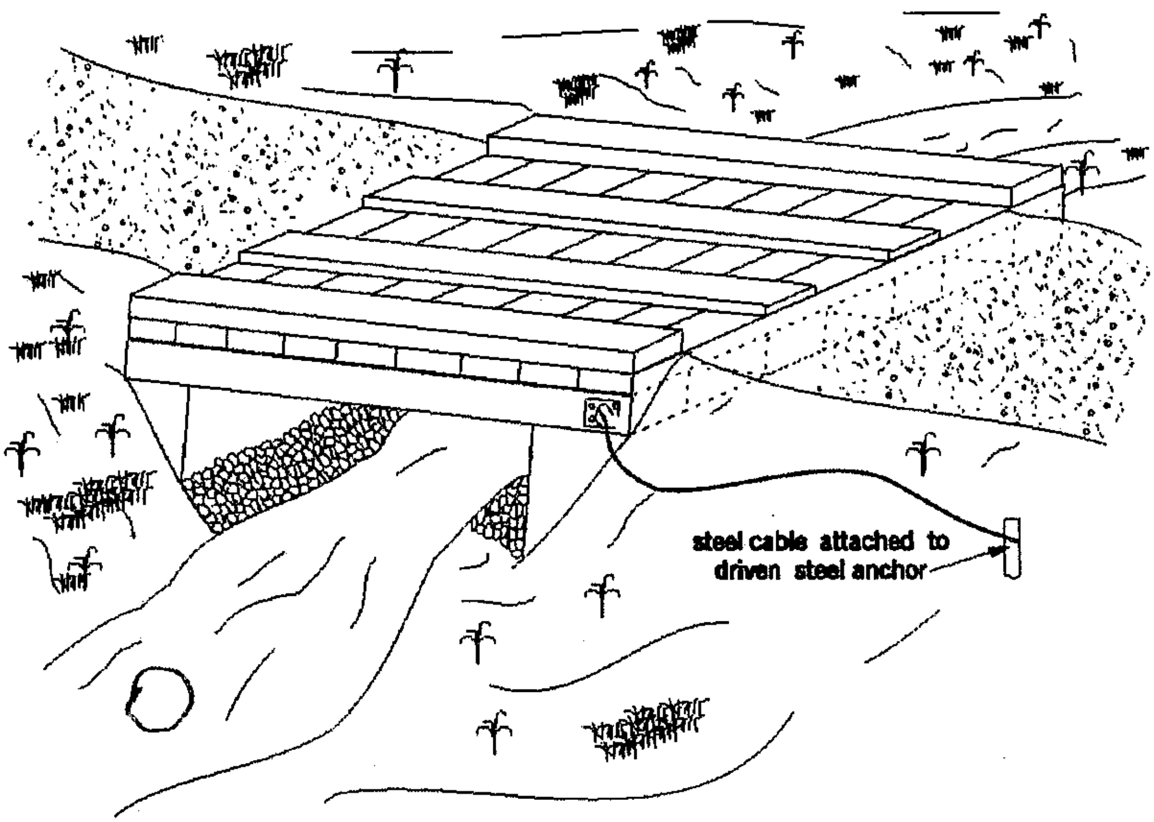
2. Final Clean-Up - Final clean-up shall consist of removal of the temporary bridge from the waterway, protection of banks from erosion, and removal of all construction materials. All removed materials shall be stored outside the waterway floodplain.

3. Method - Removal of the bridge and clean up of the area shall be accomplished without construction equipment working in the waterway channel.

4. Stabilization - All areas disturbed during ford installation shall be stabilized in accordance with the standards and specifications in this manual.

DETAIL 66 - TEMPORARY ACCESS BRIDGE

SKETCH



TEMPORARY ACCESS BRIDGE

Construction Specifications

1. Restriction - Construction, use, or removal of a temporary access bridge will not normally have any time of year restrictions since construction, use, or removal should not affect the stream or its banks, unless the bridge is built with a pier(s) in the water.

2. Bridge Placement - A temporary bridge structure shall be constructed at or above the bank elevation to prevent the entrapment of floating materials and debris.

3. Abutments - Abutments shall be placed parallel to, and on, stable banks.

4. Bridge Span - Bridges shall be constructed to span the entire channel. If the channel width exceeds 8 feet, (as measured from top-of-bank to top-of-bank), then a footing, pier, or bridge support may be constructed within the waterway. One additional footing, pier, or bridge support will be permitted for each additional 8 foot width of the channel. However, no footing, pier, or bridge support will be permitted within the channel for waterways less than 8 feet wide.

5. Stringers - Stringers shall either be logs, sawn timber, prestressed concrete beams, metal beams, or other approval materials.

6. Deck Material - Decking materials shall be of sufficient strength to support the anticipated load. All decking members shall be placed perpendicular 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 below.

7. Run Planks (optional) - Run planking shall be securely fastened to the length of the span. One run plank shall be provided for each track of the equipment wheels. Although run planks are optional, they may be necessary to properly distribute loads.

8. Curbs of fenders - Curbs or fenders may be installed along the outer sides of the deck. Curbs or fenders are an option which will provide additional safety.

9. Bridge Anchors - Bridges shall be securely anchored at only one end using steel cable or chain. Anchoring at only one end will prevent channel obstruction in the event that floodwaters float the bridge. Acceptable anchors are large trees, large boulders, or driven steel anchors. Anchoring shall be sufficient to prevent the bridge from floating downstream and possibly causing an obstruction to the flow.

10. Stabilization - All areas disturbed during installation shall be stabilized within 14 calendar days of the disturbance in accordance with the Standard for "Critical Areas Stabilization with Permanent Seeding."

Temporary Access Culvert

A temporary access culvert is a structure consisting of a section(s) of circular pipe, pipe arches, or oval pipes of reinforced concrete, corrugated metal, or structural plate, which is used to convey flowing water through the crossing.

Considerations

1. Restrictions – Stream closure dates for fish spawning or migration within waterways are March 15 – June 15.

   Therfore, the stream channels must not be distributed during this period. For more information about the closures based on stream uses and submerged vegetation contact the Fisheries and Wildlife Division of the Department of Health at 202 535-2260.

2. This temporary waterway crossing method is normally preferred over a ford type of crossing, since disturbance to the waterway is only during construction and removal of the culvert.

3. Temporary culverts can be salvaged and reused.

Construction Specifications

1. Restrictions - No Construction or removal of a temporary access culvert will be permitted between March 1 through June 15 of each year because fish are spawning during this period.

2. Culvert Strength - All culverts shall be strong enough to support their cross sectional area under maximum expected loads.

3. Culvert Size - The size of the culvert pipe shall be the largest pipe diameter that will fit into the existing channe1 without major excavation of the waterway channel or without major approach fills. If a channel width exceeds 3 feet, additional pipes may be used until the cross sectional area of the pipes is greater than 60 percent of the cross sectional area of the existing channel. The minimum size culvert that may be used is a 12" diameter pipe. In all cases, the pipe(s) shall be large enough to convey normal stream flows.

4. Culvert Length - The culvert(s) shall extend a minimum of one foot beyond the upstream and downstream toe to the aggregate placed around the culvert. In no case shall the culvert exceed 40 feet in length.

5. Geotextile fabric - Geotextile fabric shall be placed on the streambed and stream banks prior to placement of the pipe culvert(s) and aggregate. The geotextile fabric shall cover the streambed and extend a minimum six inches and a maximum one foot beyond the end of the culvert and bedding material. Geotextile fabric reduces settlement and improves crossing stability.

6. Culvert Placement - The invert elevation of the culvert shall be installed on the natural streambed grade to minimize interference with fish migration (free passage of fish).

7. Culvert Protection - The culvert(s) shall be covered with a minimum of one foot of aggregate. If multiple culverts are used, they shall be separated by at least 12" of compacted aggregate fill.

8. Stabilization - All areas disturbed during ford installation shall be stabilized in accordance with the standards and specifications in this manual.

Culvert Maintenance Requirements

1. Inspection - Periodic inspection shall be performed to ensure that the culverts, streambed, and streambanks are not damaged, and that sediment is not entering the stream or blocking fish passage or migration.

2. Maintenance - Maintenance shall be performed, as needed in a timely manner to ensure that structures are in compliance with this standard and specifications. This shall include removal and disposal of any trapped sediment or debris. Sediment shall be disposed of and stabilized outside the waterway floodplain.

Culvert Removal and Clean-Up Requirements

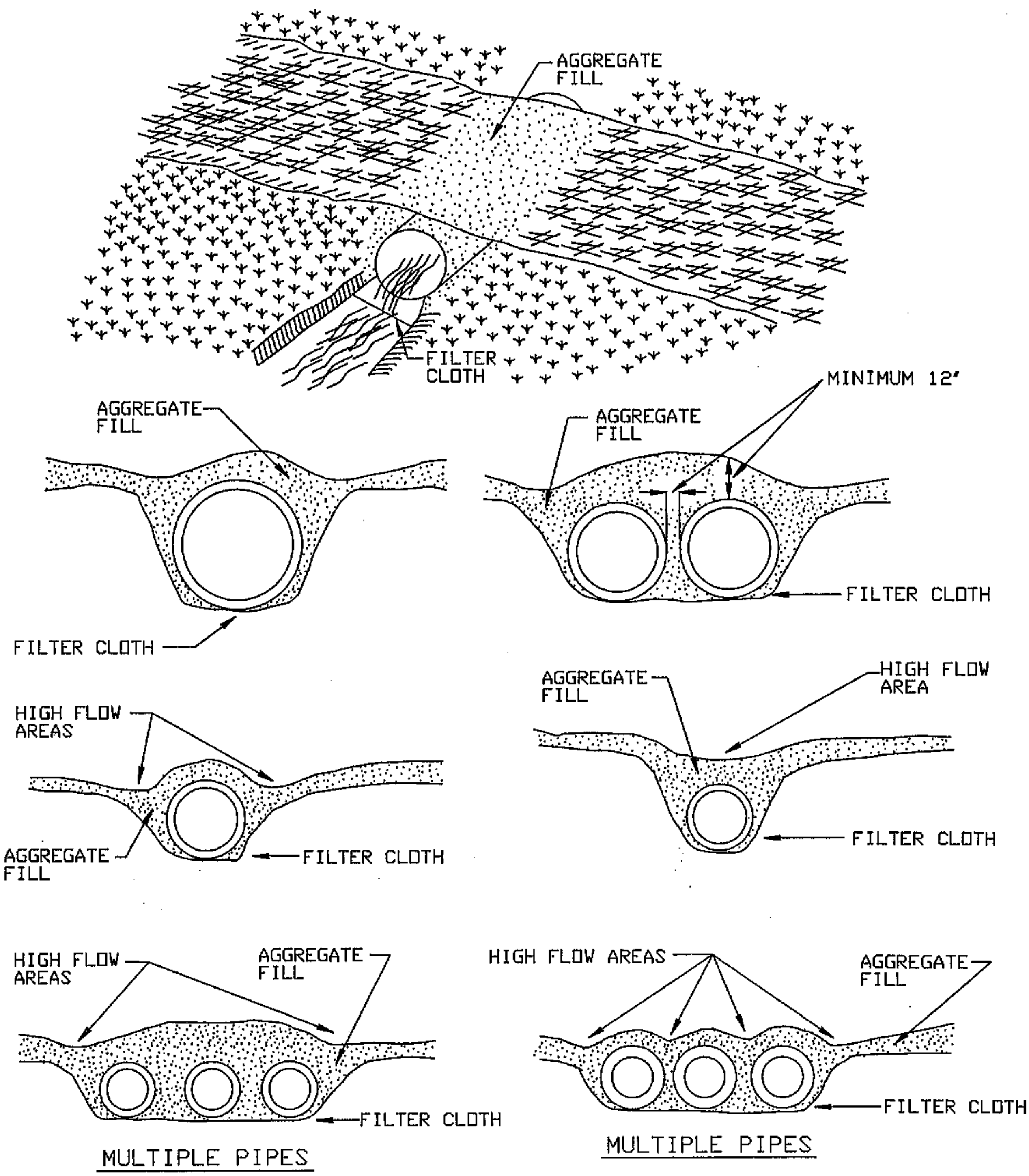
1. Removal - When the crossing has served its purpose, all structures including culverts, bedding and geotextile fabric materials shall re removed within 14 calendar days. In all cases, the culvert materials shall re removed within one year of installation. No structure shall be removed during the spawning season as stated in the general temporary access criteria.

2. Final Clean-up - Final clean-up shall consist of removal of the temporary structure from the waterway, removal of all construction materials, restoration of original stream channel cross section, and protection of the stream banks from erosion. Removed material shall be stored outside of the waterway floodplain.

3. Method - Removal of the structure and clean up of the area shall be accomplished without construction equipment working in the waterway channel.

4. Stabilization - All areas disturbed during ford installation shall be stabilized in accordance with the standards and specifications in this manual.

DETAIL 67 - TEMPORARY ACCESS CULVERT



TEMPORARY ACCESS CULVERT

Construction Specifications

1. Restrictions - No Construction or removal of a temporary access culvert will be permitted between October 1 through April 30 for Class III and Class IV Trout Waters or between March 1 through June 15 for non-trout waterways.

2. Culvert Strength - All culverts shall be strong enough to support their cross sectional area under maximum expected loads.

3. Culvert Size - The size of the culvert pipe shall be the largest pipe diameter that will fit into the existing channel without major excavation of the waterway channel or without major approach fills. If a channel width exceeds 3 feet, additional pipes may be used until the cross sectional area of the pipes is greater than 60 percent of the cross sectional area of the existing channel. The minimum size culvert that may be used is a 12" diameter pipe. In all cases, the pipe(s) shall be large enough to convey normal stream flows.

4. Culvert Length - The culvert(s) shall extend a minimum of one foot beyond the upstream and downstream toe to the aggregate placed around the culvert. In no case shall the culvert exceed 40 feet in length.

5. Filter Cloth - Filter cloth shall be placed on the streambed and streambanks prior to placement of the pipe culvert(s) and aggregate. The filter cloth shall cover the streambed and extend a minimum six inches and a maximum one foot beyond the end of the culvert and bedding material. Filter cloth reduces settlement and improves crossing stability.

6. Culvert Placement - The invert elevation of the culvert shall be installed on the natural streambed grade to minimize interference with fish migration (free passage of fish).

7. Culvert Protection - The culvert(s) shall be covered with a minimum of one foot of aggregate. If multiple culverts are used they shall be separated by at least 12" of compacted aggregate fill.

8. Stabilization - All areas disturbed during culvert installation shall be stabilized within 14 calendar days of the disturbance in accordance with the Standard for 'Critical Area Stabilization With Permanent Seeding.'

36.0 STANDARDS AND SPECIFICATIONS

FOR

TURBIDITY CURTAIN

Definition

A floating geotextile material which minimizes sediment transport from a disturbed area adjacent to or within a body of water.

Purpose

To provide sedimentation protection for a watercourse from up-slope land disturbance or from dredging or filling within the watercourse.

Conditions Where Practice Applies

Applicable to non-tidal and tidal watercourses where intrusion into the watercourse by construction activities and subsequent sediment movement is unavoidable.

Planning Considerations

Soil loss into a watercourse results in long-term suspension of sediment. In time, the suspended sediment may travel large distances and affect widespread areas. A turbidity curtain is designed to deflect and contain sediment within a limited area and provide enough residence time so that soil particles will fall out of suspension and not travel to other areas.

Turbidity curtain types must be selected based on the flow conditions within the water body - whether it be a flowing channel, lake, pond, or a tidal watercourse. The specifications contained within this practice pertain to minimal and moderate flow conditions where the velocity of flow may reach 5 feet per second (or a current of approximately 3 knots). For situations where there are greater flow velocities or currents, a qualified engineer and product manufacturer should be consulted.

Consideration must also be given to the direction of water movement in channel flow situations. Turbidity curtains are not designed to act as water impoundment dams and cannot be expected to stop the flow of a significant volume of water. They are designed and installed to trap sediment, not to halt the movement of the water itself. In most situations, turbidity curtains should not be installed across channel flows.

In tidal or moving water conditions, provisions must be made to allow the volume of water contained within the curtain to change. Since the bottom of the curtain is weighted and external anchors are frequently added, the volume of water contained within the curtain will be much greater at high tide verses low tide and measures must be taken to prevent the curtain from submerging. In addition to allowing for slack in the curtain to rise and fall, water must be allowed to flow through the curtain if the curtain is to remain in roughly the same spot and to maintain the same shape. Normally, this is achieved by constructing part of the curtain from a heavy woven filter fabric. The fabric allows the water to pass through the curtain, but retains the sediment pollutants. Consideration should be given to the volume of water that must pass through the fabric and sediment particle size when specifying fabric permeability.

Sediment which has been deflected and settled out by the curtain <u>may be removed</u> if so directed by the on-site inspector or the Plan-Approving Authority. However, consideration must be given to the probable outcome of the procedure - <u>will it create more of a sediment problem by resuspension of particles and by accidental dumping of the material by the equipment involved?</u> It is, therefore, recommended that the soil particles trapped by a turbidity curtain only be removed if there has been a significant change in the original contours of the affected area in the watercourse. Regardless of the decision made, soil particles should always be allowed to settle for <u>a minimum of 6-12 hours</u> prior to their removal by equipment or prior to removal of a turbidity curtain.

It is imperative that the intended function of the other controls in this chapter, to <u>keep sediment out of the watercourse</u>, be the strategy used in every erosion control plan. However, when proximity to the watercourse makes successfully mitigating sediment loss impossible, the use of the turbidity curtain during land disturbance is essential.

<u>Design Criteria</u>

1. Type I configuration (see Detail 68A) should be used in protected areas where there is no current and the area is sheltered from wind and waves.

2. Type II configuration (see Detail 68A) should be used in areas where there may be small to moderate current running (up to 2 knots or 3.5 feet per second) and/or wind and wave action can effect the Curtain.

3. Type III configuration (see Detail 68B) should be used in areas where considerable current (up to 3 knots or 5 feet per second) may be present, where tidal action may be present and/or where the curtain is potentially subject to wind and wave action.

4. Turbidity curtains should extend the entire depth of the watercourse whenever the watercourse in question is not subject to tidal action and/or significant wind and wave forces.

5. In tidal and/or wind and wave action situations, the curtain should never be so long as to touch the bottom. A minimum 1-foot "gap" should exist between the weighted lower end of the skirt and the bottom at "mean" low water. Movement of the lower skirt over the bottom due to tidal reverses or wind and wave action on the flotation system may fan and stir sediments already settled out.

6. In tidal and/or wind and wave action situations, it is seldom practical to extend a turbidity curtain depth lower than 10 to 12 feet below the surface, even in deep water. Curtains which are installed deeper than this will be subject to very large loads with consequent strain on curtain materials and the mooring system. In addition, a curtain installed in such a manner can "billow up" towards the surface under the pressure of the moving water, which will result in an effective depth which is significantly less than the skirt depth.

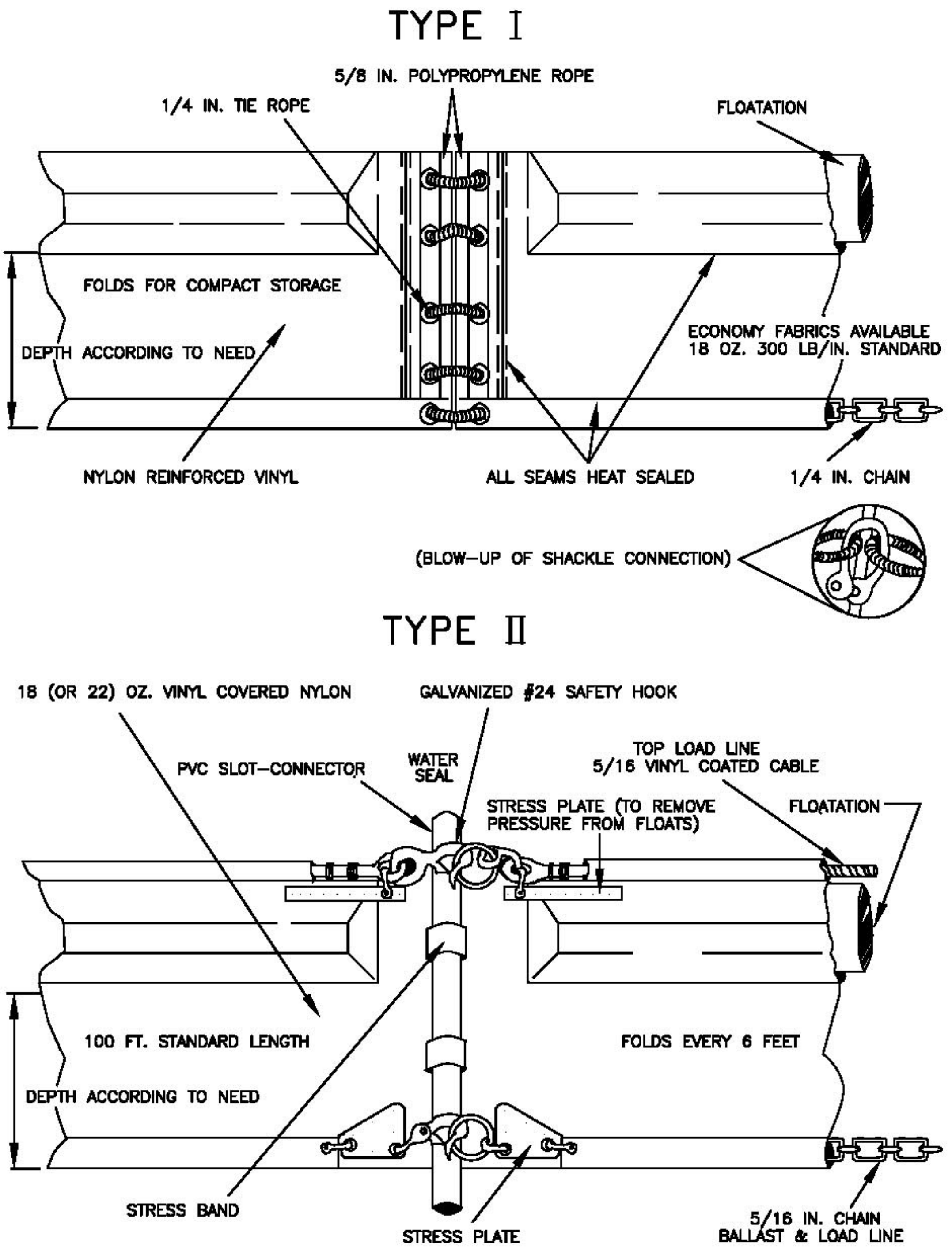
7. Turbidity curtains should be located parallel to the direction of flow of a moving body of water. Turbidity Curtain should not be placed across the main flow of a significant body of moving water.

8. When sizing the length of the floating curtain, allow an additional 10-20% variance in the straight line measurements. This will allow for measuring errors, make installing easier and reduce stress from potential wave action during high winds.

9. An attempt should be made to avoid an excessive amount of joints in the curtain; a minimum continuous span of 50 feet between joints is a good "rule of thumb."

10. For stability reasons, a maximum span of 100 feet between joints (anchor or stake locations) is also a good rule to follow.

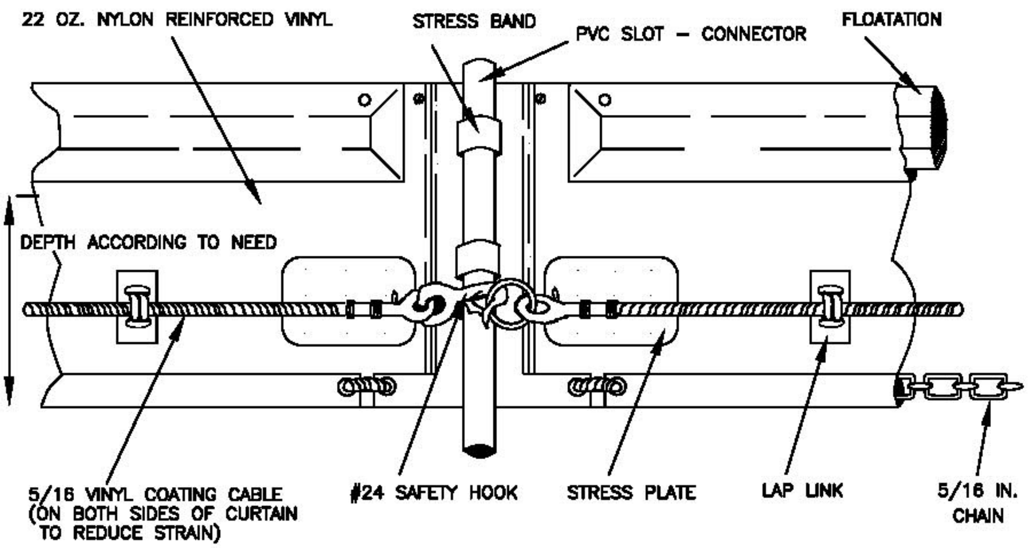
DETAIL 77A - TURBIDITY CURTAIN



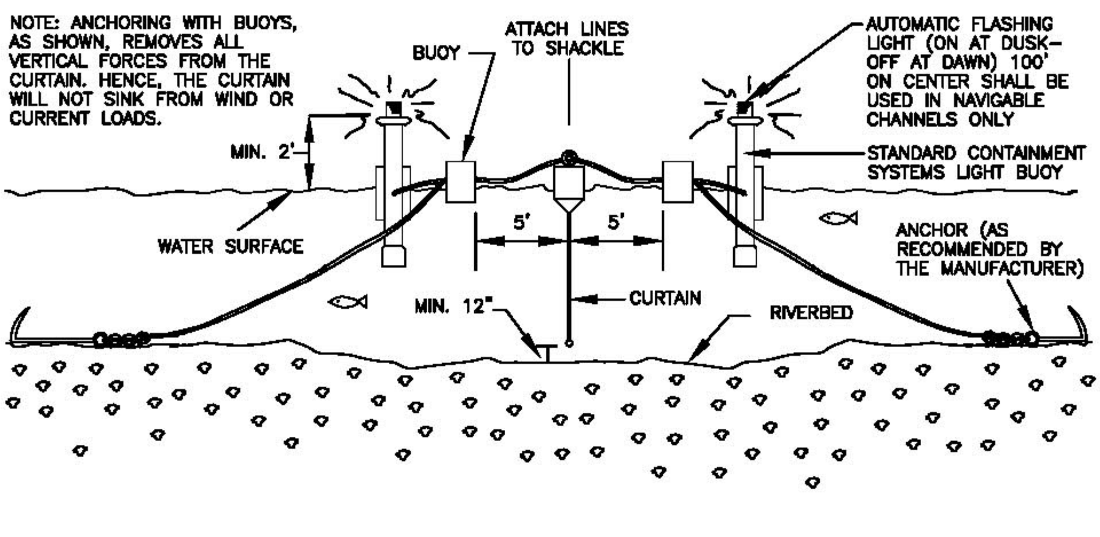
U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H - 39 - 4	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

DETAIL 77B – TURBIDITY CURTAIN

TYPE III



ORIENTATION WHEN INSTALLED
(TIDAL SITUATION – TYPE III)



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H – 39 – 5	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

11. The ends of the curtain, both floating upper and weighted lower, should extend well up into the shoreline, especially if high water conditions are expected. The ends should be secured firmly to the shoreline (preferably to rigid bodies such as trees or piles) to fully enclose the area where sediment may enter the water.

12. When there is a specific need to extend the curtain to the bottom of the watercourse in tidal or moving water conditions, a heavy woven pervious filter fabric may be substituted for the normally recommended impervious geotextile. This creates a "flow-through" medium which significantly reduces the pressure on the curtain and will help to keep it in the same relative location and shape during the rise and fall of tidal waters.

13. Typical alignments of turbidity curtains can be seen in Detail 68C. The number and spacing of external anchors may vary depending on current velocities and potential wind and wave action; manufacturer's recommendations should be followed.

Construction Specifications

Materials

1. Barriers should be a bright color (yellow or "international" orange are recommended) that will attract the attention of nearby boaters.

2. The curtain fabric must meet the minimum requirements noted in Detail 68C.

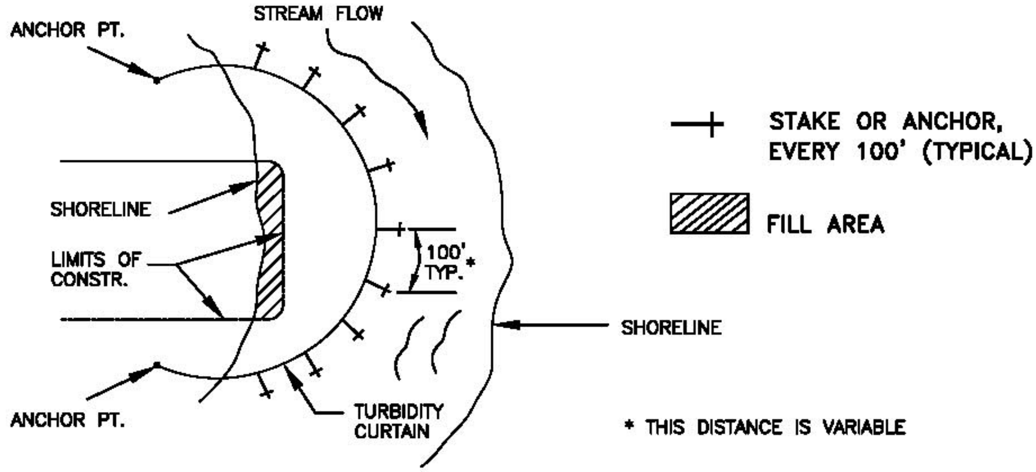
3. Seams in the fabric shall be either vulcanized welded or sewn, and shall develop the full strength of the fabric.

4. Floatation devices shall be flexible, buoyant units contained in an individual floatation sleeve or collar attached to the curtain. Buoyancy provided by the floatation units shall be sufficient to support the weight of the curtain and maintain a freeboard of at least 3 inches above the water surface level (see Detail 68B).

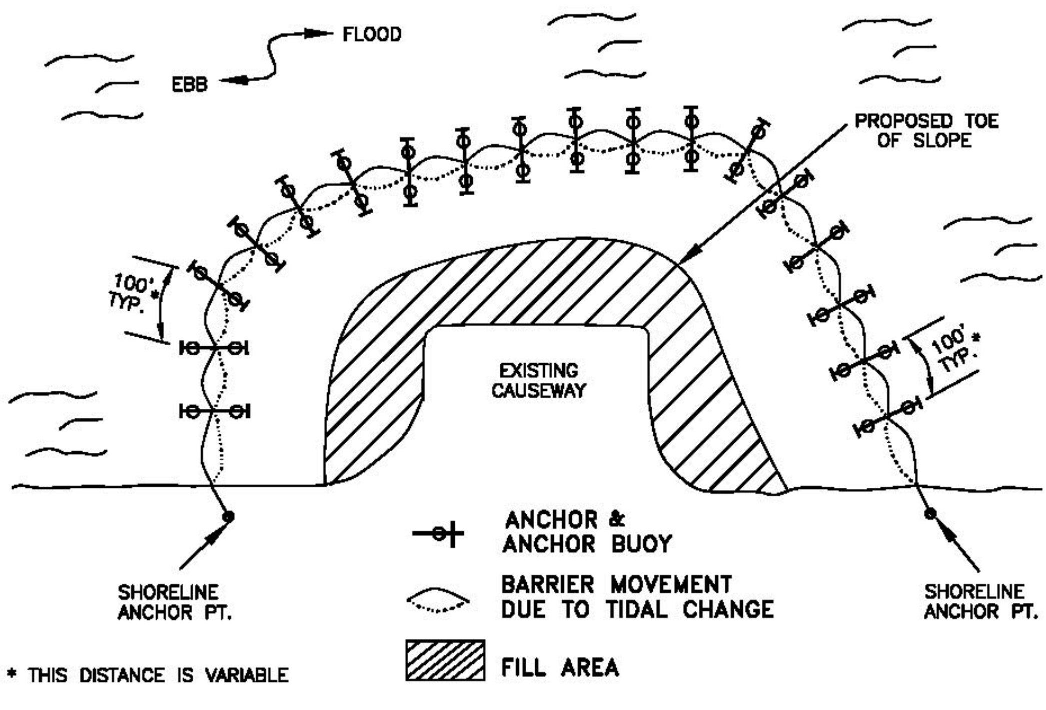
5. Load lines must be fabricated into the bottom of all floating turbidity curtains. Type n and Type ill must have load lines also fabricated into the top of the fabric. The top load line shall consist of woven webbing or vinyl-sheathed steel cable and shall have a break strength in excess of 10,000 pounds. The supplemental (bottom) loadline shall consist of a chain incorporated into the bottom hem of the curtain of sufficient weight to serve as ballast to hold the curtain in a vertical position. Additional anchorage shall be provided as necessary. The load lines shall have suitable connecting devices which develop the full breaking strength for connecting to load lines in adjacent sections (see Details 68A and 68B) which portray this orientation).

DETAIL 77C - TURBIDITY CURTAIN

TYPICAL LAYOUTS:
STREAMS, PONDS & LAKES (PROTECTED & NON-TIDAL)



TIDAL WATERS AND/OR HEAVY WIND & WAVE ACTION



U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCE CONSERVATION SERVICE	PAGE H - 39 - 7	WATERSHED PROTECTION DIVISION DISTRICT OF COLUMBIA DEPARTMENT OF HEALTH

Table 37

PHYSICAL PROPERTIES OF TURBIDITY CURTAIN FABRIC

Physical Property	Requirement
Thickness, mils	45
Weight/oz./sq. yd.:	
Type I	18
Type II	18 or 22
Type III	22
Grab Tensile Strength, lbs.	300
UV Inhibitor	Must be included

Source: Adapted from The Ralph Lemon Company product literature

6. External anchors may consist of wooden or metal stakes (2- x 4-inch or 2 1\2-inch minimum diameter wood or 1.33 pounds/linear foot steel) when Type I installation is used; when Type II or Type III installations are used, bottom anchors should be used.

7. Bottom anchors must be sufficient to hold the curtain in the same position relative to the bottom of the watercourse without interfering with the action of the curtain. The anchor may dig into the bottom (grappling hook, plow or fluke-type) or may be weighted (mushroom type) and should be attached to a floating anchor buoy via an anchor line. The anchor line would then run from the buoy to the top load line of the curtain. When used with Type III installations, these lines must contain enough slack to allow the buoy and curtain to float freely with tidal changes without pulling the buoy or curtain down and must be checked regularly to make sure they do not become entangled with debris. As previously noted, anchor spacing will vary with current velocity and potential wind and wave action; manufacturer's recommendations should be followed. See orientation of external anchors and anchor buoys for tidal installation in Detail 68 B.

Installation

1. In the calm water of lakes or ponds (Type I installation) it is usually sufficient to merely set the curtain end stakes or anchor points (using anchor buoys if bottom

anchors are employed), then tow the curtain in the furled condition out and attach it to these stakes or anchor points. Following this, any additional stakes or buoyed anchors required to maintain the desired location of the curtain may be set and these anchor points made fast to the curtain. Only then, the furling lines should be cut to let the curtain skirt drop.

2. In rivers or in other moving water (Type II and Type III installations) it is important to set all the curtain anchor points. Care must be taken to ensure that anchor points are of sufficient holding power to retain the curtain under the existing current conditions, prior to putting the furled curtain into the water. Again, anchor buoys should be employed on all anchors to prevent the current from submerging the flotation at the anchor points. If the moving water into which the curtain is being installed is tidal and will subject the curtain to currents in both directions as the tide changes, it is important to provide anchors on both sides of the curtain for two reasons:

    a) Curtain movement will be minimized during tidal current reversals.

    b) The curtain will not overrun the anchors and pull them out when the tide reverses.

    When the anchors are secure, the furled curtain should be secured to the upstream anchor point and then sequentially attached to each next downstream anchor point until the entire curtain is in position. At this point, and before unfurling, the "lay" of the curtain should be assessed and any necessary adjustments made to the anchors. Finally, when the location is ascertained to be as desired, the furling lines should be cut to allow the skirt to drop.

3. Always attach anchor lines to the flotation device, not to the bottom of the curtain. The anchoring line attached to the floatation device on the downstream side will provide support for the curtain. Attaching the anchors to the bottom of the curtain could cause premature failure of the curtain due to the stresses imparted on the middle section of the curtain.

4. There is an exception to the rule that turbidity curtains should not be installed across channel flows; it occurs when there is a danger of creating a silt build-up in the middle of a watercourse, thereby blocking access or creating a sand bar. Curtains have been used effectively in large areas of moving water by forming a very long-sided, sharp "V" to deflect clean water around a work site, confine a large part of the silt-laden water to the work area inside the "V" and direct much of the silt toward the shoreline. Care must be taken, however, not to install the curtain perpendicular to the water current.

5. See Detail 68C for typical installation layouts.

Removal

1. Care should be taken to protect the skirt from damage as the turbidity curtain is dragged from the water.

2. The site selected to bring the curtain ashore should be free of sharp rocks, broken cement, debris, etc. so as to minimize damage when hauling the curtain over the area.

3. If the curtain has a deep skirt, it can be further protected by running a small boat along its length with a crew installing furling lines before attempting to remove the curtain from the water.

Maintenance

1. The developer/owner shall be responsible for maintenance of the filter curtain for the duration of the project in order to ensure the continuous protection of the watercourse.

2. Should repairs to the geotextile fabric become necessary, there are normally repair kits available from the manufacturers; manufacturer's instructions must be followed to ensure the adequacy of the repair.

3. When the curtain is no longer required as determined by the inspector, the curtain and related components shall be removed in such a manner as to minimize turbidity. Remaining sediment shall be sufficiently settled before removing the curtain. Sediment may be removed and the original depth (or plan elevation) restored. Any spoils must be taken to upland area and be stabilized.