Montana Stream Permitting

A Guide for Conservation District Supervisors and Others

Conservation Districts Bureau

Montana Department of
Natural Resources and Conservation

June 2001

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Channel Evolution Model—Simon (1989).

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INTRODUCTION

This manual is designed to provide guidance to Montana Conservation District Supervisors in making decisions on 310 Permits. The purpose of the 310 Law is to ensure that projects will be carried out in ways that minimize impacts to the stream or river, or to adjoining landowners' property.

The guiding principle behind wise stream management is to select tools and methods that are compatible with a stream's natural tendencies, and to minimize undesirable side effects. Often, this means letting a stream set its own course, forming and re-forming natural meanders, or abiding by historical flood patterns. When more hands-on management is necessary, the best tools and methods are those that support natural stream form and function.

To that end, this manual includes chapters on stream form and function, stream management, irrigation structures, soft and hard engineering methods, and the permitting process. Examples of stream projects are provided, along with design criteria for different types of projects.

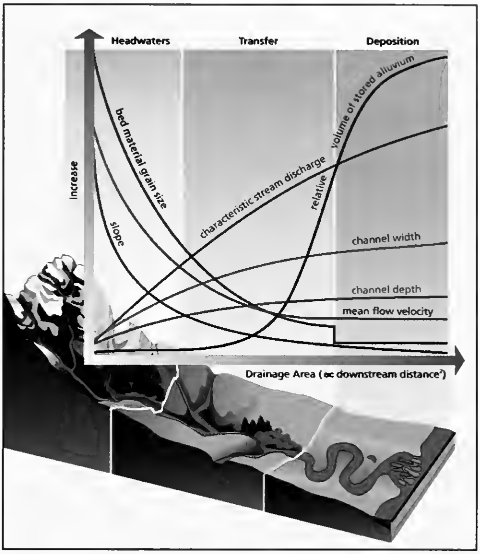
This document is a guide only and should not be construed as a rule for projects. Some conservation districts have adopted construction standards for certain projects and others may or may not allow all of the projects listed in this guide, depending on the local circumstances.

For more information, contact the Conservation Districts Bureau, Montana Department of Natural Resources and Conservation, 1625 Eleventh Avenue, Helena, MT 59620, (406) 444-6667.

Stream Form and Function

STREAM PROCESSES

A basic understanding of stream form and function is essential to good project design. The ability to recognize a stable stream, and understand causes of instability, is important for anyone who reviews, designs, and installs bridges, culverts, weirs, and other structures. These same skills play a crucial role in stream management, from riparian grazing to flood control.



In a general scheme, stream form and function can be divided into three broad categories:

Headwater Zone (sediment erosion)
Transfer Zone (sediment transport)
Depositional Zone (sediment deposition)

Headwater Zone (erosion)

- Headwater streams are frequently supply limited, meaning that they can carry more sediment than is available.
- Headwater streams are typically higher gradient, incised channels that carry sediment from slope and in-channel upland sources (Rosgen A-channel type).

Transfer Zone (transport)

- Transfer zone streams are usually characterized by wide, developed floodplains and meandering channel patterns (Rosgen B- and C-channel types).
- Transfer zone channels are moderate gradient, classic U-shaped glacial trough valleys.
- Channels can move large amounts of bed and bank sediments during peak flows.

Depositional Zone (deposition)

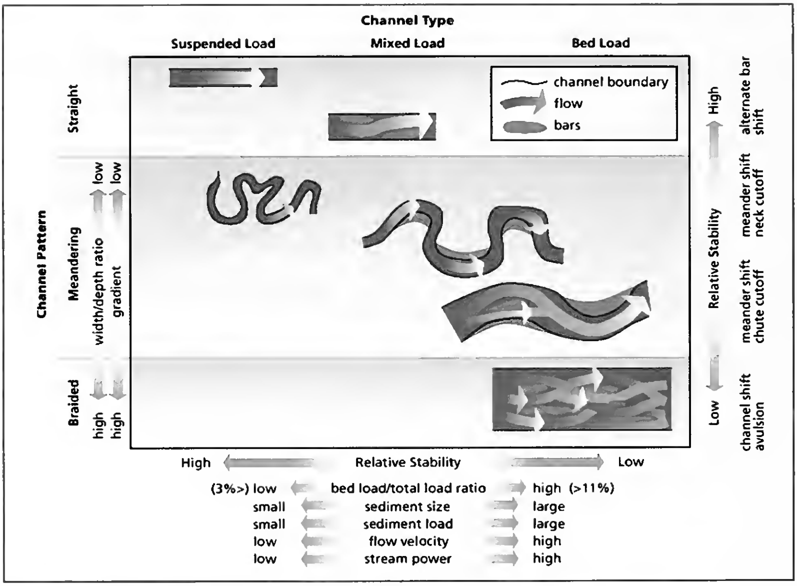
- Depositional streams feature a wide valley bottom, well-developed floodplains, and terraces (Rosgen C-, E- and D-channel types).
- This zone is functionally depositional, although significant transport through the valley bottom is also a dominant process depending on channel stability and channel type.
- The valley is typically flat, wide, and formed of glacial outwash (in glaciated terrains), and/or reworked stream and lake sediments.

In the depositional zone, channel stability is influenced by riparian vegetation more than in other zones, where terrain often confines the stream. Healthy riparian corridors usually enhance lateral stability and a stable meander pattern if there are no chronic sources of sediment, and if peak flows are within their natural range in terms of magnitude, frequency, and duration. A stable stream is one that maintains its general pattern and profile over time.

STREAM CLASSIFICATION

Schumm and Rosgen classification systems

The Schumm diagram shows how channel plan form is related to hydraulic variables and process. The two photographs below illustrate a shift in channel stability related to channel straightening; the shift is also marked on the Schumm diagram. This type of channel is classified as a C channel in the Rosgen System. The Rosgen System (next page) divides channels into seven main types (A to G).



From *Classification of Alluvial Channels*, Schumm, 1977.

This channel (Rosgen C4 type) shows good stability.

An adjacent reach shows signs of instability due to channelization up- and downstream.

STREAM CLASSIFICATION (*continued*)

Relative stability – Rosgen Type A

Good

Poor

Rosgen A channel in good condition

- Steep headwater channels.
- Step/pool with large woody debris.
- Low suspended sediment load.
- Quite stable when formed in cobbles or boulders.
- These channels can be important spawning areas for trout.

Activities that cause problems

- Sidecast road fill from forest roads.
- Loss of riparian trees and instream woody debris.
- Poorly installed culverts (too steep or too long) that block fish passage.
- Increased sediment from vegetation and timber removal or poor road drainage.
- Undersized culverts cause deposition at inlet, trap woody debris, or erode at the outlet.

STREAM CLASSIFICATION (*continued*)

Relative stability – Rosgen Type B

Good

Fair

Poor

Rosgen B channels

- Fairly steep (greater than 2% grade).
- Can be wide and shallow (width-to-depth ratio greater than 12).
- May be fairly stable, especially when formed in large cobbles.
- Frequently have irrigation diversions serving pastures lower in the valley.
- Can provide important spawning habitat for fish.

Stable B channels can adjust

- B channels can move lots of cobble and gravel at peak flow.
- Instability is not usually caused by minor land-use changes or channel projects.
- Geology plays an important role in structural changes.
- Vegetation also plays an important role in channel stability.
- Woody debris can provide important fish habitat, and should be left if possible.

B channels can be unstable

- Channels may aggrade or degrade, or erode banks.
- Instability can be inherent where bedload transport is high.
- Ice jams and debris jams are frequent in these locations.
- Irrigation diversions and stream crossings should avoid constricting the channel.

STREAM CLASSIFICATION (*continued*)

Relative stability – Rosgen Type C

Good

Fair

Poor

C channels are common

- Meandering streams typical in broad valleys and/or cottonwood-willow riparian corridors.
- Can be wide and shallow (typically width-to-depth ratio greater than 12).
- May be fairly stable when banks and floodplain are well vegetated.
- The floodplain is active (floodprone).
- Provide important fisheries habitat.

C channels are sensitive to land use or hydrologic change

- C channels carry large amounts of sediment during peak flow.
- Channels rely on abundant vegetation to maintain a stable width-to-depth ratio.
- Lateral bank erosion up and downstream can be accelerated by poorly designed projects.
- Soft bioengineering should be considered as a substitute for hard methods such as rip-rap.

C channels are inherently dynamic systems

- Meanders migrate naturally over time.
- Restricting meander or bank movement is usually counter-productive to channel stability.
- Development of frequent mid-channel bars indicates reduced stability.
- Attempts at channelization can lead to severe instability.

Relative stability – Rosgen Type E

Good

Fair

Poor

E channels are narrow and deep

- Commonly a strongly meandering stream in agricultural areas.
- Low width-to-depth ratio (less than 12).
- Slope is gentle (less than 0.02).
- May be fairly stable when banks and floodplain are well vegetated.
- The floodplain is active (floodprone).
- May or may not have riparian shrubs/trees.
- Can provide important fisheries habitat.
- This "good" channel has been restored and is the same site as shown in the "poor" photo below.

E channels are sensitive to land use or hydrology

- Channels rely on vegetation to maintain a stable width-to-depth ratio.
- Lateral bank erosion up and downstream can be accelerated by poorly designed projects.
- Loss of vegetation or overgrazing can result in conversion to a wider and shallower C channel.
- Soft bioengineering works well and should be considered as a substitute for hard methods such as rip-rap.

E channels are common in pasture and agricultural areas

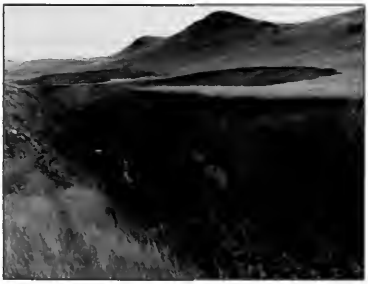
- Grazing and confined animal operations can have significant impacts on channel health.
- Road approaches to stream crossings may dike floodplains if fill is elevated.
- Hard bank stabilization can often be avoided by use of vegetative methods.
- Use of barbs/vanes should be avoided.
- Degraded E channels may heal quickly if allowed to revegetate.

STREAM CLASSIFICATION (*continued*)

Rosgen Types D, F, and G

D channel

F channel



G channel

D channels are braided and unstable

- Braided channels have poor lateral bank stability and scour depths can be extreme.
- Braided channels carry large amounts of bedload gravel.
- Design of stream crossings or channel restoration is difficult.
- Stream crossings should avoid braided reaches.
- C channels risk becoming D if disturbed by land use or other factors.

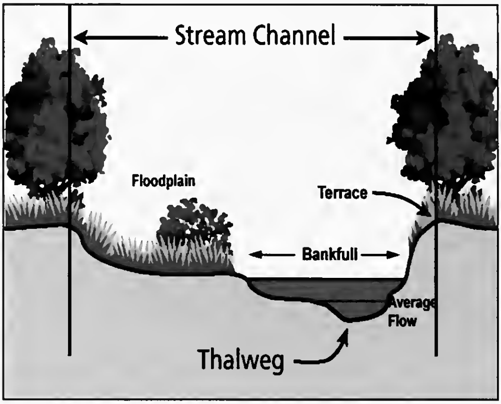
F channels typically have high unstable banks

- Photo above shows E channel becoming established in a former F channel.
- F channels are deeply incised or downcut, and meandering.
- May develop in response to severe impacts (channelization, overgrazing, augmented flows), or be natural remnants of climate change.
- Challenging to repair, and usually cannot be restored to former floodplain.

G channels are typically characterized as gullies

- Found on alluvial fans, downcutting channels, or severely disturbed stream systems.
- Can deliver large amounts of sediment to downstream reaches.
- Rock weirs may help with grade control.
- Revegetation efforts may meet with limited short-term success.
- Restoration may be expensive.

FLOW CHARACTERISTICS



Understanding stream flow is essential for successful stream management. An understanding of both peak flow and low flow conditions is required when evaluating stream-related structures.

Discharge and channel geometry

Average discharge

Average discharge is defined as that flow rate which, if continued every day of a year, would yield the annual volume of water produced by the basin. The average discharge usually fills a channel to about one-third the channel depth, and this flow rate is equaled or exceeded about 25 percent of the days in a year.

Bankfull discharge

Bankfull discharge is defined as the discharge at which channel maintenance processes are the most effective. That is, the discharge that moves sediment, forms or removes bars, forms or changes meanders, and generally does the work that results in the average characteristics of the channel. The bankfull flow has an average return interval of approximately 1.5 to 2 years, although this number can vary from 1.1 to 2 years or more.

Understanding bankfull dimensions is important for evaluating the design of culverts, bridges, and other instream structures. These structures should be designed to maintain sediment transport and convey water. Replicating stable bankfull dimensions of width, depth, and slope will help ensure that sediment transport processes remain in a natural range. Significant deviation from bankfull dimensions may lead to increased bank erosion, lateral instability, and stream bed aggradation or degradation.

The average flood event (usually with a recurrence interval of 1.5 to 1.8 years) is associated with channel changes, especially in streams with reaches that are not structurally controlled, such as portions of the Bitterroot or Yellowstone rivers. Adjustments may include lateral scour, channel abandonment (avulsion and formation of meander cut-off chutes), pool filling, channel straightening, and local changes in slope.

DETERMINING BANKFULL FLOW

USGS gage records

Bankfull elevation can be determined from U.S. Geological Survey (USGS) gage station records, through flood frequency analysis and development of hydraulic geometry, or from the following principal indicators:

Point bar indicators

Point bars can be used as an approximation of bankfull elevation. The point bar is the sloping surface that extends into the channel from the depositional side of a meander. The top of the point bar is at the level of the floodplain because floodplains generally develop from the extension of point bars as a channel moves laterally by erosion and deposition over time. Depositional, flat features are the best indicator of bankfull elevation.

Vegetation indicators

The bankfull level is usually marked by a change in vegetation, such as the change from point bar gravel to forbs, herbs, or grass. Shrubs and willow clumps are sometimes useful but can be misleading. Willows may occur below bankfull stage, but alders are typically above bankfull. Confirm vegetation indicators with depositional features.

Topographic breaks

A topographic break is often evident at bankfull elevations. The stream bank may change from a sloping bar to a vertical bank, or from a vertical bank to a horizontal plane on top of the floodplain. Bankfull is often marked by a change in the size distribution of sediment and soil materials at the surface.

Bankfull definition also generally describes the mean high water mark in the 310 law. Jurisdiction for conservation districts includes the mean high water mark and the immediate banks of the river or stream.

Point bars can provide an indicator of bankfull height in the field.

This bridge stringer is set at bankfull height. Projects should avoid this situtation, which traps debris.

Bankfull is not always obvious and can be difficult to visualize in some channel types.

FLOOD/PEAK FLOW

Estimating peak flow in Montana

Peak flow is closely related to precipitation, drainage area, channel dimensions, and other easily measured variables. Peak flow can be estimated from equations developed by the U.S. Geological Survey (USGS 92-4048).

Flood frequency analysis

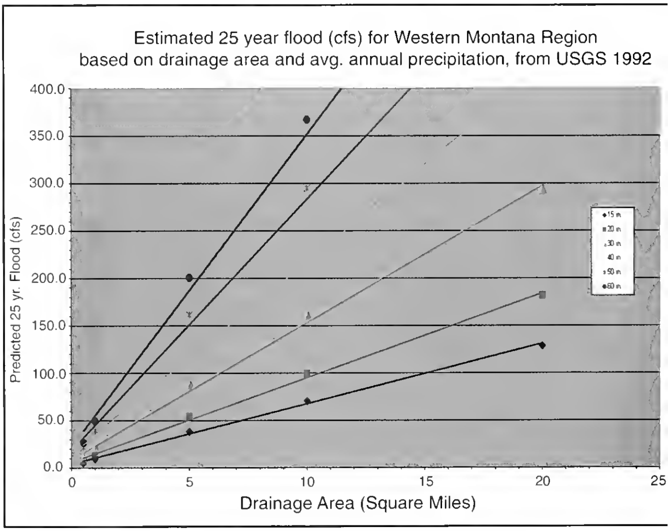
Flood frequency is expressed in terms of recurrence interval. This interval is the period of time, on average, that the associated flow will be equaled or exceeded one time (for example, a 100-year flood).

Estimating flood frequency and size

Peak flows for small Montana watersheds can be estimated using equations developed by the U.S. Geological Survey. These equations are generally most applicable to watersheds smaller than 20 square miles. Equations have been developed for eight regions in Montana. The equations relate peak flow frequency to easily measured variables, and provide a good first estimate of expected flood events.

For gaged sites (or paired watersheds), flood frequency can be determined by analyzing annual maximum flow values (the largest flow peak that occurred during each year of record). Few smaller watersheds have adequate flow information, and determination of flood discharges usually must be estimated from USGS equations or other methods.

Designing instream structures to the bankfull dimension (with recurrence interval of 1.5 to 2 years) often does not meet requirements for good stream function. Standard design criteria require passing the 25-year or 100-year flood event depending on the site situation. In the Columbia River Basin, the U.S. Forest Service currently requires that stream crossings be capable of passing a design flow equivalent to the 100-year flood. Some projects will need to comply with local floodplain regulations, which may limit the allowable backwater caused by a project.



From Water Resources, Investigation Report 92-4048 (1992), USGS.
Note: the 100-year flood is 30 to 50 percent larger than the 25-year flood.

FLOOD/PEAK FLOW (*continued*)

USGS equations for peak flow in Montana

Region / Regression equation	Standard error of estimate (percent)	Average standard error or prediction (percent)	Equivalent years of record
West Region			
$Q2 = 0.042\,A^{0.94}\,P^{1.49}$	51	52	1
$Q5 = 0.140\,A^{0.90}\,P^{1.31}$	45	47	2
$Q10 = 0.235\,A^{0.89}\,P^{1.25}$	44	45	2
$Q25 = 0.379\,A^{0.87}\,P^{1.19}$	44	45	3
$Q50 = 0.496\,A^{0.86}\,P^{1.17}$	45	46	3
$Q100 = 0.615\,A^{0.85}\,P^{1.15}$	46	48	4
$Q500 = 0.874\,A^{0.83}\,P^{1.14}$	53	55	4
Northwest Region			
$Q2 = 0.266\,A^{0.94}\,P^{1.12}$	41	44	2
$Q5 = 2.34\,A^{0.87}\,P^{0.75}$	30	34	8
$Q10 = 7.84\,A^{0.84}\,P^{0.54}$	27	31	13
$Q25 = 23.1\,A^{0.81}\,P^{0.40}$	23	27	26
$Q50 = 25.4\,A^{0.79}\,P^{0.46}$	22	26	39
$Q100 = 38.9\,A^{0.74}\,P^{0.50}$	32	38	24
$Q500 = 87.1\,A^{0.67}\,P^{0.49}$	52	59	18
Southwest Region			
$Q2 = 2.48\,A^{0.87}\,(HE+10)^{0.19}$	84	88	1
$Q5 = 24.8\,A^{0.82}\,(HE+10)^{-0.16}$	67	69	2
$Q10 = 81.5\,A^{0.78}\,(HE+10)^{-0.32}$	60	63	3
$Q25 = 297\,A^{0.72}\,(HE+10)^{-0.49}$	57	60	4
$Q50 = 695\,A^{0.70}\,(HE+10)^{-0.62}$	60	63	5
$Q100 = 1{,}520\,A^{0.68}\,(HE+10)^{-0.74}$	62	66	5
$Q500 = 7{,}460\,A^{0.64}\,(HE+10)^{-0.99}$	75	80	5
Upper Yellowstone—Central Mountain Region			
$Q2 = 0.117\,A^{0.85}\,(E/1000)^{3.57}\,(HE+10)^{-0.57}$	69	72	2
$Q5 = 0.960\,A^{0.79}\,(E/1000)^{3.44}\,(HE+10)^{-0.82}$	50	53	7
$Q10 = 2.71\,A^{0.77}\,(E/1000)^{3.36}\,(HE+10)^{-0.94}$	43	46	12
$Q25 = 8.54\,A^{0.74}\,(E/1000)^{3.16}\,(HE+10)^{-1.03}$	40	44	14
$Q50 = 19.0\,A^{0.72}\,(E/1000)^{2.95}\,(HE+10)^{-1.05}$	42	46	14
$Q100 = 41.6\,A^{0.70}\,(E/1000)^{2.72}\,(HE+10)^{-1.07}$	46	50	14
$Q500 = 205\,A^{0.65}\,(E/1000)^{2.17}\,(HE+10)^{-1.07}$	58	63	15

(Continued on the next page)

FLOOD/PEAK FLOW (*continued*)

USGS equations for peak flow in Montana (continued)

Region / Regression equation	Standard error of estimate (percent)	Average standard error or prediction (percent)	Equivalent years of record
Northwest Foothills Region			
$Q2 = 0.653\,A^{0.49}\,(E/1000)^{2.60}$	78	88	4
$Q5 = 3.70\,A^{0.48}\,(E/1000)^{2.22}$	43	52	13
$Q10 = 8.30\,A^{0.47}\,(E/1000)^{2.10}$	37	48	19
$Q25 = 20.3\,A^{0.46}\,(E/1000)^{1.95}$	38	50	25
$^{*}Q50 = 47.7\,A^{0.47}\,(E/1000)^{1.62}$	41	54	28
$^{*}Q100 = 79.8\,A^{0.48}\,(E/1000)^{1.40}$	47	62	28
$^{*}Q500 = 344\,A^{0.50}\,(E/1000)^{0.98}$	71	75	31

* Equation not valid if the ungaged stream originates in the Northwest Region.

Region / Regression equation	Standard error of estimate (percent)	Average standard error or prediction (percent)	Equivalent years of record
Northeast Plains Region			
$Q2 = 15.4\,A^{0.69}\,(E/1000)^{-0.39}$	81	85	3
$Q5 = 77.0\,A^{0.65}\,(E/1000)^{-0.71}$	60	63	6
$Q10 = 161\,A^{0.63}\,(E/1000)^{-0.84}$	52	56	10
$Q25 = 343\,A^{0.61}\,(E/1000)^{-1.00}$	51	53	14
$Q50 = 543\,A^{0.60}\,(E/1000)^{-1.09}$	49	53	17
$Q100 = 818\,A^{0.59}\,(E/1000)^{-1.19}$	51	56	18
$Q500 = 1{,}720\,A^{0.57}\,(E/1000)^{-1.37}$	63	68	18
East-Central Plains Region			
$Q2 = 141\,A^{0.55}\,(E/1000)^{-1.88}$			
$Q25 = 1{,}545\,A^{0.50}\,(E/1000)^{-1.79}$			
$Q100 = 2{,}620\,A^{0.49}\,(E/1000)^{-1.62}$			
Southeast Plains Region			
$Q2 = 537\,A^{0.55}\,(E/1000)^{-2.91}$			
$Q25 = 3{,}240\,A^{0.51}\,(E/1000)^{-2.55}$			
$Q100 = 5{,}850\,A^{0.50}\,(E/1000)^{-2.51}$			

Variables:
Q - flood magnitude in cubic feet per second
t - the given recurrence interval, in years
A - drainage area, in square miles
P - mean annual precipitation, in inches
HE - percentage of basin above 6,000 feet elevation
E - mean basin elevation, in feet

Reference: *Analysis of the Magnitude and Frequency of Floods and the Peak-Flow Gaging Network in Montana, Water Resources Investigations Report 92-4048 (1992).* U.S. Geological Survey, Helena, Montana.

CAUTION:

These equations provide an initial estimate for perennial streams, but may not be accurate in all situations. To avoid inaccuracies in estimating peak flow, first read and understand the reference cited at left.

FLOOD/PEAK FLOW (*continued*)

Example of calculations from USGS publication 92-4048.

Example 1. (Using the regression equations when the drainage basin is in one region)

Determine the flood magnitude for a recurrence interval of 100 years for an ungaged site in the Southwest Region where the contributing crainage area (A) is 16.4 mi^2 and the percentage of absin above 6,000 ft. elevation (HE) is 75.

From the Southwest Region equations (table 2), the flood magnitudes for 10, 25, and 100-year recurrence intervals are:

$$Q_{10} = 81.5\, A^{0.78}\, (HE+10)^{-0.32}$$
$$= (81.5)\, (16.4)^{0.78}\, (75+10)^{-0.32}$$
$$= (81.5)\, (8.86)\, (0.241)$$
$$= 174\ ft^3/s$$

$$Q_{25} = 297\, A^{0.72}\, (HE+10)^{-0.49}$$
$$= (297)\, (16.4)^{0.72}\, (85)^{-0.49}$$
$$= (297)\, (7.49)\, (0.1134)$$
$$= 252\ ft^3/s$$

$$Q_{100} = 1{,}520\, A^{0.68}\, (HE+10)^{-0.74}$$
$$= (1{,}520)\, (16.4)^{0.68}\, (85)^{-0.74}$$
$$= (1{,}520)\, (6.70)\, (0.0373)$$
$$= 380\ ft^3/s$$

Example 2. (Using the regression equations when the drainage basin is in two regions)

Determine the flood magnitude for a recurrence interval of 50 years for a site in northeastern Montana where 12.5 mi^2 of the total drainage area is in the Northeast Plains Region and 35.2 mi^2 of the total drainage area is in the East-Central Plains Region. That part of the drainage absin in the Northeast Plains Region has a mean basin elevation (E) of 3,120 ft. That part of the drainage basin in the East-Central Plains Region has a mean basin elevation (E) of 2,780 ft.

From the Northeast Plains Region equations, the flood magnitude for a 50-year recurrence interval is:

$$Q_{50} = 543\, A^{0.60}\, (E/1{,}000)^{-1.09}$$
$$= (543)\, (47.7)^{0.60}\, (3.12)^{-1.09}$$
$$= (543)\, (10.17)\, (0.289)$$
$$= 1{,}600\ ft^3/s$$

From the East-Central Region equations, the flood magnitude for a 50-year recurrence interval is:

$$Q_{50} = 2{,}100\, A^{0.49}\, (E/1{,}000)^{-1.72}$$
$$= (2{,}100)\, (47.7)^{0.49}\, (2.78)^{-1.72}$$
$$= (2{,}100)\, (6.64)\, (0.172)$$
$$= 2{,}400\ ft^3/s$$

The weighted average flood magnitude for a 50-year recurrence interval is:

$$Q_{50} = 1{,}600\, (12.5/47.7) + 2{,}400\, (35.2/47.7)$$
$$= 419 + 1{,}771$$
$$= 2{,}190\ ft^3/s$$

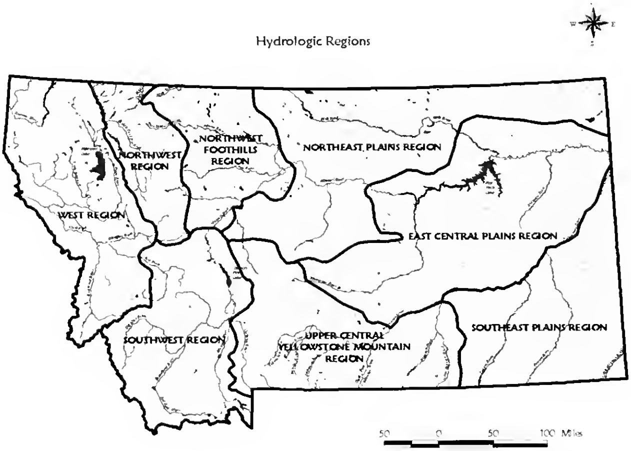
FLOOD/PEAK FLOW (*continued*)

Example 3. (Transferring data from a gaged site)

Determine the flood magnitude for a recurrence interval of 100 years for the Tobacco River near Eureka, Montana, at an ungaged site where the drainage area is 310 mi^2. From table 1 (West Region), the drainage area of the gaged site (station 12301300) is 440 mi^2 and the 100-year recurrence interval flood is 3,220 ft^3/s. Because the ungaged drinage area (310 mi^2) is between 0.5 and 1.5 times the gaged drainage area (440 mi^2), equation 3 can be used to calculate the flood magnitude. From the equations for the West Region (table 2), the exponent for drainage area (A) for a 100-year recurrence interval flood is 0.85. Using equation 3, the flood magnitude for a 100-year recurrence interval at the site is:

$$
\begin{aligned}
Q_{100} &= (310/440)^{0.85}\,(3{,}220) \\
&= (0.743)\,(3{,}220) \\
&= 2{,}390 \text{ ft}^3/\text{s}
\end{aligned}
$$

HYDROLOGIC REGIONS MAP



From *Analysis of the Magnitude and Frequency of Floods and the Peak-Flow Gaging Network in Montana, Water Resources Investigations Report 92-4048* (1992). U.S. Geological Survey, Helena, Montana.

BANK AND CHANNEL STABILITY

Aggrading (filling in or depositing) channel reaches can be indicative of streams out of balance.

Degrading (scouring/downcutting) channels are common when streams have been straightened.

Scour and deposition still occur in equilibrium channels, and can be accelerated by removal of vegetation.

Understanding why streambanks erode or channels are unstable requires an awareness of stream dynamics.

Dynamic equilibrium and channel stability

Maintaining the balance

A stable channel is able to transport the flows and sediment in such a manner that the dimension, pattern, and profile of the river is maintained without either aggrading (filling) or degrading (scouring). Stream systems naturally tend toward minimum work and uniform distribution of energy, or "dynamic equilibrium." This means that changes in channel form (such as bank erosion) are the stream's attempt to maintain a balance in water and sediment. Stable streams do move over time, and stream management should accommodate these natural changes.

Sediment in equals sediment out

Under conditions of dynamic equilibrium, streams achieve a balance so sediment loads entering a stream reach are equal to those leaving it (sediment/water balance). Imbalance results in either aggradation or degradation. When more sediment enters a reach than leaves it, aggradation will occur as the stream's transport capacity is exceeded. In contrast, degradation occurs when a stream has excess energy and more sediment leaves a reach than enters it. Bank instability problems are frequently apparent where streams are aggrading or degrading.

Channel shape varies to keep the balance

The ability of a stream to carry its sediment load largely depends on cross-section geometry and channel slope. A channel cross section that maintains a stable geo-metry and channel slope will generate enough force to transport sediment and convey water through the reach. Channel geometry adjusts to accommodate sediment input and discharge.

Land use makes a difference

Stream management can influence how the stream responds to flood events. Both human and natural factors can cause significant changes in channel stability.

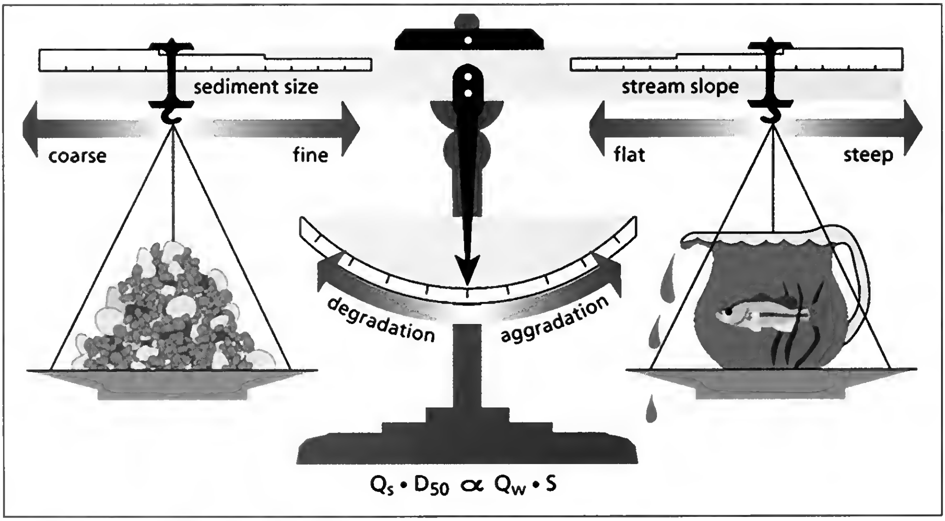
LANE'S DIAGRAM

Lane's diagram – don't leave home without it!

Lane's relationship shows stream process is a function of four main factors:

- Sediment discharge (Qs)
- Sediment particle size (D50)
- Streamflow (Qw)
- Stream slope (S)

Lane's relationship suggests that a channel will be maintained in dynamic equilibrium when changes in sediment load and bed-material size are balanced by changes in streamflow or channel gradient. A change in one of these factors causes changes in one or more of the other variables such that a stable condition tends to become re-established.



Lane (1955). American Society of Civil Engineers.

A large amount of sediment is being added by a 30-foot high bank (below the trees).

How has the stream adjusted?
1) Aggraded the meander (added more sediment to scale).
2) Steepened slope with meander cutoff (slide stream slope to right).

These adjustments are the river's initial attempt to find balance, as described in Lane's diagram.

THE LANE DIAGRAM (*continued*)

Lane's diagram shows that, qualitatively, for a stream to remain in "balance," sediment size times sediment quantity moved by a stream is directly proportional to the slope of the stream times the discharge:

$$(\text{sediment quantity}) \times (\text{sediment size}) \propto (\text{stream slope}) \times (\text{water discharge})$$

It is apparent that an increase in a variable on one side of the "equation" will cause a decrease in the other variable; likewise, a decrease in one forces an increase in the other.

For example, if a stream has been straightened between two points, the distance the water flows in the channel is decreased, but the elevation difference between the points remains the same. Since slope is defined as the elevation change divided by the distance traveled, the slope of the stream increases with channel straightening. If slope is increased, the scale begins to tip towards degradation.

Several adjustments may occur as a result of increased slope, maintaining the balance of the Lane diagram. The immediate adjustment is usually erosion, or increased sediment quantity being washed through the straightened reach. A second adjustment is a tendency for the remaining bed sediment particle size to increase, or "armoring". This occurs as smaller bed sediment particles are carried downstream, leaving behind the larger ones. A third adjustment may be local change in channel slope as eroded sediment is redeposited downstream of the straightened reach (aggradation). Erosion moving upstream of the straightened reach may also contribute increased sediment quantities. These sediment transport changes lead to a readjustment of slope (and channel shape). Thus, it can be seen that changes in one factor (slope, in this case) can lead to simultaneous adjustments in the other Lane Diagram variables.

CHANNELIZATION

Streams react to channelization

Channelization–or straightening–is harmful to most stream systems, and problems eventually shift to adjoining stream reaches.

On straightened streams, the channel slope steepens, which can result in channel adjustments such as:

- Headcut formation upstream.
- Channel downcutting.
- Increased bank erosion rates.
- Aggrading or degrading reaches.

Diking for flood control is also a form of channelization, and can have significant consequences for stream stability and adjoining landowners. Stream projects should seek to avoid channelization of natural streams whenever possible.

In some cases, straightened streams can be restored by re-creating natural meanders or installing grade control structures to compensate for over-steepened conditions.

Some bank stabilization measures can be detrimental to stream integrity. Often erosion shifts to unreinforced reaches where natural meander patterns can be re-established. Strongly meandering Rosgen Type C and E channels are especially sensitive to channeliation or poorly planned bank stabilization.

Channelized streams seek to re-establish equilibrium by forming meanders with scour and deposition. This stream is depositing sediment in an overwide channel, and is re-establishing a meandering, bankfull dimension channel.

Rivers constrained by extensive highway and railroad embankments may suffer widespread instability.

This river has maximized meander length given infrastructure constraints, but remains unstable over much of its length.

CHANNELIZATION (*continued*)

The width-to-depth ratio is out of balance on this straightened reach of stream. The channel is slowly rebuilding a new floodplain and meandering channel.

Comparing the elevation of the straightened channel and the old channel streambed (background) gives some indication of the degree of downcutting.

Rip-rap for bank protection is a common response to erosion on channelized rivers, but hard bank stabilization may prevent the river from re-establishing the missing channel length and stable meandering form.

The legacy of channelization

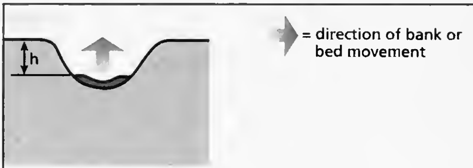
Historic, large-scale channel straightening and realignment continue to result in channel adjustments with each spring runoff. Bank stabilization, especially with inflexible structural methods, is commonly proposed on historically channelized reaches. Hard stabilization does not generally promote good stream health, and soft methods may not be successful in channelized reaches unless the underlying problem can be addressed.

Increasing meander length, or allowing the stream to erode banks and rebuild floodplains naturally may be the best strategy to restore stream integrity. This approach can be difficult to accept in situations where valuable land is lost or structures are threatened.

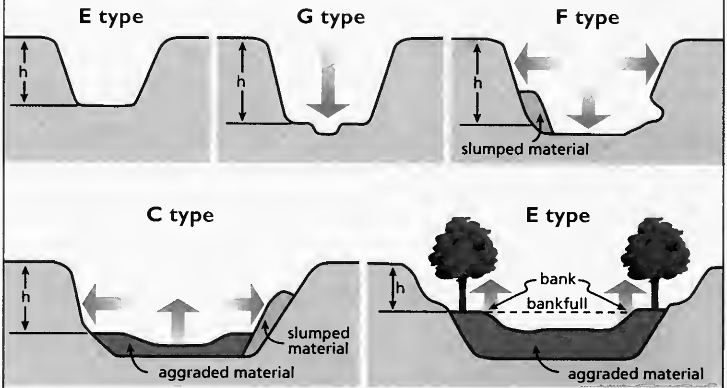
Whenever possible, natural stream function should be promoted as an alternative to potentially harmful structural stabilization. As landowners (and managers) learn more about stream process, they gain a greater appreciation of the long-term consequences of bank stabilization efforts.

Changes in channel characteristics (width, depth, slope, entrenchment, sinuosity, and velocity) commonly follow an evolutionary sequence as illustrated in the diagram on the following page.

CHANNEL DOWNCUTTING AND RE-ESTABLISHMENT OF EQUILIBRIUM



In response to channelization, or imposed higher flows, the channel downcuts and begins to widen (E type to G to F).



As the channel re-establishes equilibrium at a new elevation, the new floodplain is colonized by riparian vegetation (C type to E type). This process can take decades or more to complete.

This channel has downcut severely due to excessive flow introduced for irrigation (Rosgen G type).

Downstream in the drainage, a new equilibrium channel with meanders, point bars, and floodplain is beginning to develop (F channel moving to C).

Stream Management

MEANDER CUTTING

Meanders evolve naturally over time

Highly sinuous, meandering streams often form fairly stable channels. Floodplain and bank vegetation is key in maintaining stability. Natural channel migration occasionally cuts a meander, forming an abandoned oxbow. Meander "cut-offs" are a natural part of stream channel process, but can be accelerated by poor stream management. Extensive rip-rap to constrain the channel may lead to meander cutting up or down stream. Removal of beaver can also increase the probability of meander cutting.

Sediment sources are important

Excess sediment from upstream erosion is a major cause of cutoffs. Many meanders are cut off because stream energy is insufficient to carry incoming sediment through a bend. When a sediment plug forms on the entrance to a meander bend, the stream will cut through the floodplain or point bar.

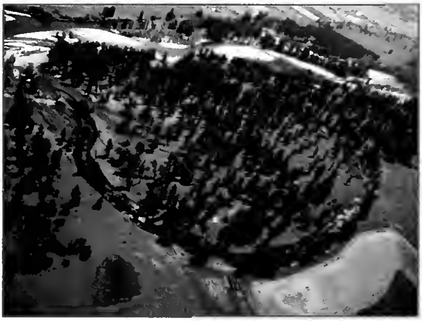
Restoration is sometimes possible

When a meander is abandoned, the channel responds by increasing its slope, velocity, and ability to carry sediment. This may cause accelerated bank cutting and erosion up or downstream. In some cases, a stable meander pattern can be re-established, but only after first controlling upstream erosion to reduce the stream's sediment load.

Let nature take its course

In many cases (possibly most), allowing natural meander cutoffs to occur without intervention may be the best strategy for ensuring long-term river health. Meanders evolve and "age" as a natural adjustment. Although it is not always easy to determine what "natural" is, it is seldom wise to work against a river's natural process.

As meanders age and the radius becomes tighter, cutoffs become more likely.



Meander abandonment happens frequently in altered stream environments.

Meander abandonment occurs naturally as loops intersect. This site is not suitable for meander reactivation.

BANK AND RIPARIAN VEGETATION

Healthy vegetation promotes healthy river channels

Vegetation serves many functions

Riparian vegetation is an integral and important component of a healthy stream environment. Trees, shrubs, grasses, and other plants help to stabilize banks, regulate water temperature and nutrient levels, filter sediment, and provide cover and food for fish and other organisms.

Vegetation is crucial in stabilizing some channels

Riparian vegetation along otherwise unconfined stream channels is especially significant for maintaining a stable stream corridor. Streams with high bedload transport rates are very sensitive to upstream changes in water and sediment supply. The channel may move laterally, eroding the banks. Floodplain vegetation slows lateral movement and reduces overbank flood velocities.

Clearing riparian areas is costly

Land management activities that reduce riparian vegetation (such as home building and livestock grazing) can cause bank erosion even during low flows. When this occurs, a series of channel adjustments may lead to a change in channel type, for example from a single threaded channel to a multiple threaded, over-widened, braided channel. Accelerated bank erosion and channel migration are seen in more sensitive channel types.

Good stream management should include a plan for monitoring and eliminating or reducing noxious weeds, while reseeding with native plants to protect against erosion.

Encouraging the growth of shrubs and trees such as willow, alder, cottonwood, red osier dogwood, chokecherry, spruce, and other riparian species will improve the system health.

Remnant willows are found in many floodplains converted to agricultural uses.

Assisted by rip-rap, a single tree does what it can. Where are the replacements in the floodplain?

Replacement trees are colonizing the expanding point bar floodplain. The channel is moving several feet per year (20+ ft. in 1997), much to the dismay of the landowner.

PONDS (IMPOUNDMENTS)

Instream ponds mean maintenance

Instream ponds fill with sediment

Instream ponds disrupt the flow of sediment through a stream. Gradually, the pond or reservoir will fill with sediment and gravel. In extreme cases, clean water below the impoundment picks up sediment from bed and banks, increasing erosion downstream.

Instream ponds, or impoundments, require engineering

Instream ponds require an engineering design to address sedimentation, outflow structure capacity, dike stability, and fish passage issues. At a minimum, structures should be designed to safely convey the 100-year flood through an emergency spillway. Larger ponds and lakes classified as "high hazard" by the state require additional engineering to ensure structural integrity.

If you must impound, do it off stream

Off-stream ponds avoid many of the complications of instream structures, and may be exempt from most conservation district permitting. Ditches, headgates, or water intakes for the pond located in the perennial channel do, however, require a 310 permit. Diversion designs should ensure adequate control of diverted water to prevent flood damage to pond embankments or outflow structures. Off-stream ponds can adversely affect instream temperatures and, in turn, fisheries.

Hundreds of thousands of cubic yards of sediment have filled much of this reservoir.

This small impoundment has filled with gravel and plants are taking hold.

WOODY DEBRIS REMOVAL

Debris jams typically occur during bankfull or greater floods as natural blowdown or channel migration into floodplain areas delivers trees to downstream reaches. Debris stranded on gravel bars, structures, or channel braids can cause bedload deposition, changes in channel location, and damage to structures. Debris can make a channel more complex, benefitting fish by increasing habitat.

Although it is tempting to remove woody debris, such cleaning should be kept to a minimum.

Landowners sometimes remove debris to:

- Reduce erosion due to redirected stream flows.
- Reduce flooding.
- Eliminate new obstructions at culverts, headgates, or bridges.
- Prevent new channels from forming around blockage.
- "Clean up" the stream area.

Undesirable impacts may include:

- Impacts to channel and banks with heavy equipment.
- Sediment release to downstream reaches.
- Diminished bank stability.
- Adverse effects on riparian vegetation and fisheries.

Debris serves a purpose

Woody debris is an important component of many stream systems, providing fish habitat and channel stability. The following questions should be considered carefully:

- Is debris significant to fish habitat or channel stability?
- Will removal reduce fish habitat or channel stability?
- Will equipment damage the banks or channel?
- Can removal be accomplished without damaging the riparian area?

Guidelines

- Before removing debris, consider the type of stream, amount of debris, and the potential for damage.
- In general, removal should be limited to situations where debris build-up will cause significant property damage.
- Do not remove debris to counter natural changes in channel location or overflow channels.

BEAVER DAMS

Beaver dams play an important role in stream stability and riparian plant communities. Their effects, however, vary from stream to stream. Before removing beaver dams, weigh the benefits against potentially undesirable channel changes.

Beaver dams are sometimes removed to:

- Reduce flooding.
- Eliminate obstructions at culverts, headgates, or bridges.
- Prevent new channels from forming around dam.
- Drain wetland areas.
- Eliminate beaver damage to mature streambank trees.
- Provide access for migratory fish spawning areas.

Removing beaver dams may cause undesirable side effects, such as:

- Channel down cutting.
- Sediment release to downstream reaches.
- Diminished bank stability.
- Lowering of water table.
- Damage to riparian vegetation and fisheries.

Beaver have enhanced channel stability and riparian conditions at this site.

Subsequent removal of beaver led to channel instability.

The role of beaver

- Many stream systems have evolved with beaver as a natural component of the riparian system.
- Beaver dams maintain high water tables, provide refuge for fish during low flows, and store sediment.
- In some cases, removing beaver dams may have detrimental effects on the health of the stream.

Guidelines

- Generally, beaver dams should not be removed unless flooding upstream will cause significant damage to property.
- Do not remove dams to counter natural changes in channel location, overflow channels, or flooding.
- Consider fencing as an option to protect trees.

LIVESTOCK GRAZING IN RIPARIAN AREAS

Developing off-stream water can improve grazing

Excessive livestock grazing can harm bank stability and riparian health. Impacts are most common on sensitive channel types, for example Rosgen C and E channels. Progressive loss of woody shrubs and bank trampling contribute to channel instability.

As damaged channels become wider and shallower, fish habitat is lost, and the riparian zone becomes more vulnerable to flood damage, erosion, and channel migration.

Stream projects and livestock grazing

- Streambank stabilization projects that replace and/or enhance riparian vegetation in grazed areas must consider livestock use of the site. Uncontrolled livestock access to the banks may preclude successful revegetation. The project may need to include fencing to protect streambanks.
- Proposed stream improvement projects may involve development of off-stream stock water sources, and fencing off a stream. The off-stream water source may be a pond or tank that draws water from a perennial stream, and returns it to the stream.
- Development of armored livestock watering access points, along with fencing of the stream, is an alternative to developing an off-stream water source.

Careful management of livestock with modified grazing schemes or fencing on damaged streams can dramatically improve riparian health. More information on grazing methods can be obtained in *Best Management Practices for Grazing* (DNRC, 1999) from the Conservation Districts Bureau, Montana Department of Natural Resources and Conservation.

Wide, shallow channels resulting from heavy grazing are poor fish habitat.

Damage from continuous heavy grazing or confined animals can often be reversed while still allowing agricultural practices.

Loss of mature riparian trees and shrubs can result in braiding on sensitive channel types.

ROADS

Roads can contribute significant amounts of sediment to streams

Erosion from roads near streams can be a significant source of sediment, harming water quality and fish habitat.

Some studies suggest that in the mountainous West, forest roads contribute as much as 85 to 90 percent of the sediment reaching streams in disturbed forest land.

Main sources of sediment

- Stream crossings (improperly designed approach grades, poorly armored culvert inlets or outlets).
- Side casting during road maintenance.
- Unstable fill slopes on roads parallel to streams.
- Poorly designed or ineffective drainage features (ditches, cross drains, water bars).
- Erosion from cut slopes, drain ditches, and road surfaces.

To avoid harm to fisheries and water quality, roads and stream crossings should be designed to reduce the potential for sediment delivery. Such projects warrant careful attention to grading and drainage. Road approaches should be kept below six percent grade if possible, and provided with drainage relief every 200 feet on the approach to the crossing. Vegetated swales and filter zones can reduce sediment before runoff reaches the stream.

For more guidance, see *Forestry Best Management Practices*, and the *Sediment and Erosion Control Manual*, available from the Montana Department of Natural Resources and Conservation.

Poor drainage on granitic soils can deliver large amounts of sediment to streams.

Silt fence helps prevent sediment delivery on newly constructed roads, but does not substitute for proper drainage features.

Runoff from heavy rains can deliver large quantities of sediment to stream systems.

FLOOD CONTROL

What causes flooding? It is essential to identify the causes of flooding before selecting flood control measures.

Causes of flooding

"Normal" stream conditions

Bankfull floods occur approximately every 1.5 to 2 years. Natural overbank flows should be expected frequently in channel types with a well-developed floodplain. Frequent flooding is not necessarily an indication of abnormal stream conditions.

"Abnormal" flooding conditions

Abnormal floods occur when streams experience non-equilibrium conditions, such as aggradation (channel filling), channel constriction (undersized structures), and extreme debris or ice jams.

Aggradation ("filling")

Aggradation is a common cause of "abnormal" flooding conditions due to reduced channel capacity. Aggradation, or channel filling, results when more sediment enters a stream than the channel can carry.

Aggradation is common in depositional areas on alluvial fans, transitions at narrow canyons to wide valleys, and in flat valleys with certain sediment, slope, and discharge characteristics. Aggrading channels have high lateral instability—severe bank erosion—and are often braided with large gravel point bars and medial bars.

The tendency to aggrade or braid is natural in many river systems, but can be accelerated by channel changes (slumps, dewatering, land use, or dikes) that influence sediment supplies and carrying capacity.

Many natural channels overtop the banks every 1.5 to 2 years, on average.

Aggrading "filling" channels result from excess sediment supply or reduced transport capacity.

Attempting to control flooding on aggrading channels with excavation and berms is rarely successful because the channel continues to fill.

FLOOD CONTROL (*continued*)

Channel constriction

Undersized culverts and bridges, extensive diking, debris, or ice jams can cause backwater conditions and increase flooding problems.

Chronic backwater conditions can cause bedload (gravel) to deposit upstream of the obstruction, further exacerbating flooding problems. Designing structures to pass the 100-year flood will help alleviate channel constrictions and associated flooding.

Natural floodplain function

Flows that overtop the bank are common in natural channel types that are not confined (Rosgen C-, D-, and E-types). These channels are typical of broad, lower gradient valleys and have associated floodplain plant and wetland communities that are adapted to recurring flood conditions.

Diking or levees to control floods may adversely affect channel stability and riparian plant communities.

Ice jams are common in some channel types, and can cause flooding to much higher elevations than the 100-year flood (Blackfoot River).

This reach of the Blackfoot River (same location as above) is a moderate risk area for major ice jams. Wider, shallower channels have more frequent icing problems.

Aggradation from a failed culvert crossing has decreased channel capacity and increased flood risk to the road that has encroached on the floodplain.

Levees provide flood control for development in floodplains. Levees require ongoing maintenance, however, and have the potential to severely impair channel function.

FLOOD CONTROL (*continued*)

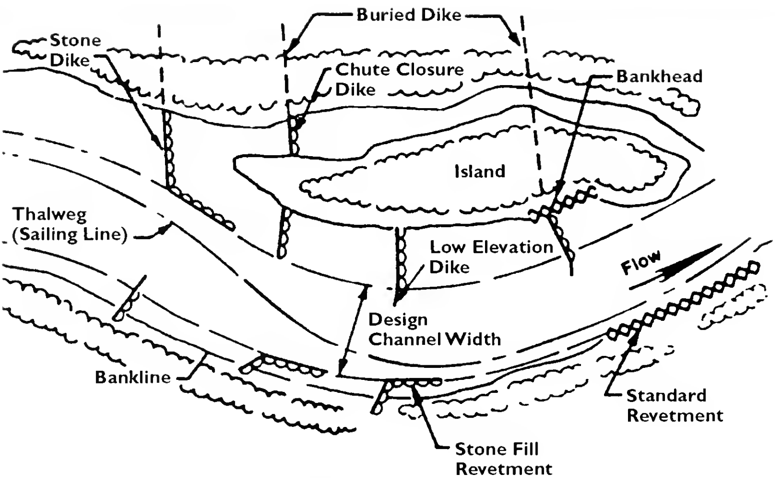
Usually the terms "*dikes*" and "*levees*" are used interchangeably. However, there is a difference as defined by the U.S. Army Corps of Engineers.

Dikes

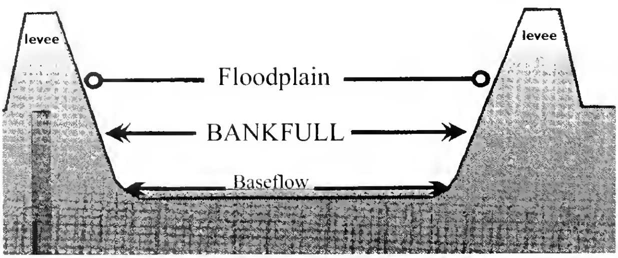
A dike is a *structure placed in the channel*, for the purpose of redirecting flow in the channel. Historically, dikes have been made of stone, concrete rubble, piling, fence materials, tree trunks, etc.

Levees

A levee is a *structure placed on the stream bank or floodplain* and above the channel for the purpose of preventing flood waters from affecting dry land. A levee can be thought of as a long, linear dam that keeps a low area from flooding.



Dikes. Drawing from U.S. Army Corps of Engineers, 1993.



Levee. Diagram adapted from Rosgen, 1996.

SELECTION OF FLOOD CONTROL METHODS

If channel flooding is abnormal due to on-site channel obstruction, the problem can be corrected by removing the blockage or replacing the structure to handle peak flows, ice, or debris.

If the channel is aggrading, cause and effect must be carefully evaluated. Finding a long-term solution may be difficult. The sediment source may be located off site, or the problem may be large scale, even regional. Dikes are of limited use because further aggradation occurs as dike or bank elevation is increased. Channel excavation or dredging is often a temporary solution because channels rapidly refill with sediment. Levees may raise flood water elevations, increasing flood stages upstream or across the river. Always consult your local floodplain administrator before building a dike or levee.

This levee was stabilized to protect downstream development from flooding, although the landowner with the levee did not particularly want to constrain the river.

Channel excavation may be appropriate when:

- Cause and effect are clearly understood (flooding is due to a culvert backwater or hillside slump into the channel).
- Cause can be addressed to prevent recurrence.
- Gravel excavation occurs in a limited area, requires a single entry, and upstream sources are unlikely to rapidly refill the excavated section of the channel.
- Fisheries and channel stability impacts are judged to be minimal.

Dikes and levees may be appropriate when:

- Protection of public infrastructure takes precedence over stream function.
- Dikes can be designed to avoid significant stream and floodplain impacts.
- An engineered design meets all permit requirements.
- Alternatives to dikes are deemed unacceptable (see below).

Alternatives to dikes and levees include:

- Raising the grade of structure(s) threatened by frequent flooding.
- Using berms to deflect flooding from a specific structure, rather than confining the stream channel.
- Relocating threatened structures.
- Restoring the channel to address channel instability issues.

These alternatives to dikes can provide long-term security, and can be cost effective compared to on-going maintenance typical of flood control projects.

Stream Crossings

ROAD CROSSINGS AND CHANNEL GEOMETRY

Stream crossings on perennial streams include:

- Bridges
- Culverts
- Fords

Stream-crossing designs must consider:

- Channel geometry.
- Peakflow capacity, scour depth, and erosion.
- Bedload, ice, woody debris passage.
- Fish passage.
- Road approach grades.
- Floodplain impacts (such as diking with fill).
- Relative cost.
- Potential upstream and downstream effects.

Choosing a location with a stable cross section is critical to project success. This failed bridge had inadequate span and was located on an actively migrating river reach.

Channel geometry

Channel stability and geometry must be evaluated for all stream crossings. Specifically, the design must take into account vertical (degrading or aggrading) and lateral (bank erosion and migration) instability.

Vertical instability

- Downcutting can scour and undermine bridge abutments.
- Culverts control streambed elevation upstream, but downcutting may leave the outlet perched above the channel. This tends to restrict fish passage.
- Aggrading channels can fill bridge and culvert cross sections and reduce channel capacity.

Lateral instability

- Channel migration results in poor alignment of culverts and bridges over time.
- Abutments and road fill may erode with poor alignment.
- Sediment transport is interrupted by poor alignment.

Location

- Choose a crossing site in a stable, relatively straight reach of channel where possible.
- An incised (deep, narrow) channel cross section is preferred to a wide, shallow location.
- Look up and downstream of the crossing for signs of overall channel stability.
- Choose a location where the road approach will be level or slightly rising.
- Cross the stream perpendicular to the channel whenever possible.

PEAK FLOW CAPACITY

Instream hydraulic structures should generally be sized to handle the 25-year flood at a minimum, and preferably the 100-year flood. Flood peaks are estimated from regional regression equations, stream gaging stations, or measurements of channel geometry and high water marks. Regional regression equations for Montana provide a reasonably good first approximation (see pages 1.10 through 1.13).

Bridges

Sizing is accomplished by modeling with hydraulic programs, and evaluating backwater conditions on rivers with official floodplain mapping. County floodplain regulations generally allow no more than half a foot of backwater for bridge designs.

Smaller bridge structures should seek to accommodate the bankfull channel width with a clear span, and avoid constricting the channel during major flood events (25-year or greater). Designs should pass estimated flood peaks without significant backwater (pooling) upstream. Relief culverts may be needed in side channels or floodplain areas.

Culverts

At a minimum, drainage culverts should be sized to allow passage of a 25-year flood event with a full inlet. On perennial streams, consider sizing the pipe to pass the 100-year event to minimize backwater conditions. The culvert size required to pass a 100-year flood event may be no more than one size larger than that needed for a 25-year flood event. Adequate capacity is especially important on streams with high bedload transport, icing potential, or large amounts of woody debris. Culvert designs with arch, box-shaped, or round pipes with flared inlets provide better peak flow passage than standard round pipes.

Fords

Properly sited and constructed fords can replicate natural channel geometry and thus do not normally have peak flow capacity or debris problems. For this reason, fords may be a viable alternative to fixed structures in some situations.

This bridge is set slightly above bankfull, but does not have wingwalls. Location on a meander is not ideal, although upstream rip-rap limits lateral movement. Note that the point bar is still growing under bridge.

This arch pipe is sized to carry the predicted 25-year flow, but causes backwater at the 100-year flow.

A half-hearted effort at armoring the inlets, but note that the pipes are set below grade, which is good for fish passage.

BEDLOAD / WOODY DEBRIS / ICE CAPACITY

In river systems with high bedload transport, or large amounts of woody debris, the crossing structure must allow for passage of these materials. High bedload transport channels have characteristically large width-to-depth ratios. A bridge or culvert cross section has a much lower, fixed width-to-depth ratio. Even in the absence of large backwater effects, the change in channel hydraulics through a structure can interfere with sediment transport.

Bridge and culvert design must account for:

- Probable reductions in stream cross section and flow area with gravel deposition (or debris catchment).
- Bedload conveyance through the bridge cross section or culvert.
- Potential changes in channel alignment and bank erosion in adjoining reaches.
- Ice jams and woody debris.

Bridges are generally preferred to culverts where debris, ice, and bedload sediment concerns are significant. Proper sizing for 25-year to 100-year flood conditions generally addresses bedload, debris, and ice concerns by ensuring adequate peak flow capacity. Woody debris passage generally requires 1 or 2 feet of clearance between the bottom of the bridge stringer and the high water surface. Ice passage also requires extra clearance.

A rule of thumb on smaller bridges is to allow at least 2 feet of clearance between the top of the stream bank or floodplain and the bottom of the stringer. If debris jams and icing are a problem, increase the span, do not use center piers, and include ice breakers on the front of piers.

This undersized culvert caused large amounts of gravel to deposit in the channel upstream. Woody debris must be cleaned frequently from the inlet.

This bridge stringer was set below bankfull, and had problems with ice jams and flow capacity.

Debris jams are often associated with center piers on bridge crossings. A clear span is preferable to piers.

ROAD APPROACHES

Road approaches require planning

- Road approaches at stream crossings should be graded to rise slightly to meet the abutments.
- Gently rising approaches reduce the potential for storm runoff to deliver road sediments to the channel.
- Stream crossings should be located to accommodate optimal approaches when possible.
- Long, steep grades and side cast fill may deliver significant amounts of sediment to streams.
- Install proper drainage features such as rolling dips, cross drains, road crown, and ditches.
- Follow state BMPs to minimize sedimentation.
- Avoid long road approaches that form a dike across the floodplain.

Guidelines

- Maintain road approaches at 2 percent grade or less, and preferably rising to meet the abutment.
- Drainage features should be provided every 200 feet on long downhill approaches. Route drainage through a filtration zone before entering a stream.
- Select a crossing location to avoid long road segments that sidecast road fill into the stream or floodplain.
- Stabilize road fill with reseeding, slash windrows, hay bales, erosion fabric, or silt fence to prevent sedimentation of channels.
- Some level of hydraulic or structural engineering analysis should be performed for most bridge crossings.

Stream crossings with long, steep downhill approaches often route sediments directly to the channel.

Stream crossings on shallow channels with broad floodplains must rise to meet the bridge, or the bridge will end up being too low, like this one.

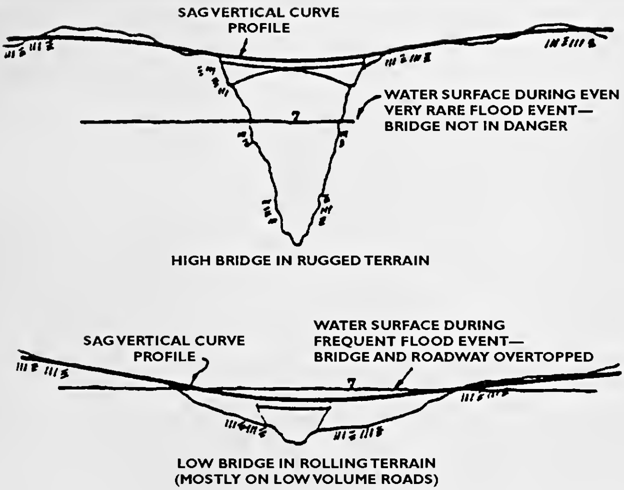
CAUTION:

- Long, steep road approaches to the stream crossing should be avoided.
- Proper drainage must be provided to avoid routing surface water runoff into stream channels.
- Long, in-sloped ditches must not channel runoff into the stream or floodplain.
- Avoid diking the floodplain with long elevated road approaches across broad flat valley bottoms.

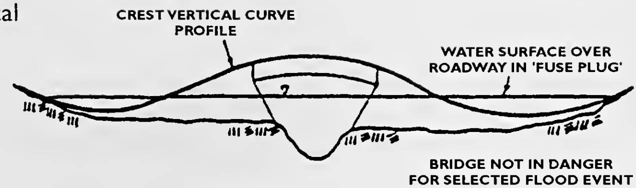
ROAD APPROACHES *(continued)*

When possible, road approach fills for bridges and culverts should be placed low and near the floodplain elevation so the road will be overtopped before the bridge or culvert is washed out. This allows the relatively inexpensive repair of replacing road fill or surface instead of replacing a bridge or large culvert. By placing road approaches low, the road approach acts like an emergency spillway, passing flood waters that the bridge or culvert is unable to pass. Examples of road approach fills across floodplains and channels are shown below.

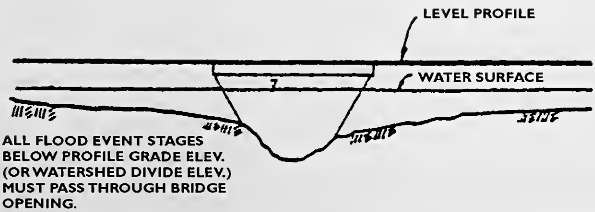
Sag-vertical curves



Crest-vertical curve



Level profile



From FHWA HEC-20, *Stream Stability at Highway Structures*

BRIDGES

Well designed bridges are the preferred option for permanent stream crossings because they usually have the least impact on channel process and fish passage. Most bridges should be designed by an engineer, with hydraulic and structural analysis.

Typical small bridge construction

Timber

- Timber bridges are most applicable to stream crossing up to about 30 feet.
- Timber is suitable for light load requirements.
- Stringers can be raw logs, milled beams, or laminated beams.
- Raw log abutments can be labor intensive and have a short project life.
- Equipment needs for construction are modest.

Steel

- Railcars can be used for bridges 30 to 65 feet. Longer spans usually require piers.
- Steel I-beam, wood, or corrugated steel decking for 20 to 100+ foot spans.
- Long project life is an advantage of steel.
- Steel allows a longer clear span than timber, reducing the need for center piers, which can catch debris.

Concrete

- Typical small bridge design is a pre-stressed slab with poured concrete abutments.
- Use beam construction for larger bridges.
- Heavy load capacity and minimal beam depths for the slab (versus stringers and beams) are an advantage.
- An engineered design is usually required.
- Often used for abutments and wingwalls.
- Long project life.

Wood cribbing has a limited life, but can work well for smaller bridges. This bridge has adequate clearance for ice, debris, and peak flows.

Railcar bridges are popular and fairly solid, but often are not installed properly. This one is set low relative to bankfull, but it is a temporary installation.

The structural beam on many railcars hangs low and ends up falling below bankfull elevation.

ABUTMENTS AND PIERS

Abutments

- Abutment design must account for scour depth in the stream bed to prevent undermining of footings.
- Generally, the minimum depth for footings is below the frost line and piers should be well below the lowest point of the streambed at the crossing.
- Footings may need to extend 10 feet deep or more in unstable rivers.
- For most smaller bridge projects, observing the depth of nearby pools gives a good indication of minimum footing depth.
- Abutments can be constructed from a variety of materials, and should include wingwalls to stabilize road fill on the approaches.

Bridge Piers

Avoid designs with center piers if possible because they tend to catch debris, causing scour and channel instability during peak flows.

- Wood spans exceeding 30 feet, or steel spans approaching 50 to 60 feet, require piers for support.
- Longer bridge spans requiring heavy load capacity should have an engineering review.

A well-constructed abutment has adequate wingwalls to support road fill.

Concrete can make good abutments, provided the footing is placed below scour depth. This footing should be 2 feet lower.

A low stringer in an aggrading channel does not leave much room for water. Note that the beam hangs low in the center and restricts peak flow capacity and debris passage.

Stacked median barriers often make poor abutments. The absence of wingwalls, footings, and a 1:1 fill slope mean this bridge is likely to require additional maintenance.

STREAM CROSSINGS

CULVERTS

Culverts can perform well on stream crossings, provided they are properly sized to handle peak flows. Fish passage must be considered when selecting and placing a pipe.

Culvert styles

- **Round** – standard corrugated metal pipe.
- **Pipe Arch/Squash** – less backwater and lower final fill elevation than round pipe.
- **Arch** – wide open bottom facilitates passage of fish, debris, and sediment (available only in corrugated metal).
- **Structural Plate** – larger size of arch pipe, bridge substitute.
- **Plastic Round** – similar to round corrugated culvert, easy to handle, but can be harder to install properly. Indefinite project life.
- **Concrete Box** – flat concrete bottom is poor for fish passage.

Design and installation

- Size culverts to handle 25-year (minimum) to 100-year flood.
- Sizing is generally adequate when bankfull cross-sectional area is equaled.
- Inlet water elevation at design flow should not exceed the elevation of top of pipe (no headwater).
- Place culverts on grade, or slightly below grade of natural stream bed. Footings for bottomless culverts must be set well below the expected scour and frost depths.
- Place culverts below grade (1 to 2 feet) if oversized pipes are used to facilitate fish passage.
- Culverts must be long enough to accommodate road fill slopes.
- Inlet and outlet of pipe should be armored with rock to prevent scouring.
- Installation should be completed as quickly as possible during low flow to minimize impacts to fisheries and water quality.
- Install culverts at right angles to the channel whenever possible.

Undersizing pipes to save money is a poor strategy.

Bottomless arch or box pipes (shown here) promote fish passage and create less backwater than round pipes of the same size.

CAUTION:

- Proper siting of culvert crossings in a stable, relatively straight reach is critical.
- Culverts must adequately pass peak flows, debris, ice, and allow fish passage.
- Culvert crossings should be avoided in aggrading streams, or on laterally unstable stream locations.
- Fish passage considerations may require oversized pipes, baffled culverts, open-bottomed arches, or bridges.
- Corrosive soil or water conditions may damage metal pipe.
- Multiple side-by-side culverts should be discouraged because they catch debris and have a greater tendency to wash out.

CULVERTS (*continued*)

Culvert siting

Headwater channels (Rosgen A)

- Typically steep gradient channels with deep fill over pipe.
- Culvert length must be adequate to accomodate fill slopes.
- Fish passage is frequently poor due to shallow or high-velocity flows or long culverts.
- Open bottom arches are an alternative to enhance fish passage when required.
- Culverts can be oversized and then set below stream grade to promote fish passage.

Mid-valley channels (Rosgen B)

- Moderate gradient channels, often cobble bottom with narrow floodplains.
- Adequate ice and debris passage can be difficult to accomodate with pipes.
- Oversized culverts placed below grade (1 to 2 feet) can promote fish passage by allowing a gravel bottom to form in pipe.

Valley bottom channels (Rosgen C/D)

- Low gradient channels often with poor lateral stability.
- Undersized pipes can cause gravel deposition and channel instability upstream.
- Site selection in stable reach is critical.
- Bridges and open bottom arches should be considered to accommodate channel dynamics and debris.

Valley bottom channels (Rosgen E)

- Sinuous, narrow, deep channels, often silt or fine gravel beds with broad floodplains.
- Round and especially arch pipes can work well.
- Avoid raising fill across floodplain on approach road to crossing.

Downcutting channels (Rosgen G)

- Vertically unstable channels with downcutting.
- Scouring downstream of pipe will leave the "downcutting" pipe perched above grade at the outlet unless the stream grade is stabilized.

Concrete box pipes frequently have poor fish passage characteristics because of the smooth, flat bottom.

The shotgun (or perched outlet) culvert impedes fish passage, and can result from placing the culvert too high, or installing the culvert in a channel that has a tendency to downcut without grade control downstream of the outlet.

Multiple pipes are sometimes acceptable, but they can catch debris. Consider aluminum box or squash pipes.

STREAM CROSSINGS

CULVERT DESIGN AFFECTS FISH PASSAGE

Poor fish passage

1. Steep culvert.
2. Fast, shallow flow through pipe.
3. High jump at outfall.
4. No pool at outfall entrance.

Typically found in Rosgen A-, G- and sometimes B-channels. These installations can be complete barriers to fish migration and must be avoided on spawning tributaries.

Improved fish passage

Constructed approach pools

1. Flatter grade.
2. Deeper, slower flow.
3. Constructed approach pools.

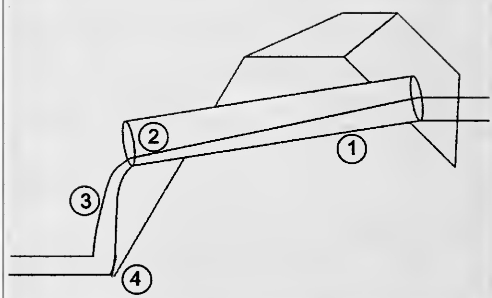
Useful in all channels with poor entrance conditions, especially Rosgen B, C, and G channels. Stable approach pools may be difficult to contruct in wide, shallow channels.

Optimal fish passage

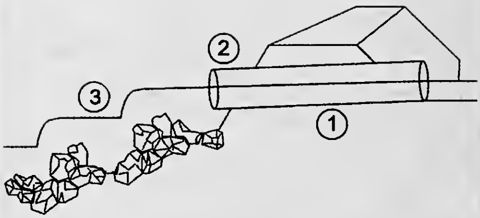
Culvert set below natural stream grade

1. Flat grade (less than 2 percent).
2. Deeper, slower flows allow formation of natural bed in pipe.
3. Pool at outfall.
4. Oversize pipe set 1 to 2 feet below grade.

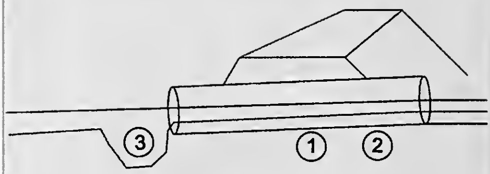
Steeper gradient streams may require rock pools. Shorter culverts are easier for fish to pass.



Poor



Better



Section 3 may require rock grade control on downstream riffle

Best

FORDS

Fords are used as a temporary crossing in wide shallow channels with gravel or cobble bottoms and infrequent traffic.

Applications

- Temporary crossings, gravel/cobble bottoms/light traffic.
- High width-to-depth ratio channels.
- Emergency access.
- Only used if impacts to channel stability, fisheries, and water quality are minimal.
- Generally, fords are not appropriate for permanent crossings.

Fords may be a viable alternative for intermittent or shallow wide channels that resist other solutions.

Design and construction techniques

- Unreinforced fords can be effective in solid substrate with light traffic.
- With heavier traffic (such as log trucks) or softer gravel channel bottoms, channels generally require some type of reinforcement.
- Reinforcement materials include rock, timber, concrete plank, geogrid, and filter fabrics.
- Size rock to resist scour and stream shear stress.
- Use filter fabric to prevent losing rock into soft channel bottoms.
- Geogrid rock/gravel-filled mats or fabrics are designed according to load requirements.
- Timber can be used for temporary crossing on small channels (such as winter logging with snow bridge over logs).
- Match the natural cross section of the stream as closely as possible to protect streambed stability.
- Consider the season ford will be used to minimize impacts to fisheries or water quality.

To protect water quality, avoid fords on perennial channels with poor approaches and inadequate drainage control.

CAUTION:

- Fords are not appropriate for deep narrow channels (Rosgen E type) or soft channel bottoms without reinforcement.
- Fords are not appropriate for most permanent installations unless traffic is very infrequent.
- Channel dynamics can be impaired if ford cross section does not match natural channel cross section.
- Sediment releases with traffic may cause unacceptable harm to fisheries.
- Fords may be subject to travel restrictions.
- Road approaches must not direct road surface runoff into channel.
- Fords are often seasonal crossings at normal or low flows only.

Irrigation Structures

IRRIGATION STRUCTURES

Selecting an appropriate design

Stream form and function

- Diversions should accommodate natural stream geometry and channel dynamics.
- Evaluate stream width-to-depth ratio, and match these dimensions if possible.
- Diverting water leaves less water in the stream to carry the same sediment load, likely leading to aggradation and channel instability.

Careful design helps reduce impacts to the stream and cuts maintenance costs on irrigation diversions.

Channel stability and capacity considerations

- Ensure that vertical and lateral channel stability is adequate.
- Evaluate effects of permanent rock weir versus removable structure (permanent structures may aggrade).
- Permanent instream structures should not restrict channel capacity when not diverting water.

Period of diversion

- High Water Operation – ability to regulate peak intake rates is important to prevent ditch failures.
- Low Water Operation – maintaining sufficient head to fill ditch can be challenging as stream drops.
- Year Round Diversion – icing and regulation of flows may make year-round diversions difficult.
- Type of Structure – permanent and temporary structures each have advantages.

Headwater elevation required

- Required ditch operating elevation and high/low water elevations in the stream should be estimated.
- "Checking up" of water should be kept to the minimum height required to divert adequate irrigation water.
- Diversions requiring minimal checking of stream elevation include rock weirs, barbs, and temporary cobble berms.
- High head installations require structural methods, and may have greater impacts on channel stability.
- High head and even low head structures can pose a hazard to boaters and anglers.

Fish passage

- Fish passage can be impeded by structures with drops exceeding 1 foot, or drops with poor entrance conditions and staging pools.
- Flat sills or diversion floors downstream of drop structures impede fish passage.
- Low head structures promote good fish passage.
- High head structures require some modification to facilitate fish movement.
- Fish ladders can be incorporated into the design if water availability is adequate to allow a flow of several cubic feet per second to continue past the diversion.
- In some cases, a "wasteway" ditch for return of excess diverted water can provide fish passage around an irrigation structure.
- Fish screens can be used at irrigation inlets to prevent fish from entering.

CONCRETE / WOODEN PIN & PLANK DIVERSIONS

Formed concrete diversions are generally similar in form and function to standard wooden pin and plank type structures.

Applications

- High head check structures (greater than 3 feet).
- Low width-to-depth ratio channels.
- Concrete is preferred when frost heaving could damage a wood structure, or a special shape or function is required (pneumatic spillway gates, fish ladder, or a combination bridge crossing and diversion).

Concrete may be preferred to wood for longevity. This structure is not fish friendly because of the height of the drop and the flat slab downstream.

Design and construction techniques

- The open area of an unchecked diversion should accommodate the bankfull width of the stream.
- Structures should not impede floodplain function.
- Collapsible or removable braces are recommended in streams that carry significant amounts of woody debris or have a history of ice jams.
- Keep stopboards under 4 feet in length for ease of handling.
- Wingwalls must be of adequate length to retain fill materials.
- Provisions for fish passage should be considered.
- A sluiceway can be designed in the floor to enhance fish passage at low flows (post and irrigation season).
- Standard designs are available throughNRCS offices.

Wooden diversion structures have a limited life but are easily constructed.

CAUTION:

- Backwater can cause bedload gravel to accumulate, destabilizing the stream channel.
- Icing and spring peak flow can damage the structure if flashboards are left in place.
- It may be difficult to adjust or remove stop boards during spring floods.
- Fish passage may be impeded unless mitigation measures are designed into the structure.
- Avoid restricting the channel cross section with abutments.
- Avoid placing a sill or slab above or below the grade of the existing stream channel.
- Avoid creating boating hazards, if possible.

ROCK V AND W WEIRS / VANES

Rock V and W weirs are used for grade control and can provide a means of diverting irrigation water in situations where a permanent structure will not cause problems with channel stability.

Rock weirs are appropriate on wide shallow channels where adequately sized rock is available. Use a "V" shape in narrow channels and a "W" shape in larger channels. Do not use weirs if a permanent change in bed elevation will adversely impact channel stability.

Applications

- Control channel bed elevation.
- Help guide water to ditch entrance.
- Promote bank stability by reducing grade and focusing flows to the center of the channel.

This weir has a relatively flat profile (without "cap" rocks) typical of an installation to check water at irrigation diversions. **Caution:** sediment transport can be reduced, causing channel instability in high bedload rivers.

Design and construction techniques

- Rule of thumb: maintain a 1 foot drop or less over each structure.
- Large angular boulders are best to prevent movement during high flows.
- Use footer rocks to prevent scour and undermining.
- Increased weir length means less fluctuation in water height with changes in discharge.
- Pools will rapidly fill with sediment in streams transporting heavy bed loads.
- Channel stability in meandering, gravel bed rivers can be very sensitive to weir design (shape, alignment, elevation, etc.).
- Boulder weirs are generally more permeable than other materials and might not perform well for directing low flows.
- Voids between boulders can be chinked with smaller rock and cobbles to maintain flow over the crest. **Caution:** this reduces sediment transport capacity and can severely impact the channel.
- With center at lower elevation than the sides, weirs will maintain a concentrated low-flow channel. ***Note: See weir description under "Hard Engineering Methods" (pages 6.2 and 6.3).***

GRAVEL BERM DIVERSIONS

Annual construction of gravel berms for irrigation diversions in rivers using heavy equipment has generally been discouraged by permitting agencies. Impacts on channel stability and fisheries can be significant.

Gravel berms may be appropriate:

- When impacts to channel stability and fisheries are judged to be minimal.
- On larger braided rivers where permanent structures are not feasible.
- When alternative practices are unavailable.

Alternatives

- Ditch cleaning to improve capacity.
- Low head rock V or W weirs and barbs.
- Relocation of ditch entrance upstream.
- Conversion to pumping station.
- Infiltration galleries (generally less than 5 cubic feet per second).

Design and construction techniques

- The gravel berm should be constructed to the minimum level needed to divert water.
- No gravel should extend above low water elevation.
- The length of berm and encroachment into the channel should be kept to a minimum.
- The berm should be knocked down or removed after the irrigation season to reduce impacts to the river channel.
- Minimize disturbance of streambanks and vegetation when using heavy equipment.
- Consider hauling gravels to site rather than excavating to avoid destabilizing the streambed.

Gravel berms are essentially an extension of the ditch. Relocating the ditch entrance upstream may reduce the need for instream berms.

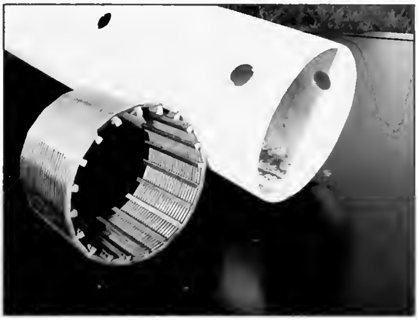
Berms, like barbs, can direct flow against the opposite bank and cause erosion on the other side of the river.

CAUTION:

- Leaving permanent berms in place can destabilize stream channels.
- Construction of berms can disturb incubating eggs and spawning fish.
- Alternatives to berms should be considered whenever feasible.

INFILTRATION GALLERIES

Infiltration galleries are constructed by burying rings, perforated pipe, or well screen in or adjacent to the stream channel, and daylighting the pipe in an open ditch downgradient.


Infiltration galleries make use of buried screens or perforated pipe.

Infiltration galleries may be appropriate for:

- Cobble and gravel bed rivers with low silt accumulation (Rosgen B and some C channels).
- Smaller (less than 15 cubic feet per second) diversion rates.
- Preventing entrapment of fish.
- Laterally unstable channels where conventional structures fail.
- Debris-laden channels.

Design and construction techniques

- Infiltration galleries require adequate hydraulic gradient (ditch-water slope).
- Engineering calculations are required to size the length and diameter of screen.
- Size of slots or perforations depends on riverbed gravel sizes.
- Provision must be made to prevent scour exposure of buried screen.
- Must provide access to allow backwashing (cleaning) of screens.

CAUTION:

- Annual maintenance is generally required with air or water backwashing to remove silts from the system.
- Channel downcutting, scour and fill, or migration can expose and damage the pipe.
- Design by an experienced engineer is recommended.

INFLATABLE GATE DIVERSIONS

Inflatable rubber or fabric bladders are most common as spillway control structures on dams. Water inflatable bladders can also be used alone without permanent structures for temporary diversions at construction sites or to control flooding. Both structurally supported and unsupported bladders may serve as irrigation diversions.

Inflatable bladder gates are generally used in specialized applications where precise control of water is important.

Use inflatable bladders:

- When precise control of headwater conditions is needed.
- When automatic control is desired.
- As an alternative to berms.
- To allow the release of diversion during flooding or emergencies such as debris jams.
- To help prevent ditch failures by improving control over diversion rates.

Design and construction techniques

- The base structure is similar to a concrete diversion structure.
- Precise concrete forming is required.
- Steel assembly is bolted to concrete.
- Steel panels fold nearly flush with structure when deflated.
- The compressor system requires electricity, but can be solar powered.
- Available in sizes suitable for small diversions.
- Engineering design recommended.

CAUTION:

- Bladders are sturdy, but can be damaged by debris, ice scouring, or excessive gravel deposition.
- Maintenance and electrical requirements may limit applications.
- Hire an experienced engineer to design the structure.

IRRIGATION STRUCTURES

FISH PASSAGE

Fish passage is often impeded by irrgation structures, especially check board structures that span the width of the channel. Fish passage is especially critical during spring and fall spawning runs.

Fish passage is promoted by low head diversions such as rock weirs, but is limited by high head diversions (flashboard structures), unfavorable velocity, or approach conditions (a common problem with culverts). Trout are detered by drops over 1 foot, especially if there is no approach pool. Types of fish ladders include baffles, pool and weirs, and controlled side channels.

Pool and weir structures can be made of natural materials or engineered structures.

Design considerations

- Maintain drops of less than 1 foot per structure.
- Provide an entrance pool before a drop, and an exit pool after a drop.
- A series of stop boards in 0.5- to 1-foot steps through wood floor structures offer adequate passage if flows are sufficient (more than 1 cfs).
- Fish passage requires allowing several cfs to flow past a diversion during spawing runs.
- Constructed channels or waste ditches can provide passage around irrigation structures.

The flat floor and high drop of a pin and plank structure limits fish passage unless fitted with a fish ladder.

Denil fish ladders have a series of baffles to allow fish passage for small diversions.

Denil fish ladders should be long enough to ensure that the outlet end is submerged during operation.

FISH SCREENS

Fish screening

Using fish screens on diversions prevents the loss of both juvenile and mature fish in irrigation ditches. Almost any size diversion can trap significant numbers of fish. Reducing flows to 25 percent and then closing ditches gradually over several days may allow fish to migrate back to the main channel. Although flow rates cannot be regulated under the 310 Law, voluntarily avoiding excessive diversion rates can help reduce fish losses throughout the irrigation season.

Fisheries agencies can help with design and funding for fish screens. Standard designs include flat screens with brushes and rolling drum screens. Infiltration galleries also can provide excellent fish protection.

Design considerations

- Screen mesh size is typically 1/8-inch to 5/32-inch to protect fry.
- Approach velocities to screen should not exceed 0.4 feet per second.
- A bypass pipe (commonly 10-inch diameter) or channel is needed before the screen to redirect fry to main channel.
- The bypass may require 0.5 to 2 cfs of water.
- Leakage around screens must be prevented with well-maintained rubber gaskets.
- Self-cleaning screens may include a paddle wheel, electric power grid, or solar power.
- Costs vary depending on design, but range from $1,000 to $3,000 per cfs of diverted water.

CAUTION:

- Screening should be designed by an experienced professional.
- Icing, peak flows, debris, and vandalism can readily damage screens.
- All screens require periodic maintenance including debris removal, lubrication, seal replacement, and protection from ice damage.
- Carefully control the diversion rate to avoid over-loading the screen capacity.

Portable drum screens are suitable for small flows (less than 3 cfs).

Large drum screens can accomodate a wide range of flows (from 5 to 50 cfs or more).

Fish screens are effective for preventing fish loss in irrigation ditches. A by-pass channel is needed to redirect fry to the main channel. A flat screen relies on brushes to clear debris.

HEADGATES

Standard headgates

Waterman C-10 and R-5 slide gates

Waterman gates are standard for small to medium diversions on all stream types.

C-10 gates work well when:

- Round culvert meets diversion needs.
- Positive seal for control of diverted water is needed.
- Adjustable diversion rates are important.

R-5 gates may be preferred when:

- Using squash pipes, or wood headwalls in medium to large diversions.
- Some leakage is acceptable and ice formation is not a problem.

Wooden gates

- Constructed with a dimensional lumber box and flashboards to control the diversion rate.
- Use on small diversions needing an inexpensive inlet gate.
- Some leakage occurs through the stopboards, which can cause icing problems

Design considerations

- Place headgates in a protected position to avoid damage by ice or debris.
- Placement on the outside of stable meanders more easily captures flows, but also more fish.
- Placement on inside of meanders results in sediment deposition at the gate.
- Use adequate fill to bed and bury the pipe.
- Headwalls are often required to retain fill.
- Headgate should be sized in accordance with the water right for that diversion.
- Consider installing fish screens (see page 4.8).

A C-10 gate generally benefits from a headwall to stabilize fill. Rock can work, but the slope leaves the gate frame exposed to ice and debris.

Typical prefabricated metal R-5 headgate structure used for squash or arch pipes.

This is a well-constructed gate with wingwalls and positive control at high flows.

DAMS AND DAM SPILLWAYS

Dams, berms, and dikes must be designed to be stable during saturated conditions. All dams and impoundments, whether on-stream or off-stream, require an emergency spillway to safely pass peak flows without eroding.

Design considerations

- Dams generally require engineering design to ensure that fill materials and foundations are appropriate.
- All dams must include emergency spillways capable of safely carrying the 25- to 100-year flood.
- Spillways must be designed with adequate freeboard to prevent overtopping of unprotected areas of the dike or dam.
- Earthen dam slopes must generally be shallower than 2:1 slopes (commonly 3:1 or less).
- Dam spillways can be rock, concrete, wood, or geotextile-lined vegetated swales.
- Consult with a qualified professional before constructing dams and spillways.

CAUTION:

- Construction of new dams on perennial streams may be limited by fisheries, floodplain, water rights, or other environmental considerations.
- On-stream dams tend to accumulate silt, impede fish passage, and may raise water temperatures.
- Many small dams do not have adequate spillways and are prone to failure during flood conditions.
- The appearance of leaks on the dam face or at the toe may mean failure is imminent, especially if seeps are muddy or turbid.
- Dam designs should be reviewed by qualified professionals.
- Also, see concerns listed under "Ponds (Impoundments)," page 2.3.

This unique drop structure is a concrete channel studded with rock to slow velocities. Structures are more commonly large rock or formed concrete.

Canal checks, or outflow pipes, are commonly used on small ponds to control water elevations. Canal checks and standpipe structures do not substitute for emergency spillways.

FLOW MEASUREMENT DEVICES

Water rights and flow measurement

The Montana Department of Natural Resources and Conservation or irrigation districts may require measurement devices on diversions and ditches to verify correct water diversion rates. Flumes located in ditch channels do not require the 310 permit for installation.

Parshall and Montana flumes

- Are most common in larger ditches and flat gradient applications where backwater needs must be kept to a minimum.
- Allow passage of sediment and debris.
- Can be designed to measure both high and low flows with an insert.
- Are available in pre-fabricated steel and fiberglass.
- Require suitable bedding material or concrete to prevent leakage around the structure.
- Become inaccurate if not level.

Rectangular, V-Notch, and Cipoletti weirs

- Are common in smaller diversions.
- Create backwater in the ditch because an upstream pool is required.
- Can catch sediment or debris.
- Can block fish passage out of a ditch if no entrance pool is present below the drop.

Parshall flumes cause minimal backwater, and work well in low-gradient applications.

The Montana flume is a shortened, less accurate version of the Parshall.

Design considerations

- Select the size of device based on both minimum flows and maximum capacity.
- Flat gradient ditches require devices (such as flumes) that create minimal backwater.
- Proper installation is required for accuracy. The device must be level, with no leakage or settling.
- Approach conditions for weirs require low velocities and "contracted" conditions for accuracy.
- Locate the device away from the ditch entrance to prevent damage by ice and debris.
- Design assistance is available from NRCS and water resources professionals.

Types of flumes

- **Parshall Flume**—less drop required, larger diversions.
- **Montana Flume**—inexpensive version of Parshall, less accurate.
- **Trapezoidal Flume**—lower backwater over range of flows than Parshall.
- **H Flume**—requires significant drop, best for canal turnouts.
- **Adjustable A Flume**—similar to Parshall but can be adjusted once installed for proper drop through flume.

FLOW MEASUREMENT DEVICES (*continued*)

Many types of specialized flow measurement devices are available beyond the more common types of flumes and weirs mentioned here. NRCS or other water resources professionals can help select and site appropriate devices for flow measurement.

Open channel flow

- Stage-discharge measurements can be used to develop a rating curve for an open channel with a staff gage.
- Rating curves are developed by taking flow measurements with a velocity meter at several different flow rates.
- Weed growth can shift the stage-discharge relationship during the irrigation season (especially in low-gradient ditches).
- Culverts can be used to estimate flow if conditions are "inlet controlled." This condition occurs when flow is constricted and it drops as it enters the pipe.
- Open channel rating curves developed for staff gages are not always an acceptable technique for water rights purposes.

CAUTION:

- Sizing a measurement device (or headgate) smaller than the water right could eventually forfeit the water right.
- The device must not restrict the channel if placed in natural stream.
- Access to the ditch easement for installation may be limited, making maintenance of structures difficult.

This large concrete structure functions as a cipoletti type weir.

Stage-discharge relationships can be developed for open channels (or culverts) to monitor flow in ditches.

Rectangular weirs can be used to estimate flow if pooling of water behind structure is acceptable.

IRRIGATION STRUCTURES

Soft Bioengineering Methods

BANK RESTORATION

Factors in channel form and process

Identifying the cause and solutions for bank instability can be relatively straightforward, or extremely difficult. When in doubt, professional advice is recommended before beginning a project on unstable streams. Basic factors to consider include:

- Channel type.
- Sediment transport.
- Aggrading or degrading conditions.
- Lateral movement (size of depositional bar and vegetation gives good indication of rate of movement).
- Relative condition of upstream and downstream reaches.
- Adjacent land management.
- Condition of woody, riparian vegetation.

Restoring this steep bank with site constraints is challenging, and may require bank sloping and moving the road. Clearly a potential project, but stream process must first be considered before presenting solutions.

Think about channel "process" before channel "project"

Understanding the underlying causes of bank instability is essential to selecting an effective bank treatment. Channel classification, aerial photos, and historical accounts can be helpful for interpreting channel process.

An eroding bank is often the symptom of larger channel instability in the stream system. Stabilizing an eroding bank with natural or engineered materials often does not address the underlying cause of bank erosion. In fact, extensive bank restoration in channels undergoing certain types of change can prevent the channel from making needed adjustments.

Relevant questions to ask (and hopefully answer):

- Is instability systemic or localized?
- Is bank instability only lateral, or is the stream adjusting vertically?
- Is instability accelerated or natural?
- Does land use or disturbance play a role?

Examples of factors commonly associated with localized erosion:

- Weak bank due to lack of vegetation or conversion from shrub to grass.
- Scour associated with channel obstructions (ice, structures, slumping).
- Extreme events (icing, peak flows, blowdown).
- Channel aggradation upstream of undersized structures.
- Bank failure or channel alterations upstream.

Potential causes of large scale, systemic type erosion include:

- Channel straightening.
- Highway and railroad encroachment.
- Extensive diking.
- Inherent, large-scale watershed processes.
- Extensive removal of vegetation in the watershed.

CHANNEL RECONSTRUCTION TECHNIQUES

Modifying channel grade and location

Channel restoration involving major changes to channel gradient, location, or geometry can produce substantial benefits when properly designed.

Applications

- Restoring channelized or diked reaches.
- Removing dams and other structures.
- Relocating away from hazards and infrastructure.
- Relocating due to highway construction.
- Restoring channels impacted by extreme events (debris flows, mass failure).
- Restoring channels impacted by land use (grazing, logging, subdivision).
- Creation of spawning channels or fish passage.
- Restoring a braided channel back to a single channel.

Design considerations

Design on larger projects generally requires input from specialists including hydrologists, geomorphologists, wetland-soil scientists, biologists, and engineers.

Funding may be available to help with channel restoration projects that enhance natural stream function.

CAUTION:

- Major modifications to channel gradient, shape, or location can be destructive if not properly engineered.
- Channel straightening is not generally acceptable.
- Relocating channels may require delineating wetlands, floodplains, and environmental impacts with professional assistance.

Re-establishing meanders in a channelized reach requires substantial hydrology and engineering design expertise.

Restoring natural channel width-to-depth ratio and alignment can improve stream function.

This meander has been restored with channel shaping, grade control structures, root wad/woody debris, and bank sloping sod mats.

SOFT BIOENGINEERING

River stabilization or restoration?

Set clear objectives

When selecting bank treatments consider the level of protection needed, and whether the project is intended to be "restoration" or "stabilization."

Restored banks

For restoration, banks are designed to replicate natural channel stability, and allow some bank movement over time comparable to natural rates. These projects will generally employ biodegradable fabrics and rely on vegetation established for long-term protection.

Stabilized banks

Stabilized banks are designed to withstand erosion irrespective of natural channel migration rates. These projects generally employ permanent fabrics or hard structural techniques such as riprap. Because hard armoring limits natural channel processes, they should be employed carefully to avoid adverse impacts to channel stability.

Soft bioengineering methods

Soft bioengineering methods may be preferred where:

- Adequate vegetation can be established within several years.
- Restoration has precedence over immobilizing bank.
- Costs are competitive with hard engineering due to material costs (usually the case).
- Risk associated with natural methods is acceptable.
- Hard methods are unacceptable due to potential channel impacts.

In combination with vegetation, synthetic and natural materials can provide excellent bank stability.

Stabilized bank using coconut fabric (same location as above) four months later.

Geotextiles such as jute, coconut fabric, and wood fiber are biodegradable and can last 2 to 4 years while vegetation becomes established.

GEOTEXTILE EROSION CONTROL FABRICS

Geotextile fabrics

Erosion control fabrics are made out of many different fibers. Some are completely biodegradable, and others include a plastic mesh matrix. Heavier weight fabrics are commonly referred to as Turf Reinforcement Mats (TRMs).

Natural Fabrics

- Coconut blankets
- Jute mesh
- Excelsior blankets
- Straw

Natural materials break down over several years (typically 2 to 4 years), and vegetation must provide long-term erosion resistance.

Synthetic Fabrics

- High-density polyethylene blanket
- Women polypropylene
- Geoweb

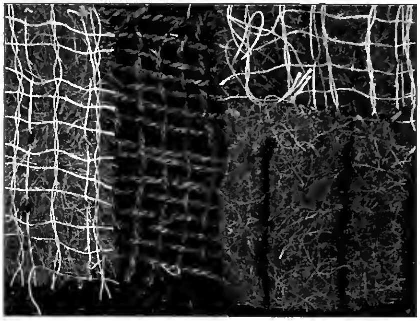
Synthetic fabrics are permanent and break down slowly over decades if exposed to sunlight.

Soft bioengineering can be strong

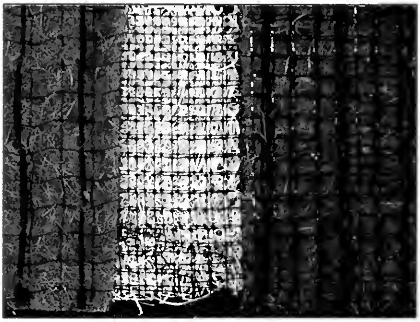
Turf reinforcement mats can provide the equivalent protection of 2-foot rip-rap with good vegetation.

Coconut or jute blankets typically last 2 to 4 years depending on conditions, at which time vegetation is most important for maintaining stability.

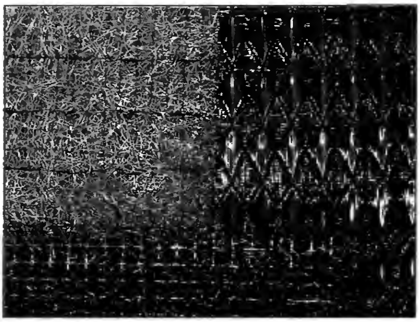
Plastic mesh can last 5 years or longer, providing continuing bank protection even in the absence of good plant cover. Synthetic fabrics provide a high level of long-term protection, but can pose a hazard for fish and wildlife.



Natural fiber erosion fabrics are commonly made with coconut or jute.



Hybrid natural and synthetic fabrics combine natural fiber with long-lasting synthetic grids to increase longevity and strength.



Synthetic fabrics are long lasting, but can pose a nuisance to anglers and wildlife.

FABRIC-WRAPPED BANKS

Geotextile fabric-wrapped banks are an excellent alternative to rip-rap for stabilization of eroding banks with natural vegetation.

Applications

- Restoring eroding banks with low to moderate erosive forces.
- Alternative to rip-rap and other hard treatments.
- In conjunction with woody debris, brush layering, or tree revetment techniques.

Design and construction techniques

- Banks are sloped at 2:1 or less when possible. Steeper 1.5:1 slopes can be vegetated, but are more vulnerable to failure.
- The toe is stabilized as required (often with rock, large cobble, or woody debris).
- Geotextile fabric is wrapped over smooth slope with topsoil plus seed, or salvaged sod.
- Raw fill materials alone may limit seed or cutting establishment.
- Staples, wood stakes, rebar, and willow cuttings are used to help hold fabric in place.
- Cuttings or plantings can be incorporated into fabric banks, either through fabric, or in lifts.

CAUTION:

- Biodegradable fabrics eventually break down and rely on vegetation for bank strength.
- Unless stabilized, the toe of the bank can scour and undermine fabric.
- A mature geotextile bank can be nearly as solid as rip-rap, and can impair channel dynamics.
- Rock toes act as rip-rap and should be used only when absolutely necessary.
- Fabric may be vulnerable to damage from ice and drifting woody debris before vegetation matures.

A single wrap of jute mesh fabric with a rock toe provides immediate protection following construction.

Same bank as above 14 months later. This is essentially a hard stabilization approach because the rock toe makes the stabilized bank stronger than a natural bank.

Proper installation of fabric mats is essential to success, including adequate foldover of the toe, overlap of the mats, anchoring with staples, live stakes, etc.

SOFT BIOENGINEERING METHODS

WATTLES / FASCINES

Willow fascines, or wattles, are dormant branch cuttings bound together into long, cylindrical bundles. Fascines are placed in shallow trenches to reduce surface erosion on slopes.

Applications

- Wattles are commonly used as slope reinforcement methods above the high water line.
- Use on slopes gentler than 1.5:1.
- Ensure adequate soil moisture for rooting cuttings.
- Ensure adequate live plant material is available.
- Requires a minimum amount of site disturbance.
- Where appropriate, wattles should be used with other soil bioengineering systems and vegetative plantings.

Willow fascines are being staked at the toe of the bank prior to wrapping the slope with geotextile fabric.

Two years later, the geotextile bank is predominantly grass, but willows are becoming established at the toe.

Design and construction techniques

- Bundles are prepared from live shrubby material such as willow or cottonwood.
- Bundles are bound with heavy twine and staked with 2 to 3 foot construction stakes.
- Bundles must be kept wet, and can be prepared up to one week before placement.
- Bundles are typically 8 inches in diameter and 6 to 10 feet long.
- Bundles are set in shallow trenches, placed on the contour, and partially covered with fine soil tamped into voids.
- Fascines can be placed in multiple rows, or used as a single row at the toe of a bank.
- Use dormant material (late winter, early spring, or fall) cuttings.

CAUTION:

- Can be vulnerable to erosion when installed below the bankfull level.
- Not effective to control large mass movement on slopes.
- May require watering on arid sites for good establishment and survival.

BRUSH LAYERING

Alternating layers of live branches and compacted backfill can be used to stabilize a slope. This produces a filter barrier that prevents erosion and scouring from streambank or overbank flows, and provides immediate soil reinforcement. Geotextile or a rock toe is often used to ensure stability while vegetation becomes established.

Applications

- Stream banks with light to moderate lateral erosion and good vertical stability.
- Small patches of bank that have been scoured out or have slumped leaving a void.
- Appropriate after stresses causing the slump have been removed.
- Eroded slopes or terraces where excavation is required to install the branches.

Design and construction techniques

- Brush layers may be incorporated into many types of slope and bank reconstruction.
- Use live willows, cottonwood, or other plant material, preferably a species that will root.
- Shape the streambank to a grade of less than 1.5:1. Lay plant material on the successive "lifts" of a fill or in trenches cut successively from the bottom to the top. Soil removed from each successively higher cut is used for fill over the brush below.
- The cut material will vary in length depending on slope dimensions. Brush may be 6 feet or longer.
- Cut branches should be laid in a criss-cross pattern for greater stability.
- Use dormant plant material (late winter, early spring, or fall) cuttings.

Brush layer technique is used here in combination with coconut fabric to restore the bank and enhance habitat.

Four years later bank remains stable at this site. Three short low profile barbs were used to reduce near-bank velocities.

CAUTION:

- Typically not effective in large slump areas.
- Droughty soils may limit establishment of cuttings.
- Toe protection is required where toe scour is anticipated.

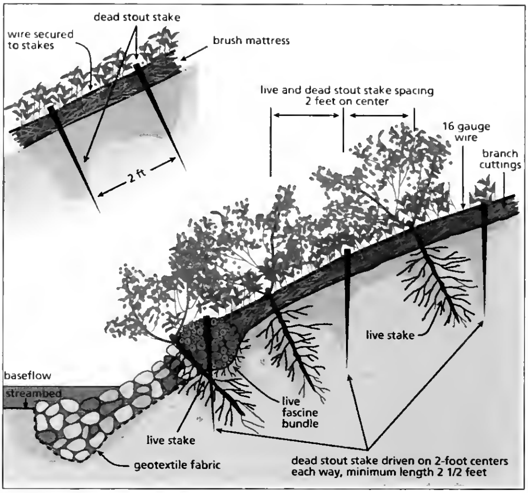
SOFT BIOENGINEERING METHODS

BRUSH MATTRESS

A brush mattress is a combination of live stakes, live fascines, and branch cuttings installed to cover and physically protect streambanks. Eventually, the cuttings sprout and establish solid vegetation. A mattress physically protects the streambank, captures sediment during flood flows, and enhances the establishment and growth of native vegetation.

Applications

- Stream banks with light to moderate lateral erosion and good vertical stability.
- Slopes of 1.5:1 or less.
- Terrace and floodplain areas.
- Appropriate where exposed streambanks are threatened by high flows before vegetation becomes established.
- Can be combined with a geotextile blanket for extra protection.



(At right) Brush mattress methods can be labor intensive, but can provide strong, natural bank stability. Shown is a combination of a rock armored toe, live facine bundles, and live stakes.

Design and construction techniques

- Layers of live and dead brush are laid in a continuous mattress from 4 inches to 1 foot thick.
- Brush is covered with wire netting or erosion fabric, or is secured with individual stakes and wire.
- Matting must be thoroughly anchored to prevent failure, and it must be protected from undercutting.
- One advantage of brush matting is that no heavy equipment is needed for installation.
- A disadvantage of brush matting is subsequent planting through the matting is difficult.
- Brush species that will root are preferred, such as willow, cottonwood, and dogwood.

CAUTION:

- Limited to the slope located above base flow levels.
- Droughty soils may limit the establishment of cuttings.
- Should not be used on slopes that are experiencing mass movement.
- Toe protection is required where toe scour is anticipated, but should be used only when absolutely necessary.

LIVE CUTTINGS

Live woody cuttings are tamped into the soil to root, grow, and create a dense root mat that stabilizes the bank.

Live willow cuttings seem to survive best when cut and planted in the early spring prior to bud break.

Applications

- To re-vegetate stream banks, slopes, floodplain.
- To repair small earth slips and slumps that are frequently wet.
- Effective where site conditions are uncomplicated.
- Construction time is limited.
- Inexpensive method if material is available.

Design and construction techniques

- Can be used to stake down geotextile erosion control fabric or stabilize areas between other soil bioengineering techniques.
- Where appropriate, should be used with other soil bioengineering and vegetative plantings.
- Enhance conditions for establishment of vegetation from the surrounding plant community.
- Stakes are 2 to 4 feet long, 0.5 to 1.5 inches in diameter, taken from 2 to 4 year old wood, and are inserted with basal end to water table or saturated soil.
- Consider dipping top ends into latex paint to aid in identification of cutting top and prevent drying out.
- Use rebar or dibble to speed installation with a starter hole.
- Most successful if planted in spring prior to leafing out, or in fall while dormant.
- Most native willow species are suitable.
- Beaver, rodents, and livestock can reduce survival of new plantings.
- Locations within the floodplain or where erosive forces are low can be sprigged with cuttings alone.

CAUTION:

- Requires toe protection where excessive toe scour is anticipated.
- Cuttings are most successful if used in conjunction with geotextile, woody debris, or rock treatments within the high water mark.
- Require protection from animals during establishment.
- Do not remove all live material from any one parent shrub or tree.

DORMANT POLE PLANTINGS

Plantings of cottonwood, willow, poplar, or other species are driven into streambanks to increase channel roughness, reduce flow velocities near the slope face, and trap sediment.

Dormant willow poles are effectively placed with a dibble on an excavator or backhoe.

Applications

- Most types of streambeds where poles can be inserted to reach the water table.
- Stabilize rotational failures on streambanks where minor bank sloughing is occurring.
- Establishing riparian trees in arid regions where water tables are deep.
- Will reduce near-bank stream velocities and cause sediment deposition in treated areas.
- Joint plantings in pre-existing rip-rap.
- Generally self-maintaining and will re-stem if damaged by beaver or livestock, but limiting livestock access will speed recovery.
- Best suited to non-gravelly streams and where ice damage potential is low.
- Poles are less likely to be removed by erosion than are live stakes or smaller cuttings.
- Can be used with geotextiles and vegetative plantings to stabilize the upper bank.

Design and construction techniques

- Poles are often used in conjunction with rock or geotextile treatments.
- Robust species such as yellow willow or cottonwood are preferred.
- Generally requires a dibble for effective installation of posts below water table.
- Use 1 inch to 5 inch diameter, dormant material collected in early spring.

CAUTION:

- Unlike smaller cuttings, post harvesting can be very destructive to the donor stand.
- Poles should be gathered as "salvage" from sites designated for clearing, or thinned from dense stands.
- Equipment access should be carefully planned to avoid damaging banks.

ROOT WADS / WOODY DEBRIS

Woody debris is an effective bank treatment in many eroding bank stabilization settings. Several approaches are possible including continuous "root-rap," individual root structures with geotextiles, and/or mature willow transplants.

Root wad protection may be appropriate when:

- Materials can be readily obtained without damage to riparian vegetation.
- Bank materials are cobble/gravel and not erodible sandy textures.
- Fish habitat and restoration is a priority.
- Installation of an effective root wad project is sensitive to careful construction technique.

Root wads and woody debris can provide substantial bank protection while enhancing fish habitat.

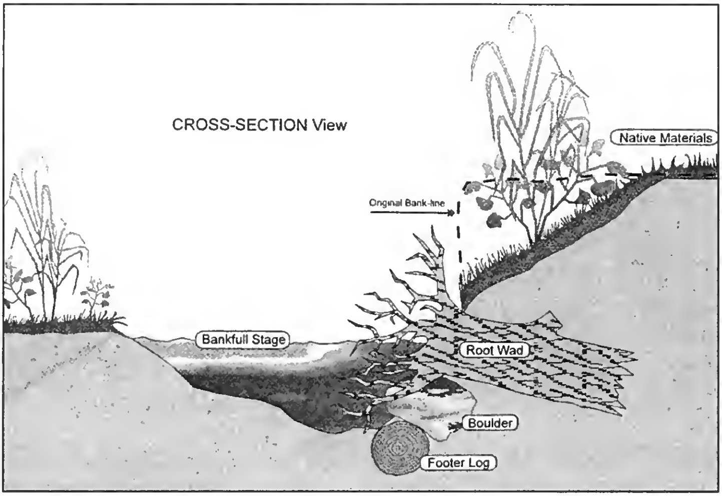
Design and construction techniques

- Will tolerate high velocities (greater than 10 feet per second) and erosive forces if logs and rootwads are well anchored.
- Native materials can trap sediment and woody debris, protect streambanks in high velocity streams, and improve fish habitat.
- Where appropriate, should be used with geotextile and vegetative plantings to stabilize the upper bank.
- Will have limited life depending on climate and tree species used. Some species, such as cottonwood, often sprout and improve stability.
- Site must be accessible to heavy equipment.
- High banks (greater than 6 to 8 feet) may limit successful placement and anchoring of tree trunks.
- Use root wads with 12 to 15 feet of the tree trunk attached. Anchor with a footer log and rocks one-and-one-half the diameter of the trunks. Tree trunk diameters should be greater than 18 inches, larger on large rivers.
- Install so the root ball remains partially submerged during low flows.
- May be used in combination with log or rock vanes.

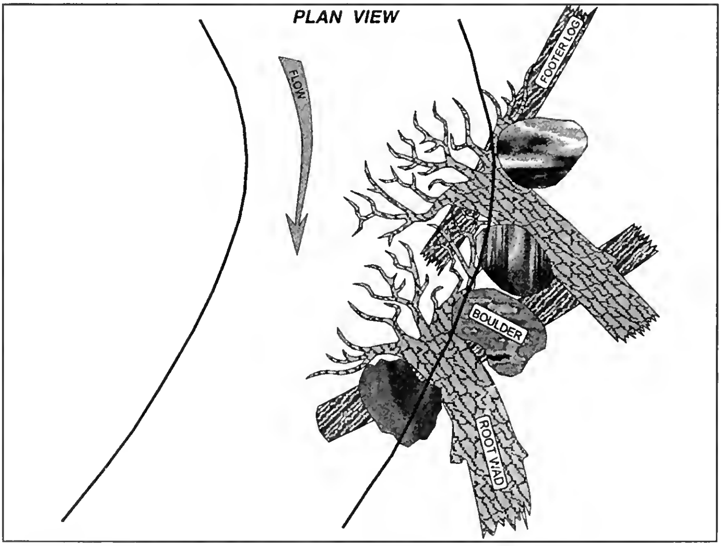
CAUTION:

- Can create scour and erosion with potential loss of structure if not adequately anchored.
- Might need eventual replacement if revegetation is poor or soil bioengineering is not used along with the structure.
- Can be expensive and time consuming to install, especially on high steep banks.
- Excavation for tree trunks and roots can destabilize banks and damage root systems of existing trees.

ROOT WADS / WOODY DEBRIS (continued)



Native material bank revetment, cross-section view. From Rosgen, 1993a.



Native material bank revetment, plan view. From Rosgen, 1993a.

SOFT BIOENGINEERING METHODS

TREE REVETMENT

A tree revetment is a row of interconnected trees attached to the toe of the streambank or to deadmen in the streambank. Revetment reduces flow velocities along eroding streambanks, traps sediment, and provides a substrate for plant establishment and erosion control.

Tree revetment should include substantial amounts of finely branched material along with trunks overlapping with the treetops facing downstream.

Applications

- Bank heights under 10 feet and bankfull velocities under 6 feet per second.
- Vertical stability is adequate: lateral bank erosion is moderate.
- Can use inexpensive, readily available materials.
- Low-cost, low-tech treatment is desired.
- Captures sediment and enhances conditions for establishment of plants.

Design and construction techniques

- Enhanced protection by incorporating branches and tree tops rather than trunks only.
- Where appropriate, use geotextiles and vegetative plantings to stabilize the upper bank.
- Use uprooted, live trees laid on their sides and secured to the bases of banks along eroded stream segments, tops pointed downstream and overlapped about 30 percent.
- The best species are those with abundant, dense branching to promote sediment trapping, and trees that are decay resistant.
- To determine tree size: the diameter of the tree's crown should be about two-thirds the height of the eroding bank, and trees greater than 20 feet tall are most economical for most applications.

CAUTION:

- An adequate anchoring system is essential. Inadequate anchoring will allow the trees to float and move back and forth against the bank, causing accelerated erosion.
- Revetment has a limited life and must be maintained or replaced periodically.
- Ice flows may damage revetment.
- Do not install directly upstream of bridges and channel constrictions because of the potential for downstream damages if revetment dislodges.
- Should not be used if the revetment would occupy more than 15 percent of the channel's cross-sectional area at bankfull level.
- Requires toe protection where toe scour is anticipated.

COCONUT FIBER ROLLS

Fiber rolls are cylinders of coconut husk fibers bound together with twine woven from coconut material. These can be used to protect the toe of a slope from erosion, while trapping sediment that encourages plant growth within and behind the fiber roll. Fiber rolls are easily installed with wooden stakes and over time will blend in to the natural environment.

Coconut logs may be used with geotextile fiber mats for bank protection. The application above relied on a rip-rap toe to stabilize the streambank.

Applications

- Low to moderate strength toe stabilization is needed in conjunction with restoration of the streambank.
- When the sensitivity of the site allows for only minor disturbance.
- Stream velocities and scouring are low to moderate.
- Can be molded to the existing curvature of the streambank.
- Requires minimal site disturbance.
- Have an effective life of 2 to 3 years.
- Are often used with soil bioengineering systems and vegetative plantings to stabilize the upper bank.
- Are typically staked near the toe of the streambank with dormant cuttings and rooted plants inserted into slits cut into the rolls.

SOFT BIOENGINEERING METHODS

Design and construction techniques

- Most commonly available in 12-inch diameter by 20-foot lengths.
- Place rolls on surface, or sometimes in a shallow trench or bench cut in the bank.
- Stake with 2- to 4-foot stakes on 3-foot centers.
- Use heavy twine to lash down each roll between stakes.
- Submerge roll at a constant depth of one-half to two-thirds of the roll's height to ensure plant survival.
- Plants can be plugged into roll after it has been in the water a short time. To ensure plant roots extend into the soil, plug plants into the sides of the roll or in soil between lifts.
- The recontoured soil behind the roll should be seeded and covered with an erosion control blanket to prevent slope erosion.

CAUTION:

- The rolls are buoyant and require secure anchoring.
- Not appropriate for sites with high velocity flows, high scour potential at the toe, or large ice build-up.
- Can be expensive and labor intensive to provide adequate staking.

Hard Engineering Methods

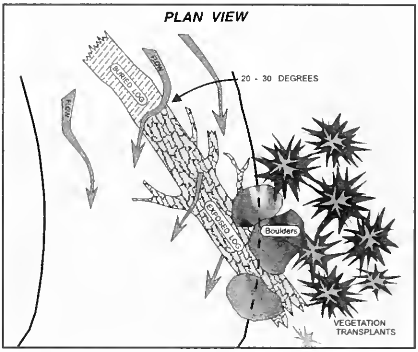
BARBS / VANES

A barb, or vane, is a low profile, sloping stone sill angled upstream. Barbs help reduce bank erosion by re-directing currents away from the bank, and are commonly spaced along the bank similar to bendway weirs.

Use barbs/vanes to:

- Reduce bank protection needs (rip-rap size and quantity) and promote natural banks.
- Protect banks for gentle (wide radius) meanders, or relatively straight banks.
- Help deflect ice and woody debris from vegetative bank treatments while they become established.

Barbs are constructed with a low sloping profile and gently "roll" the current away from the bank.



Log-spur bank feature. From Rosgen, 1993a.

Design and construction techniques

- Design parameters, particularly for shape and orientation, are somewhat subjective.
- Design and installation requires a substantial amount of professional judgment.
- Spacing: variable with meander curve (75 to 150 feet is typical on major rivers).
- Key requirements: keyed into the bank (15 feet typical), and bed (4 to 6 feet typical) for larger rivers.
- Slope of barb: generally replicates natural point bars.
- Length: variable with channel (up to one-quarter base flow width in some cases).
- Barb angle: variable with radius of meander curve and current approach angle (20 to 30 degrees
  from bank is common, but can vary according to design criteria).
- Rock size: according to shear stress and scour (2 to 4 feet diameter rocks are typical).
- Barb elevation: variable, from matching natural gravel bars, to several feet above stream bed.
- Downstream "boil" or turbulence, or upstream eddy, indicates problems with installation.
- Can include a "j" hook at the end.
- Can be constructed out of rock, logs, or a combination of both.

CAUTION:

- Erosion ("scalloping") will occur if incorrectly designed (too high, wrong angle in river, poor site).
- Barbs are not appropriate for tight radius meanders.
- Barbs often perform poorly in strongly aggrading or degrading channels.
- Design barbs for optimum performance at high flow.
- Incorrect design can cause scouring, destructive eddies along bank, and channel shifts.
- Experienced design and installation is important to success. Failure can be dramatic.

HARD ENGINEERING METHODS

BENDWAY WEIRS

A bendway weir is a low-profile upstream-angled stone sill keyed into the outer bank of a bed. Bendways are used to deflect flows away from the bank and can provide an alternative to rip-rap for bank protection. Bendway weirs reduce erosion by reducing flow velocities on the outer bank of the bend, and by re-directing current alignment through the bend and downstream crossing.

A bendway weir has a gradually sloping profile which shifts the main channel of the river to the outside of the structure. Peak flows continue to use the channel cross section above the weir elevation.

Applications

- Use on long reaches of relatively straight or gently curving banks that need protection.
- Use to reduce bank protection needs and promote natural banks.
- Bendways should be designed by an engineer and constructed by an experienced contractor.

Design and construction techniques

- Bendway design varies according to engineering specifications.
- Bendways are keyed into the bank (15 feet is typical).
- Spacing: variable with meander curve and tangent of current streamline (150 feet is typical on big rivers).
- Slope: replicate natural point bars, and sometimes steeper.
- Length: variable with channel width, ususally less than 20 percent of channel width.
- Weir angle: variable with meander curve (30- to 45-degree angle upstream typical).
- Rock size: according to shear stress/scour (2- to 3-foot rocks typical).
- Weir elevation: variable, from matching natural gravel bars, to several feet above bed.
- Permitting agencies will likely require flood modeling and an evaluation of channel capacity, sediment transport, and downstream effects.

CAUTION:

- Bendway weirs are generally not appropriate for rivers smaller than 100-feet bankfull width.
- Scalloping (bank erosion) will occur between weirs if incorrectly designed (too high or at the wrong angle in the river).
- Bendways are not appropriate for tightly meandering channels.
- Design bendways with high flow performance in mind.
- Incorrect design can cause the channel to cut a new path on the opposite bank.
- Projects should be designed by qualified, experienced professionals.

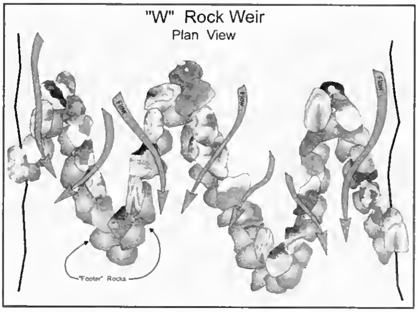
ROCK V AND W WEIRS / CROSS VANES

Rock V and W weirs are used for grade control and adjustment of width-to-depth ratio in existing or reconstructed stream channels. Upstream pointing Vs or Ws are preferred for bank protection because they provide mid-channel scour pools below the weir, which may be used as holding and feeding areas for fish.

This crossvane weir is designed to control width-to-depth ratio alignment at a bridge cross section. **Caution:** Sediment transport can be reduced causing channel instability in high bedload rivers.

Applications

- Use to control channel bed elevation and width-to-depth ratio.
- Reduces grade and directs flows to center of channel, which promotes bank stability.
- Can be used for irrigation diversion.
- Permanent bed elevation will not adversely affect channel stability.
- Provides wide shallow channels.
- Use "V" shape for narrow channels; "W" shape for larger channels.
- Adequately sized rock is usually available.



"W" rock weir. From Rosgen, 1993a.

Design and construction techniques

- Rule of thumb: maintain 1.5 feet or less of drop over each structure.
- Large angular boulders are most desirable to prevent movement during high flows.
- Require footer rocks keyed into the bank to prevent scour and undermining.
- An increased weir length will cause less fluctuation in water height with change in discharge.
- Pools rapidly fill with sediment in streams carrying heavy bed material loads.
- Boulder weirs are generally more permeable than other materials and might not perform well for diverting flows in irrigation applications.
- Designs should match natural width-to-depth ratio and avoid restricting channel cross sections.
- Downstream orientation can serve specific functions, but use caution to prevent failures.
- With center at lower elevation than the sides, weirs will maintain a concentrated low flow channel.

CAUTION:

- Improper design (often excessively high elevation, construction of channel, or poor alignment) of structure can cause scouring ("whirlpool effect") and destabilize channel.
- Weirs placed in sand bed streams are subject to failure by undermining.
- Weirs placed in strongly aggrading systems may become ineffective as sediments fill around structure.
- Potential to become low-flow fish migration barriers.
- Must avoid constricting high bedload channels.
- An experienced hydrologist or river engineer should assist with design of larger structures, or in unstable stream environments.

ROCK V AND W WEIRS / CROSS VANES (*continued*)

These large weirs eventually failed because they were built too high, and restricted sediment passage.

The same structure at left, prior to failure. The warning signs were apparent, notably the elevation of apex above the bed, and 2ft + high drop over the flat sill.

Large weirs must frequently be built in series to avoid large drops exceeding structural stability. Construction of weirs in high bedload transport streams always carries some risk of failure.

True "V" weirs generally have a row of cap rocks with spaces, rather than a flat sill. This promotes bedload passage (to some extent), but does not always work well for irrigation diversion needs.

Large weirs on unstable rivers can run to over $100,000 and still carry substantial risk of failure. Bedload deposition and scour can result in channel changes that bury weirs and scour away footings. Rivers may quickly cut new channels around the structure.

CHECK DAMS

Check dams are rock, wood, earth, and other materials placed across the channel and anchored in the streambanks to provide a "hard point" in the streambed that resists downcutting. Check dams can also reduce the upstream energy slope to prevent bed scour.

Use check dams:

- On intermittent or ephemeral gullies that are actively downcutting.
- To re-establish base grade or to build the bed of an incised stream to a higher elevation.
- To improve bank stability in an incised channel by reducing relative bank heights.
- To create fish barriers to protect genetically pure fish populations.

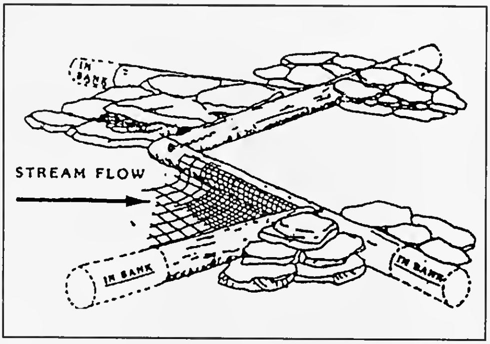
Check dams are most often used to stabilize actively downcutting channels (gullies), and are not generally recommended for use in perennial channels.

Design and construction techniques

- Common materials include rock, logs, wire fence and rock, and gabion baskets.
- Key the dam into bed and bank below scour depths and effects of lateral movement.
- Select rock size, spillway and apron, and crest shape based on a 25- to 100-year flood event.

CAUTION:

- Generally use check dams only on actively downcutting, ephemeral gullies.
- Downstream channel downcutting may continue and eventually undermine the dam.
- Siting of large structures may require geotechnical engineering.
- In perennial streams, check dams may block fish migration during low flows.
- An experienced hydrologist or river engineer should review the design of grade control structures.



Low stage check dam. From Seehorn, 1985.

RIP-RAP

Rip-rap and other hard armoring methods should be discouraged for stabilizing banks. Impacts on channel stability and fisheries can be significant. Consider other options, such as root wads, geotextiles, barbs, vanes, and bendway weirs. Where high strength is needed, consider turf reinforcement mats with a rock toe.

Use rip-rap only when:

- Long-term durability is needed.
- Design discharge and shear stress is high.
- There is significant threat to high-value property.
- Impacts to channel stability and fisheries would be minimal.
- There is no practical way to incorporate vegetation or wood into the design.
- Effective alternative practices are unavailable.

Design and construction techniques

- If you must install rip-rap, use it with bio-engineering and vegetative plantings to stabilize the upper bank.
- The key must be placed below scour depth.
- The toe is the most important part of a rip-rap project; this is the zone of highest erosion.
- Rock is unnecessary above high water mark.
- 2:1 is the recommended slope; 1.5:1 is the steepest slop on which rip-rap will stabilize.
- Rock must be angular, not rounded, for greatest strength.
- Rock is sized according to shear stress criteria for engineered designs.
- Filter fabric is needed where sandy textures will result in loss of fines through rock.
- Can be vegetated (see Pole Plantings, page 5.10).
- Rip-rap is flexible and not impaired by slight movement from settlement.

An engineered rip-rap bank provides a high degree of protection, but diminishes natural river values.

A well designed rip-rap job has 2:1 slopes and does not encroach on the river. This bank could probably have been stabilized using geotextile and vegetative methods with equal success.

This bank treatment has a rip-rap toe but uses geotextile for the bank and is a good compromise solution.

HARD ENGINEERING METHODS

RIP-RAP (*continued*)

Receding bank upstream of a rip-rap job will eventually lead to failure.

Rip-rap on channelized reaches will limit the ability of the stream to re-establish equilibrium.

Concrete is generally not acceptable for rip-rap.

Erosion has moved downstream below this rip-rapped bank.

Consider using softer vegetative techniques to stabilize banks whenever possible.

CAUTION:

- Do not use rip-rap where vegetative or soil bioengineering methods are viable.
- Rip-rap should not extend above the bankfull elevation.
- Rip-rap can be expensive if materials are not locally available.
- Install fabric or gravel bedding to prevent piping of fines.
- The design slope should not be steeper than 1.5:1.
- The bank should be sloped back to minimize rip-rap encroachment on the river.
- Keyed rock toe and key at ends of project are essential to long-term performance.
- Rip-rap may increase velocities and depth along treated bank, with significant impacts up and downstream.
- Rip-rap frequently interferes with natural stream dynamics, shifting problems to adjoining banks.

GEOGRID / GEOWEB CELLULAR CONFINEMENT TECHNIQUES

Geoweb cellular confinement systems can be used in a variety of configurations, including flat mattresses, stacking layers, and shapes assembled from combinations of baskets and mats. Cellular confinement systems can be vegetated for aesthetic or habitat purposes.

A cellular confinement system can be effective for steep slope stabilization and revegetation.

Use geoweb:

- Near vertical retaining walls on steep banks where sloping options are limited.
- To reduce rip-rap encroachments by constructing a steeper face above water levels.
- On engineered channels.
- To reinforce fords (using mattress style geoweb).

Design and construction techniques

- Geoweb can be cost-effective where a structural solution is needed and other materials are not readily available or must be brought in from distant sources.
- Fill material can be earth or rock depending on the application.
- Geoweb can be used with geotextile fabric and vegetative plantings to stabilize the upper bank.
- A stable foundation is required: often use a rock toe for river bank applications.
- Can be used on steep slopes (nearly vertical).
- More costly than rip-rap if rock is readily available.

CAUTION:

- Not appropriate for many instream applications.
- Best used above high water levels for bank stabilization.
- Requires experienced design and construction if installed on more extreme slopes or as retaining walls.

GABIONS

Wire gabion baskets can be used in a variety of configurations, including rectangular baskets, flat mattresses, and combinations of the two. Gabions can be vegetated for aesthetic or habitat purposes, but plant survival may be limited by poor growing conditions.

This gabion basket was undercut because of inadequate footing.

Applications

- Use gabions to make nearly vertical retaining walls on steep banks where sloping options are limited.
- Gabions can also form small bridge abutments, or headwalls for culverts.
- Gabions can be built where abundant 4- to 6-inch rock is available, and larger rip-rap is scarce.

Alternatives

- Live Crib Walls (steep slopes), see 6.12
- Geoweb Cellular Confinement (steep slopes)
- Geotextile Banks (1.5:1 slopes or less)

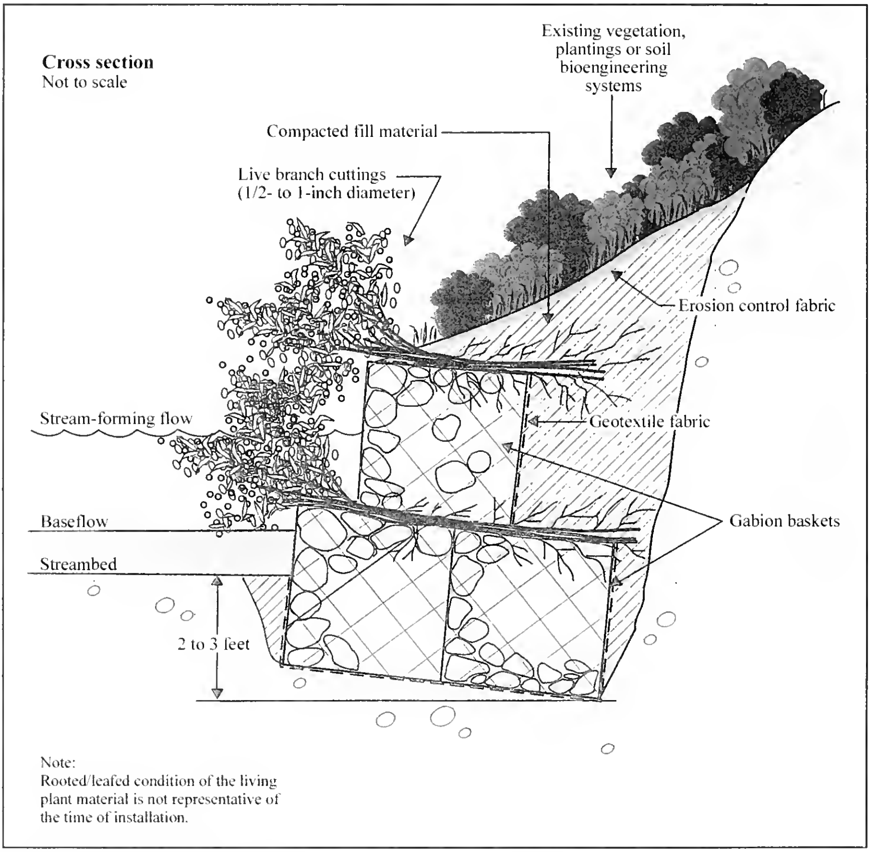
Design and construction techniques

- Gabions can be cost-effective where a structural solution is needed and other materials are not readily available or must be brought in from distant sources.
- Typical rock size is 4 to 6 inches.
- Use bioengineering and vegetative plantings to stabilize the upper bank.
- Adding soil to the basket will allow inserted cuttings to become established.
- A stable foundation is required, often uses a rock toe to bankfull elevation.
- Gabions are available in vinyl-coated wire and galvanized steel to improve durability.
- Rectangular baskets and flat mattresses are available.

CAUTION:

- Typically provide very poor fish habitats.
- Not appropriate in high bedload transport streams for bank stabilization or instream hydraulic structures.
- Abrasion or corrosive conditions can cut single or double wire baskets within 2 to 3 years.
- Wires can be hazardous for fishermen and boaters, and may be unsightly.
- Will not resist large lateral earth stresses from behind the gabion wall without special design.
- Can be labor intensive to install.

GABIONS *(continued)*



Vegetated rock gabion details, cross section view. 210-vi-EFH, December 1996.

RETAINING WALLS

Rock, timber crib, concrete, gabion

Median barriers don't usually make very good bridge abutments, or retaining walls.

An engineered gabion wall with a rock toe prevents abrasion of wire and undercutting of the footing.

Rigid structures such as median barriers rarely afford long-term success for bank stabilization.

A timber crib wall can use dimensional or raw logs.

Design and construction techniques

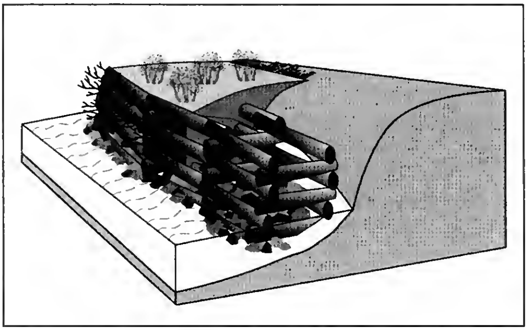
- Retaining walls require a solid footing keyed into the bed below scour depth.
- Walls must be designed to resist lateral pressure from behind wall.
- In unstable materials or for walls greater than 10 feet high, hire a qualified professional to design the wall.

CAUTION:

- The stream environment is a dynamic, flexible system.
- Use of rigid structures such as concrete walls, median barriers, gabions, and log sills frequently results in failure during natural channel adjustments.
- Avoid long, continuous retaining walls in streams.
- Retaining walls typically provide very poor fish habitat.

LIVE CRIB WALL

Live crib walls are box-like, interlocking untreated logs or timbers filled with alternating layers of soil material and live branch cuttings. Mature vegetation eventually takes over the structural functions of the cribbing. Crib walls are a possible alternative to gabion baskets.



Live crib walls can provide an alternative to gabion baskets for stabilizing steep banks.

Crib walls:

- Protect streambank with near-vertical banks where bank sloping options are limited.
- Afford a natural appearance and immediate protection, and they promote woody vegetation.
- Can be effective where a low wall might be required to stabilize the toe and reduce slope steepness.
- Are appropriate above and below water level where stable streambeds exist.

Design and construction techniques

- Cribbing may be raw logs or dimensional lumber.
- Crib slots must retain backfill material (streambank rock or cobbles).
- Crib should be anchored at least 6 feet into the banks.
- Alternating layers of fill and branch cuttings can be compacted into fill to provide vegetated walls.
- When possible, should be used with vegetative plantings to stabilize the upper bank or structure.
- Use untreated materials.

CAUTION:

- Keying cribs into banks requires a backhoe or excavator.
- Consider sloping bank back instead of vertical stabilization to reduce project costs.
- Crib walls are subject to undermining in downcutting channels.
- On slopes greater than 10 feet high or subject to mass failure, crib walls should be designed by a qualified professional.
- Crib walls are susceptible to damage from debris like ice, flooding, and rot.

Permitting, Design Construction

PERMITTING

Many permits may be applicable to projects affecting stream bed, banks, or floodplain areas. These may include:

- Natural Streambed and Land Preservation Act (310 Permit)
- Montana Stream Protection Act (SPA 124 Permit)
- Montana Floodplain and Floodway Management Act (Floodplain Permit)
- Clean Water Act (Section 404 Permit)
- Rivers and Harbors Act (Section 10 Permit)
- Short-term Turbidity Standard (318 Permit)
- Montana Land-use License or Easement on Navigable Waters
- Montana Point Discharge Elimination System (MPDES) Stormwater Permit
- State Streamside Management Zone Law (SMZ)

These permits have similar information requirements, and a joint application is required to process these applications except for MPDES and SMZ. Additional information is usually required for a floodplain permit and a land use license. An electronic version of the joint permit application is available online at www.dnrc.state.mt.us/permit.html.

Detailed information on individual permits is found in *A Guide to Stream Permitting in Montana* available from:

Montana Association of Conservation Districts
501 North Sanders
Helena, Montana 59601

This guide is also available online at www.dnrc.state.mt.us/cardd/strmpmt/stream.htm. Conservation district supervisors are not responsible for seeing that an applicant obtains all necessary permits.

Natural Streambed and Land Preservation Act (310 Permit)

This permit is required for any private, non-governmental person or entity that proposes to work in or near a perennial stream on public or private land. The permit is necessary for any activity that physically alters or modifies the bed or immediate banks of a perennially flowing stream. Joint application participant.

Contact: Local conservation district, Montana Association of Conservation Districts (above), or:

Conservation Districts Bureau
Montana Department of Natural Resources and Conservation
1625 11th Ave
P.O. Box 201601
Helena, Montana 59620-1601
Phone: (406) 444-6667

Montana Stream Protection Act (SPA 124 Permit)

This permit is required by any state, county, or municipal agency, and the U.S. Bureau of Land Management and U.S. Forest Service, that proposes a project requiring alteration of the bed or banks of any stream, perennial or otherwise. Joint application participant.

Contact: **Local office of Montana Department of Fish, Wildlife and Parks**

Montana Floodplain and Floodway Management Act (Floodplain Permit)

This permit is required for anyone planning new construction within a designated 100-year floodplain. Check with your local planning office to determine whether a 100-year floodplain has been designated for the stream of interest. Joint application participant in most counties.

Association of State Floodplain Managers
Montana Department of Natural Resources and Conservation
48 North Last Chance Gulch
P.O. Box 201601
Helena, Montana 59620-1601
Phone: (406) 444-6654 or (406) 444-6610
FAX: (406) 444-0533

Federal Clean Water Act (404 Permit)

This permit is required for any person, agency, or entity, either public or private, proposing a project that will result in the discharge or placement of dredged or fill material into waters of the United States. *Waters of the United States* includes lakes, rivers, streams (including intermittent), wetlands, and other aquatic sites. Joint application participant.

PERMITTING (*continued*)

U.S. Army Corps of Engineers
Federal Building
301 S. Park, Drawer 10014
Helena, Montana 59626-0014
Phone: (406) 441-1375
FAX: (406) 441-1380

Rivers and Harbors Act (Section 10)

This permit is required for construction of any structure in, under, or over a federally listed navigable water of the United States, the excavation or deposition of material in such waters, or the accomplishment of any other work affecting the course, location, condition, or capacity of such waters. Navigable waters in Montana are the Missouri River downstream of Three Forks, the Yellowstone River downstream of Emigrant, and the Kootenai River from the Canadian border to Jennings, Montana. Joint application participant.

U.S. Army Corps of Engineers
(address above)

Short-term Turbidity Standard (318 Permit)

This permit is required for any person, agency, or entity, either public and private, initiating a short-term activity that may cause unavoidable short-term violations of state surface water quality standards. The major application of this law is related to sediments and turbidity caused by construction or other activities. Joint application participant.

Water Protection Bureau
Permitting and Compliance Division
Department of Environmental Quality
1520 E. Sixth Avenue
P.O. Box 200901
Helena, Montana 59620-0901
Phone: (406) 444-3080
FAX (406) 444-1374

Montana Land-use License or Easement on Navigable Waters

This permit is required for any entity proposing a project on lands below the low water mark of navigable waters.

***Contact*: DNRC Land Office** or

Special Use Management Bureau
Montana Department of Natural Resources and Conservation
1625 11th Ave
P.O. Box 201601
Helena, Montana 59620-1601
Phone: (406) 444-2074

Montana Point Discharge Elimination System (MPDES) Stormwater Permit

This permit is required for any person, agency, or entity proposing construction, industrial, or mining activity that will discharge stormwater to Montana waters and construction that will disturb more than one acre within 100 feet of streams, rivers, or lakes.

Water Protection Bureau
Permitting and Compliance Division
Department of Environmental Quality
1520 E. Sixth Avenue
P.O. Box 200901
Helena, Montana 59620-0901
Phone: (406) 444-3080
FAX: (406) 444-1374

State Streamside Management Zone Law (SMZ)

This permit is required for any landowner or operator conducting forest practices that will access, harvest, or regenerate trees on a defined land area for commercial purposes on private, state, or federal lands.

Forestry Division
Montana Department of Natural Resources and Conservation
2705 Spurgin Road
Missoula, Montana 59801
Phone: (406) 542-4300

DESIGN EXPECTATIONS FROM A PERMITTING STANDPOINT

Design requirements depend upon the granting agency and expectations that may vary according to local policy. In all cases, stream project designs must be sufficiently complete to demonstrate the probability of success and any potential impacts of the proposed project. Engineered designs may be required, especially for larger scale, complicated, or intensive projects.

For all stream project permitting, a detailed description of the proposed work should include, at a minimum:

- ❑ Site map or drawing, including legal location.
- ❑ Dimensions of site where work is proposed. Use the high water mark, if known, as a point of measure.
- ❑ Quantities and types of materials (rock, trees, gravel, erosion fabric, etc).
- ❑ Construction techniques, including equipment used.
- ❑ Where excavated material will be placed.
- ❑ Revegetation and weed management plans.
- ❑ Timing of proposed work.
- ❑ How impacts to fish and aquatic habitat will be minimized.
- ❑ How impacts to the channel, erosion, sedimentation effects on water quality and stream flow, and the risks of flooding will be minimized.
- ❑ Expected benefits of the work.
- ❑ Names and addresses of adjacent landowners are required by some agencies, however, most conservation districts do not require this information.

A complete description of all proposed work is important, because any construction activity not explicitly described in the permit in writing may be considered to be a violation of the permit conditions. The applicant is responsible for providing enough information in his or her application to answer questions regarding potential impacts and mitigation of impacts.

The **310** permitting process requires the project to be effective for the intended purpose and protective of the natural streambed and banks. The 310 process is not intended to provide technical design review, certification of design, or substitute for engineering expertise.

A site visit by conservation district members is generally required to review proposed work.

The **124** permit requires projects to protect Montana's fishing waters such that they remain for all time in their natural existing state, except as may be necessary and appropriate after due consideration of all factors involved. Project applications are generally followed by a site visit by the local fisheries biologist. The permit includes requirements to protect fish and wildlife habitat and natural stream function.

The **Floodplain** permit is the local extension of DNRC floodplain and floodway management rules that are intended to minimize flood damage with floodplain developments. County floodplain permits may require engineered design to ensure certain criteria are met, such as stability in a 100-year flood, demonstration of no adverse impacts up or downstream, and analysis of effects on elevation of a 100-year flood.

The **Federal 404** permit focuses on waters of the United States, which includes lakes, reservoirs, ponds, stream channels with an ordinary high water mark, and most wetlands. This permit is required for placement of fill material in U.S. waters. U.S. Army Corps of Engineers 404 permits are required on many stream projects requiring a 310 permit, as well as on wetland areas and intermittent and ephemeral channels that have a high water mark. Many smaller stream or river projeedts fall under the streamlined 404 "nationwide" permitting system, which expedites processing of the application.

DESIGN EXPECTATIONS FROM A PERMITTING STANDPOINT *(continued)*

The **318** permit focuses on ensuring that proper sediment control measures are taken during construction to minimize impacts to water quality. Requirements are generally satisfied by the 310 permit for smaller projects that release minimal sediment to the stream. A separate 318 permit must be obtained for projects that have the potential to release significant amounts of sediment during construction.

Montana Point Discharge Elimination System (MPDES) considers water quality and sediment control on construction sites, and seeks to ensure that proper measures are taken to minimize potential impacts to surface water. Construction projects that have site disturbance near surface water, or that could discharge runoff to surface water, may require the MPDES permit. At a minimum, the permit requires a site drainage control plan with approved practices to minimize potential erosion and runoff from the site.

WETLANDS

Stream projects generally affect wetland areas to some extent, even if only along the edge of the stream channel. Impacts may be minimal, such as temporary access across soft ground during construction, or may include permanent changes, such as dikes, fill, or excavation. Although stream permitting may not address all aspects of specific wetland impacts, projects that directly or inadvertently affect wetlands can potentially be regulated by the 404 permitting process.

Identifying wetland areas that are "jurisdictional" under Clean Water Act Section 404 is not always obvious. Wetlands are defined by a certain combination of soils, vegetation, and hydrology. Wetland does not simply mean areas with standing, shallow water and cattails. Pasture, floodplain, swampy areas flooded from ditch leakage, may all be subject to wetland law. In more difficult situations, a trained specialist is required to make a "wetland delineation." National Resources Conservation Service staff, U.S. Army Corps of Engineers, and other trained professionals can make these determinations.

Because specific exemptions exist and federal wetland law changes over time, it is difficult to generalize about which stream projects or related activities may be regulated. The safe approach is to submit a 404 application to the U.S. Army Corps of Engineers, and let the agency make the determination about the project.

Applicants will be expected to describe where excavated fill materials will be placed (even if off-site), and the quantities and types of imported materials (such as rock) used on the project. Temporary or permanent access roads for the project should be accurately described.

Permitting through the Clean Water Act Section 404 may also require an evaluation of cultural resources, endangered species, historic structures, and other considerations related to federal law.

Wetlands frequently include areas adjacent to the stream channel that may not be wet during most of the year.

Wetland regulations may apply to activities in residential, agricultural, and industrial sites.

"Jurisdictional" wetlands include the entire area in this photo, not just the obviously wet area.

PERMITTING, DESIGN CONSTRUCTION

STORMWATER AND EROSION CONTROL BMPs FOR CONSTRUCTION

Construction planning and Best Management Practices (BMPs)

Efficient project planning can greatly reduce sedimentation by:
- Reducing the project duration.
- Reducing the number of times machinery enters the channel.
- Reducing overall site disturbance.
- Identifying appropriate BMPs for sediment control.

All projects should seek to:
- Minimize site disturbance.
- Preserve existing vegetation as much as possible.
- Use erosion control measures (hay bales, silt fence, drainage features, etc.).
- Reseed disturbed areas.

Dewatering construction areas with pumps requires a permit when discharging to state waters.

Sediment control is water control

Avoid excavation in running water whenever possible. Even gravelly substrates can release significant amounts of fine sediment during construction. Dewatering options may include:
- Isolating the work site with barriers (berms, tarps, coffer dams, sheet pile).
- Rerouting the channel around the work site.
- Dewatering with pumps, or diversion into irrigation ditches.

Dewatering a construction area requires a discharge permit to release discharge to surface water. Turbid water generally must be filtered through sediment retention structures prior to release. When dewatering the site causes more disturbance of the stream than installing the project in running water, silt fences, straw bales, or other sediment trapping devices should be used.

Construction timing

On river projects, the best construction time is generally during low flows in mid-summer, and sometimes in mid-winter when the ground is frozen. Fisheries, streamflows, and recreational concerns may restrict construction windows.

Construction activities with the potential to release fine sediments or dewater channels should be planned to avoid disturbing spawning fish and egg incubation. Both spring and fall periods may have spawning runs depending on fish species in the drainage. State and federal fish biologists can make recommendations during the permitting process. Construction timing may also need to consider impacts on recreational use, such as rafting or fishing.

WORKING WITH A LANDOWNER'S REPRESENTATIVES

Stream permit applications are often submitted by the landowner's representative: a consultant, construction contractor, or realtor. This person may not actually perform the project work.

A consultant, construction contractor, or engineer is often hired to design and oversee a proposed project. This person may be directly involved in the entire permitting process and implementation phase. For any of several reasons (costs, timing, etc.), however, landowners may change consultants or contractors during the process, or may plan to do the actual construction work themselves.

Out-of-state landowners sometimes hire a realtor to obtain the needed stream permits as a service to them. In these cases, the realtor's involvement usually ends here, and he or she will not be involved in the project construction stage.

It is therefore imperative that the landowner signs the permit application form, authorizing the consultant, contractor, or realtor to represent him. The decision form must also be signed by the landowner to ensure that he or she agrees to construct the project as permitted. All permit correspondence should be sent to both the landowner and his or her representative throughout the permitting process to ensure that the landowner receives all pertinent information. **The landowner is ultimately responsible for complying with conditions of the permit.**

WORKING WITH UTILITY COMPANIES ON STREAM PERMITS

When a utility company applies for a stream permit, the landowner's signature is not necessary because the company must obtain a legal right-of-way from the landowner before beginning project construction.

Glossary

GLOSSARY

Abutment – A concrete, steel, wood, or masonry structure receiving the arch, beam, truss, stringers, etc. at each end of a bridge.

Aggradation – Filling in, deposition; a reach where sediment accumulates in the channel is said to be aggrading.

Armoring – A layer of stone or other suitable material placed in the stream to protect the banks from erosion.

Avulsion – Creation of a new channel, usually during flood conditions.

Backfill – Adding dirt or gravel to replace material removed during construction or used in a void area such as behind a retaining wall.

Backwater – A rise in the water level upstream of an obstruction or constriction in the channel.

Bankfull discharge – The flow rate that moves sediment and forms or removes bars and meanders to maintain the average characteristics of a stream. The streamflow volume and depth that is normally 1.5-2 year frequency (may be 1-3 year on some streams).

Bar – A submerged or partly submerged deposit of sediment and gravel within a stream channel.

Barb – A low-profile, sloping stone sill angled upstream.

Bedload – Sediment or gravel that is not suspended in the stream but is rolled or dragged along the stream bottom.

Bendway weir – A low-profile, upstream-angled stone sill keyed into the outer bank of a stream or riverbed.

Berm – A strip of earth, usually level, built up to control surface water flows.

Best Management Practices (BMPs) – Guidelines for managing the use of a resource in a manner that protects the resource and promotes ecological and economic sustainability.

Bioengineering – Use of live, woody vegetation independently or in combination with engineering structures, for erosion control.

Bole – Trunk or stem of tree.

Channel migration – The movement or shifting of a stream channel across the width of its floodplain as banks erode and point bars expand.

Channel pattern – The winding of a stream channel as seen from above (in plan view).

GLOSSARY *(continued)*

Channel profile – The shape of a stream channel along its length or longitudinal axis. A stream's profile shows the nature and amount of elevation change over a given reach.

Channel slope – The gradient of a stream's bed; the downhill angle over which a stream flows.

Channelization – Straightening of a reach, or confinement within constructed earthfill (or other object).

Check dam – A small dam constructed in a gully or small watercourse to decrease streamflow velocity, minimize scour, and promote sediment deposition.

Crib – A hollow, structural wall formed out of perpendicular and interlocking wood beams.

Cutting – A branch or stem pruned from a living plant.

Deadman – A buried log or other large object serving as an anchor.

Debris – Materials which accumulate along and within a body of water, including logs, branches, etc., transported by water or ice.

Degradation – Scouring; a reach where sediment is removed is said to be degrading; often downcutting the bed.

Deposition – Settling out of sediment loads, which results in shallows, bars, and lateral channel movement.

Dike – A structure placed in the channel for the purpose of redirecting flow in the channel (see *Levee*).

Diversion – A structure constructed across a stream or river for the purpose of intercepting and diverting water.

Dynamic equilibrium – Changes in streambed load and bed material size are balanced by changes in streamflow or channel gradient.

Fascine – A long bundle of branches or other material placed to prevent erosion and soil movement.

Fish ladder – Angle iron or other baffles placed in a culvert to improve fish passage upstream.

Flume – A calibrated structure for measuring open channel flows. A conduit for conveying water across obstructions.

GLOSSARY (*continued*)

Footer log – A log placed below scour depth of a stream. Foundation for a rootwad and boulders.

Ford – A drive-through crossing of a stream or river.

Gabion – A wire mesh basket filled with rock that can be used in multiple layers as a structural unit.

Geotextiles – Fabric or matting made from natural fibers such as coconut or jute, sometimes woven into a plastic mesh.

Gradient – The amount a stream drops in elevation over a given distance; also referred to as "slope".

Head cutting – The upstream migration of the stream bottom due to erosion. A steep break in channel slope or bed, often unstable and migrates upstream.

Headgate – Water control structure at the entrance to a conduit or canal, such as an irrigation ditch.

Incised – A stream that has downcut (vertical erosion) is said to be incised when the bankfull flows (1.5- to 2-year) cannot reach the floodplain.

Infiltration gallery – A perforated conduit in or adjacent to the stream channel to divert water into a ditch, canal, water tank, etc.

J-Hook – A rock curved sill installed on the end of a barb or vane to direct the flow of the thalweg.

Key (in riprap) – Angular rock trenched into the streambed at the toe of the slope and trenched into each end of the stream bank to prevent scour under or behind the riprap.

Lateral instability – A condition where a stream channel is prone to migrating side-to-side across its floodplain.

Levee – A structure placed on the stream bank or floodplain and above the channel to prevent flood water from affecting dry land. A long linear dam that keeps a low area from flooding (see Dike).

Perennial stream – A stream or reach of stream that flows continuously. Conservation district administrative rules define a natural perennial flowing stream as a stream which in the absence of diversion, impoundment, appropriation, or extreme drought flows continously at all seasons of the year and during dry as well as wet years.

Pier – A support for the ends of adjacent spans in a bridge.

GLOSSARY *(continued)*

Point bar – The silt, gravel, or cobble that extends into the water from the inside of a bend or meander.

Revetment – A facing of trees, stones, or other material to reinforce a stream bank.

Resting pool – A deep pool downstream of the outlet of a culvert that allows fish to rest before swimming through the culvert.

Riprap – An assemblage of angular rock placed on the stream/river bank to protect it from the erosive forces of moving water or wave action.

Riparian – Areas adjacent to or influenced by water from streams and rivers, often referred to as the green zone .

Rootwad – A 10-20 ft. length of tree trunk and root mass placed in the stream with the trunk buried into the bank and the root mass extending out into the water.

Scour – The removal of underwater material by waves or current, especially at the base of a stream bank or shoreline.

Sediment – Solid material, both mineral and organic, that has moved from its site of origin by wind or water.

Spillway – A structure or channel used to convey water from a reservoir, to regulate the discharge of water.

Stringer – A long, horizontal timber, steel, I-beam , etc. spanning the abutments of a bridge, providing the foundation for the bridge decking.

Thalweg – The deepest part of a stream channel, where the fastest current usually occurs.

Toe – the base of a slope or stream bank.

Turbidity – Murkiness, cloudiness, caused by stirred-up sediment.

Vane – A low-profile, sloping stone sill angled upstream.

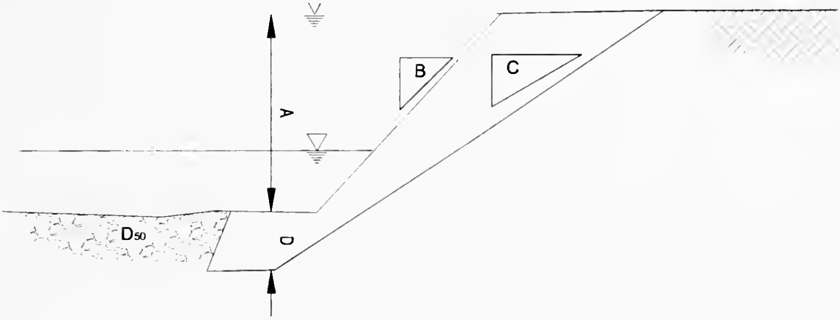
Wattle – Dormant branch cuttings bound into long, cylindrical bundles, placed in shallow trenches for erosion control.

Weir – A small dam in a river or stream.

Wingwall – A wall constructed at an angle to each side of the bridge abutment to prevent road fill material from entering the stream/river.

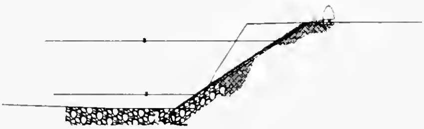
Appendix

Bank Protection Treatment

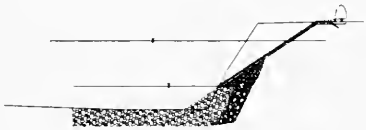


Bankfull Depth (Avg) A = ____________
Existing Slope B = ____________ (vertical, 1:1, 1.5:1, 2:1 3:1)
Bed Material (Avg Diameter) D_{50} = ____________
Bank Material (silt/clay, gravel, sand, ____________ (silt/clay, gravel, sand)
Existing Vegetation (none, grass, shrubs, trees) ____________ (none, grass, shrubs, trees)
Channel Slope (from Topo Map) ____________
Shear Stress (lb/ft^2) (τ ~62.4AB) ____________
Constructed Slope C = ____________ (vertical, 1:1, 1.5:1, 2:1 3:1)
Footer Depth D =
Bank Length
Design Bank Protection ____________ max moderate low
Design Bank Protection Technique:

Geotextile with Stone Toe

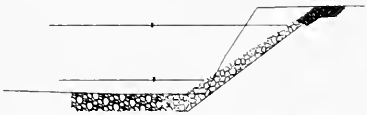


Geotextile with Rock Toe

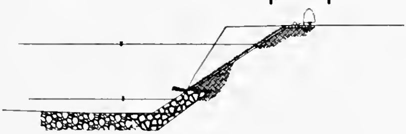


Root Wad

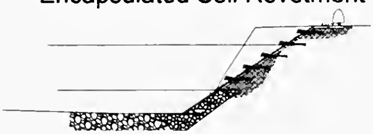
Rip Rap



Geotextile with Rip Rap Toe

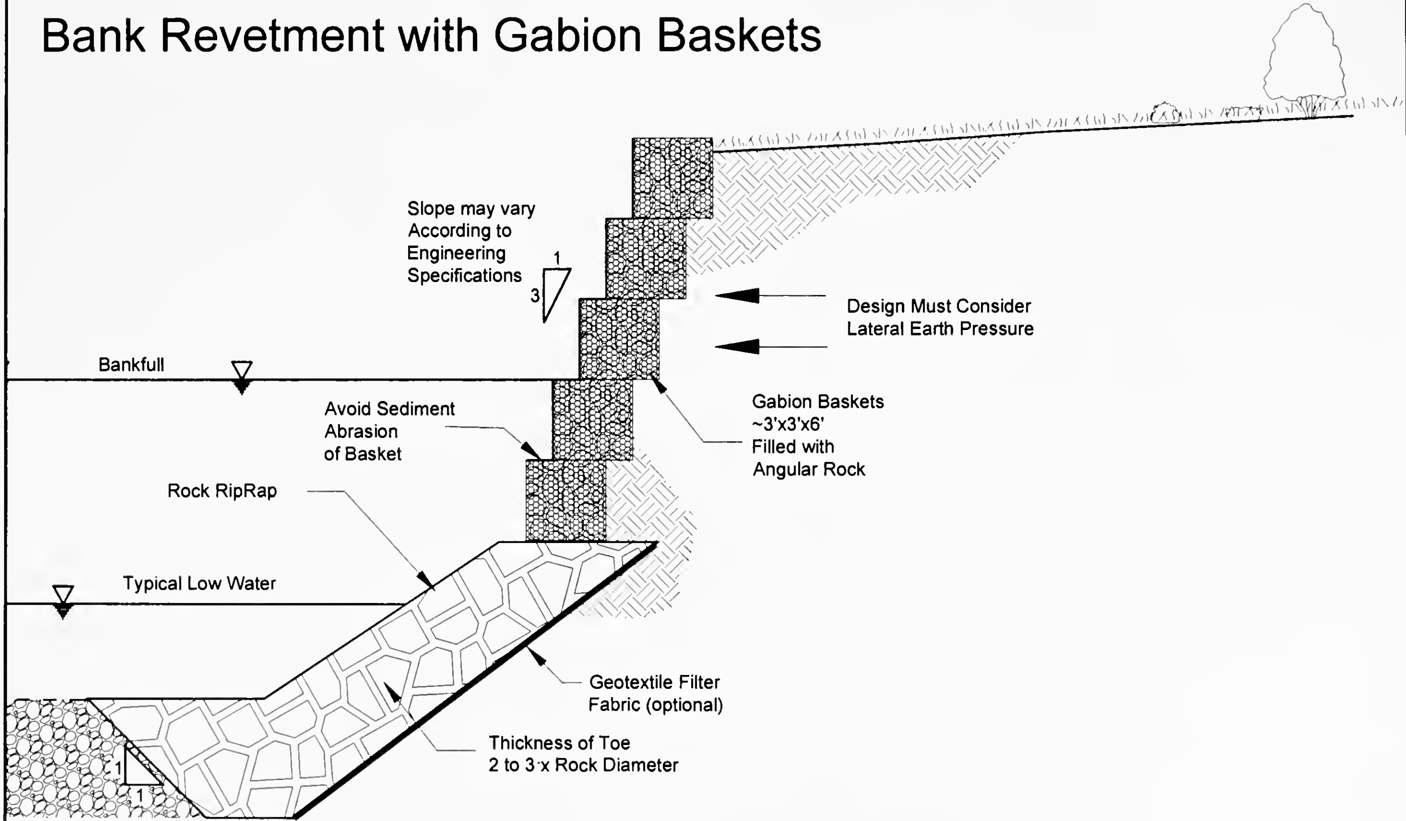


Encapsulated Soil Revetment



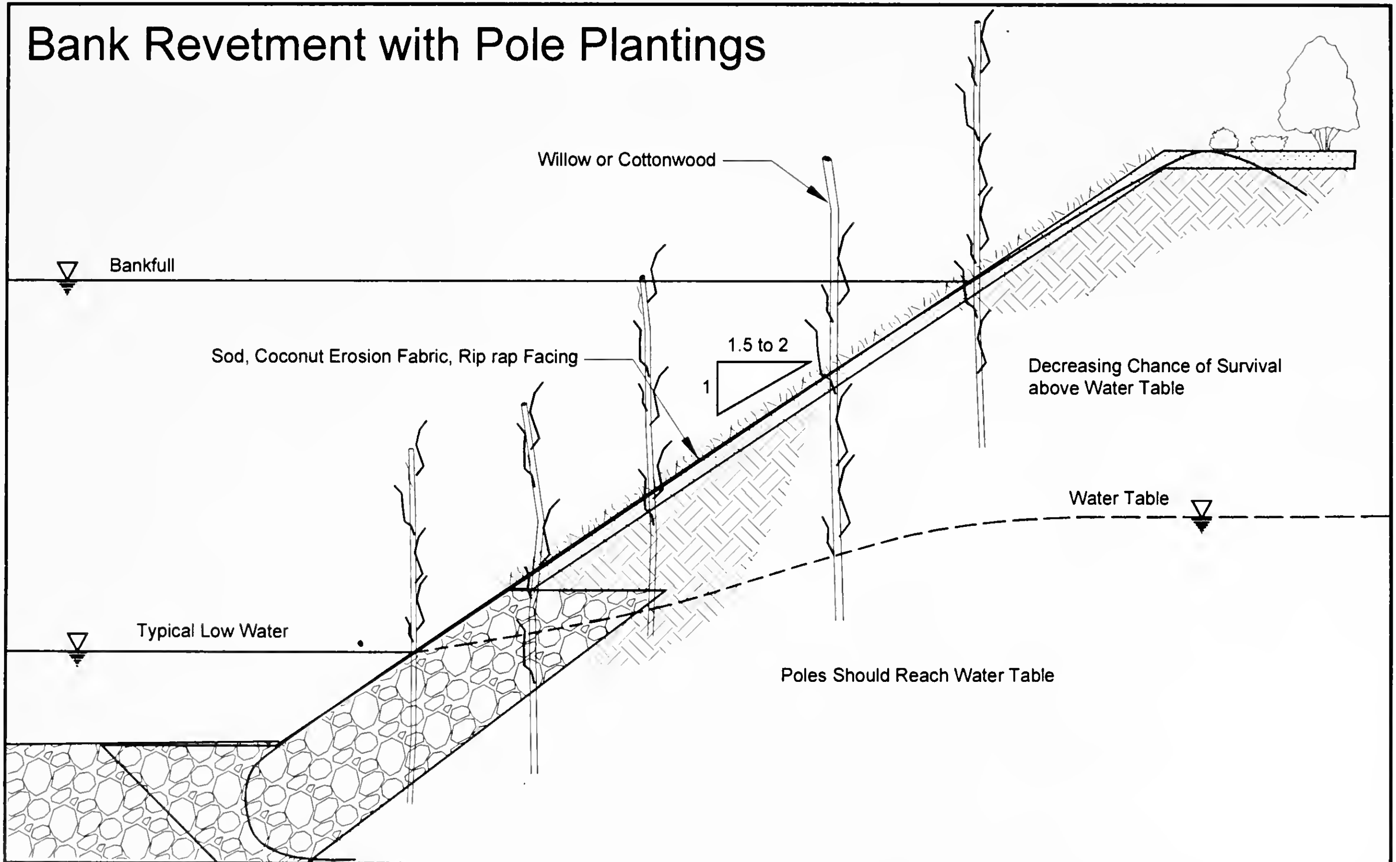
LAND & WATER CONSULTING, INC. P O BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	NOT TO SCALE	FILENAME	DRAWING TITLE Bank Protection Treatment
	DRAWN BY MW	CHECKED	FIGURE	

Bank Revetment with Gabion Baskets



LAND & WATER CONSULTING, INC P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Bank Revetment with Gabion Baskets
	DRAWN BY MW	CHECKED	FIGURE	

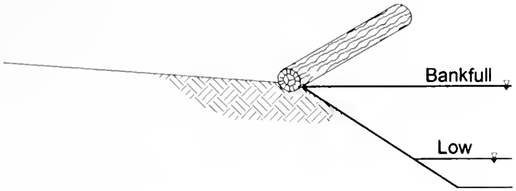
Bank Revetment with Pole Plantings



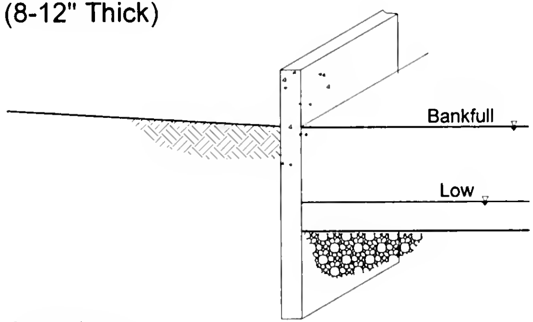
LAND & WATER CONSULTING, INC. P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Pole Planting
	DRAWN BY MW	CHECKED	FIGURE	

Bridge Abutments

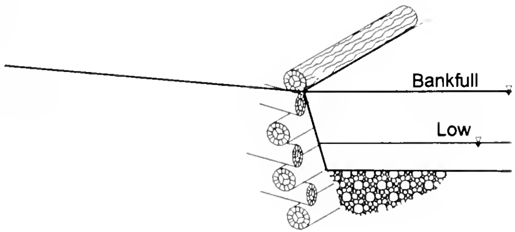
Log Sill
(24" Diameter)



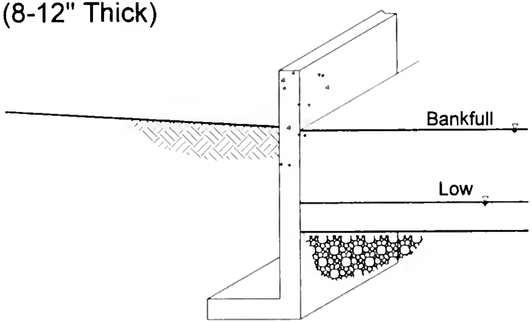
Concrete Wall
(8-12" Thick)



Log Crib



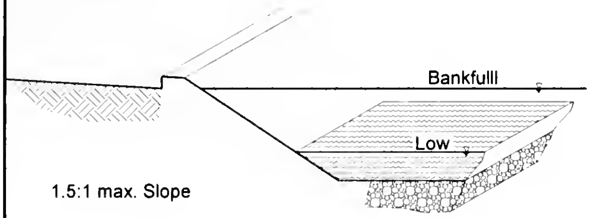
Cantelever
(8-12" Thick)



LAND & WATER CONSULTING, INC. P O BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Bridge Abutments
	DRAWN BY MW	CHECKED	FIGURE	

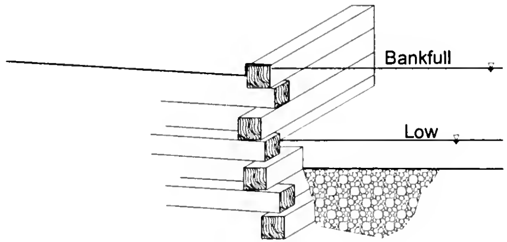
Bridge Abutments

Rip Rap

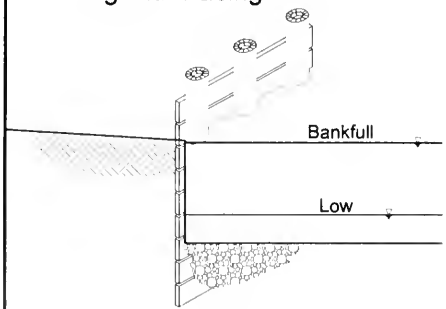


1.5:1 max. Slope

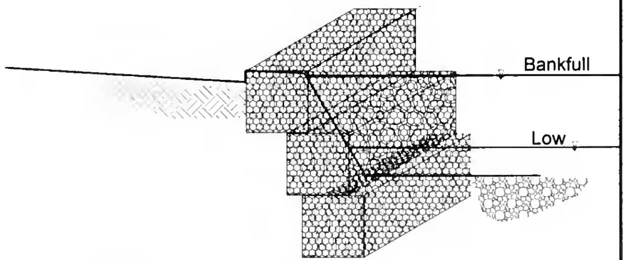
Timber Crib



Piling with Facing



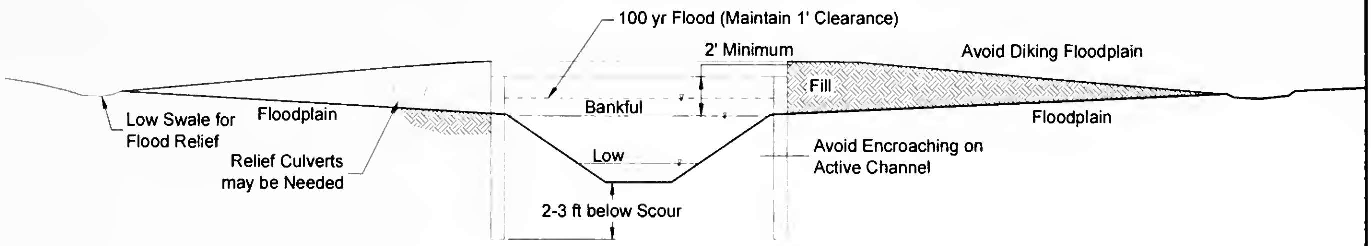
Gabion Basket



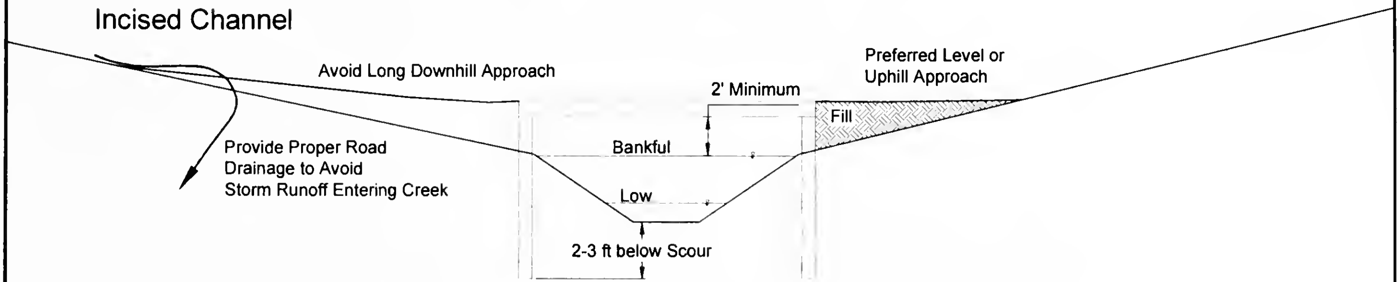
LAN_ & WATER CONSULTING, INC P.O. BOX 8254 Missoula MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Bridge Abutments
	DRAWN BY MW	CHECKED	FIGURE	

Bridge Cross Sections

Unincised Channel

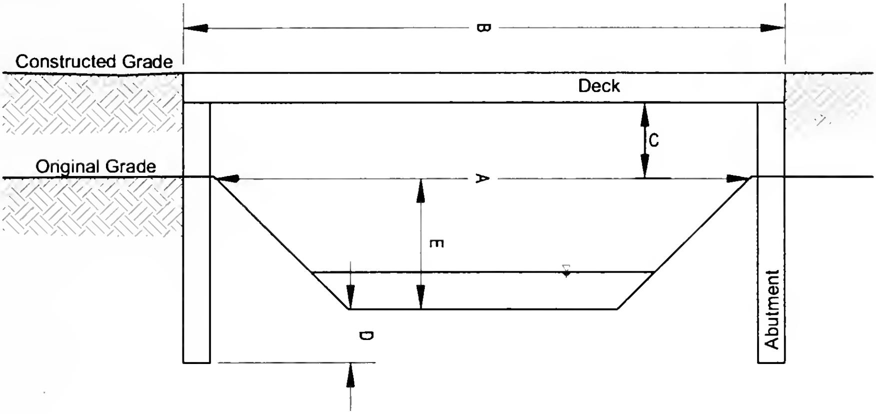


Incised Channel

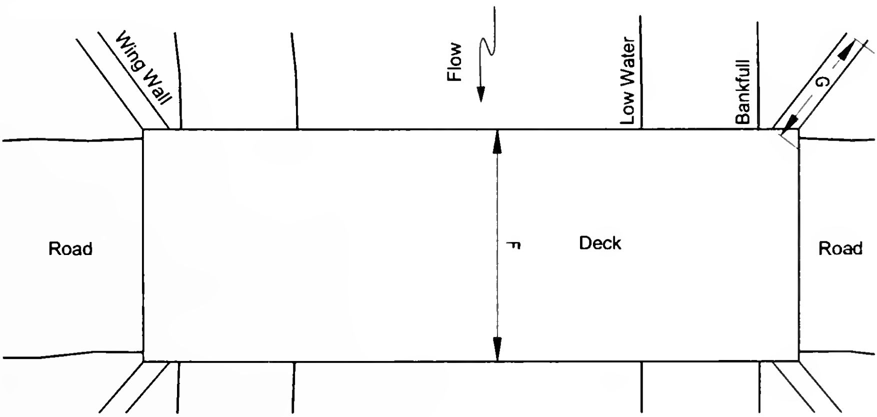


LAND & WATER CONSULTING, INC. P O BOX 8254 Missoula MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Bridge Cross Sections
	DRAWN BY MW	CHECKED	FIGURE	

Bridge Template

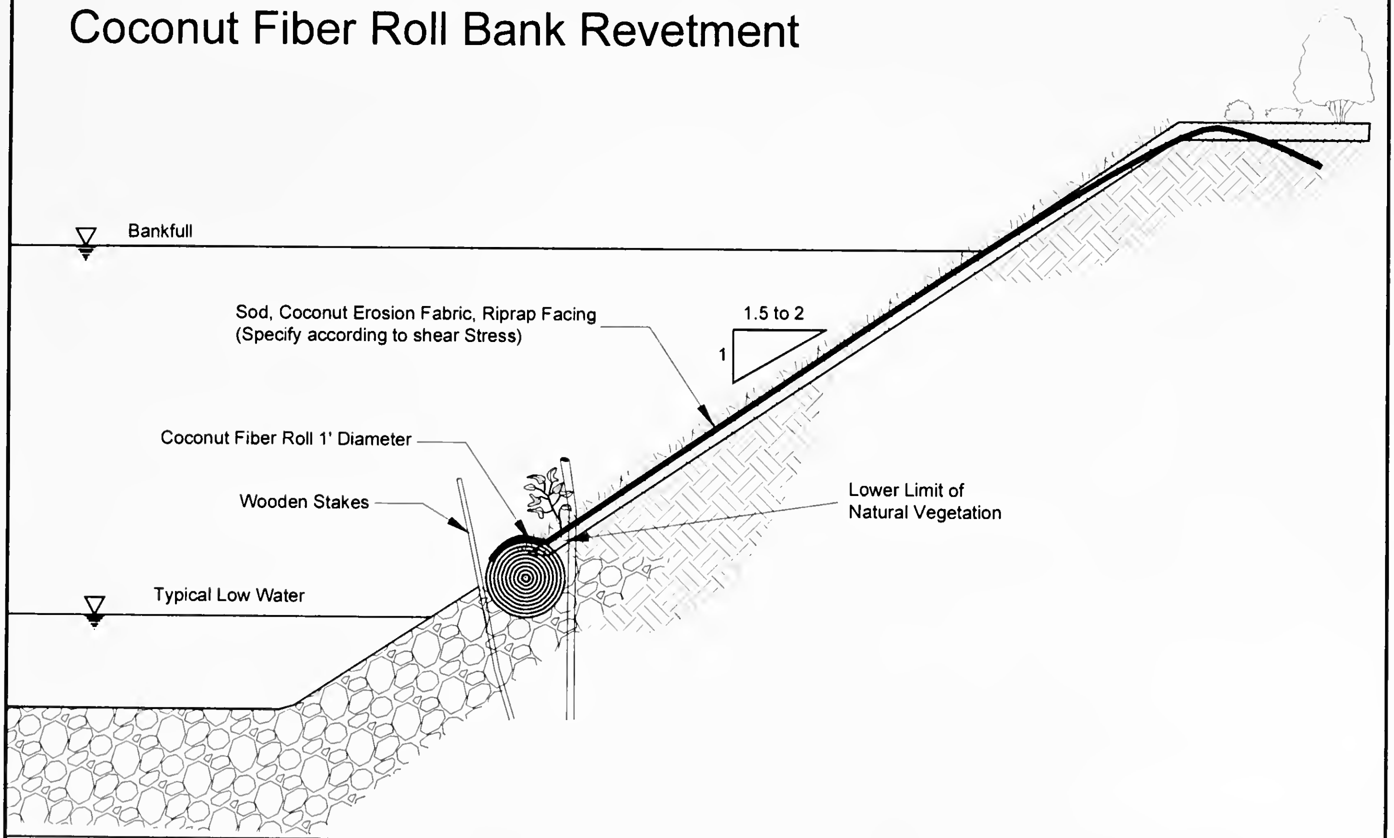


Bankfull Width	A=__________	Road Width	F=__________
Span	B=__________	Wingwall Length (E+C)x1.5	G=__________
Stringer/Bankfull Clearance	C=__________	Bridge Type	__________
Abutment Footing Depth	D=__________	Abutment Type	__________
Bankful Depth	E=__________		



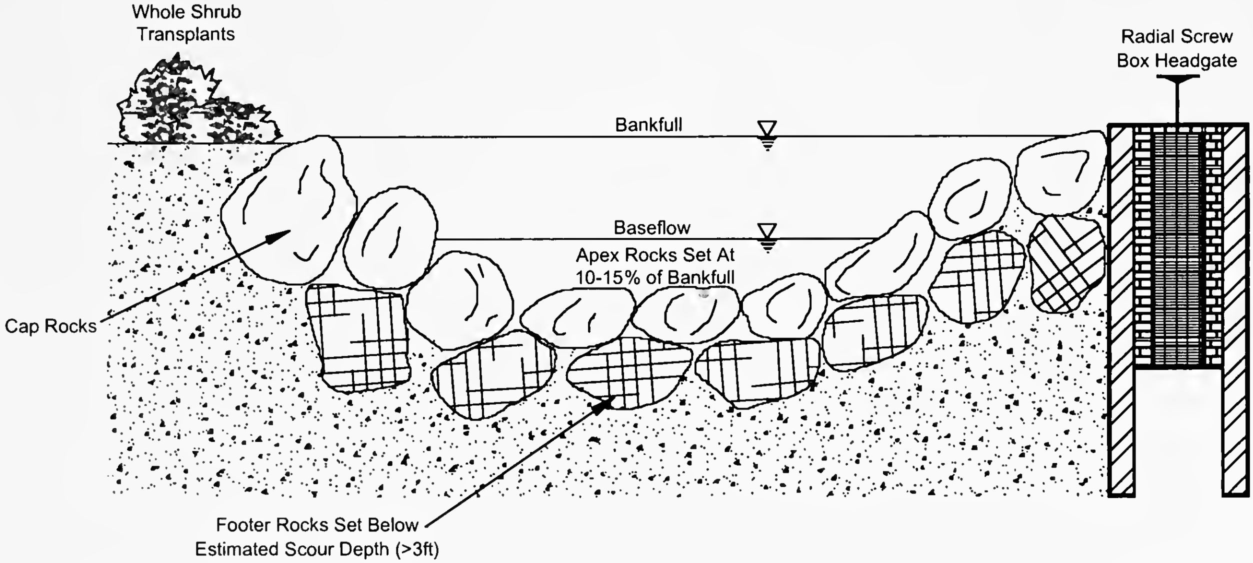
LAND & WATER CONSULTING, INC. P O BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	NOT TO SCALE	FILENAME	DRAWING TITLE Bridge Template
	DRAWN BY MW	CHECKED	FIGURE	

Coconut Fiber Roll Bank Revetment



LAND & WATER CONSULTING, INC P.O. BOX 5284 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Fiber Roll Revetment
	DRAWN BY MW	CHECKED	FIGURE	

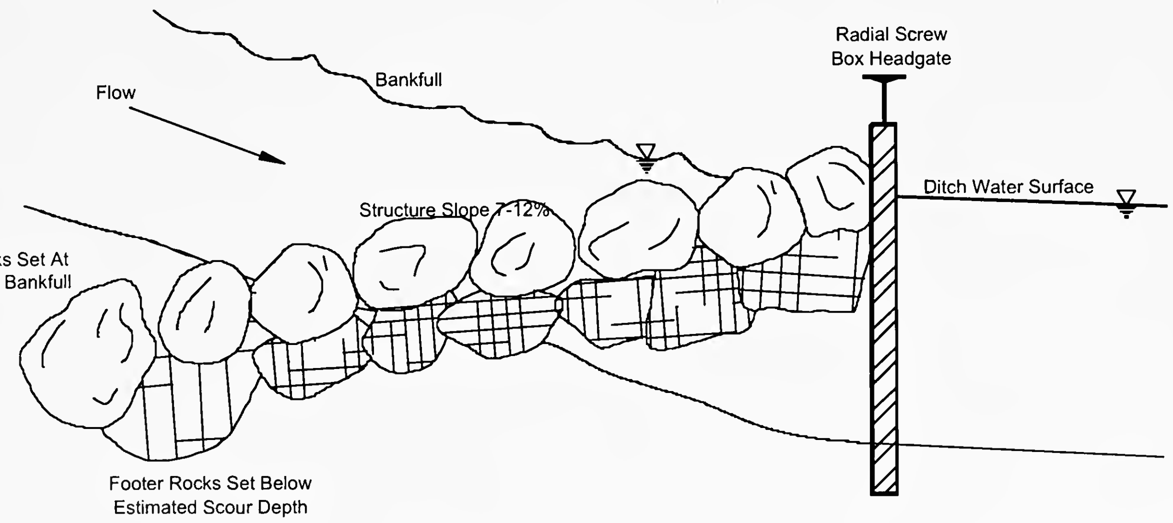
Cross Vane Diversion Structure
Cross Sectional View



Note: Design specifications are site specific and subject to change.

LAND & WATER CONSULTING, INC. P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME crsv.dwg	DRAWING TITLE Cross Vane Diversion Structure
	DRAWN BY LS	CHECKED	FIGURE	

Cross Vane Diversion Structure
Longitudinal Profile View

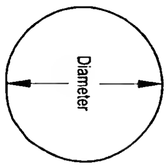


Note: Design specifications are site specific and subject to change.

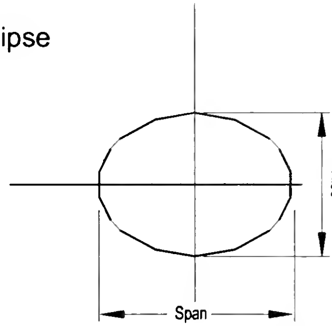
LAND & WATER CONSULTING, INC. P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME lngv.dwg	DRAWING TITLE Cross Vane Diversion Structure
	DRAWN BY JS	CHECKED	FIGURE	

Steel Culvert Shapes

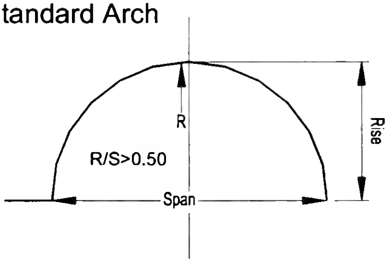
Round



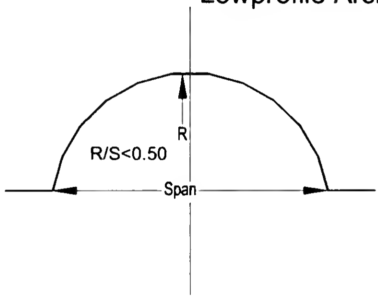
Ellipse



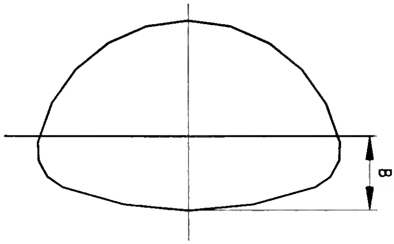
Standard Arch



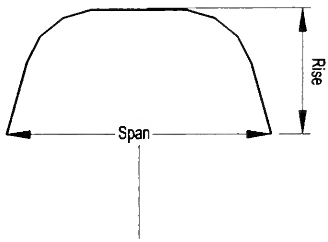
Lowprofile Arch



Pipe-Arch or Squashed



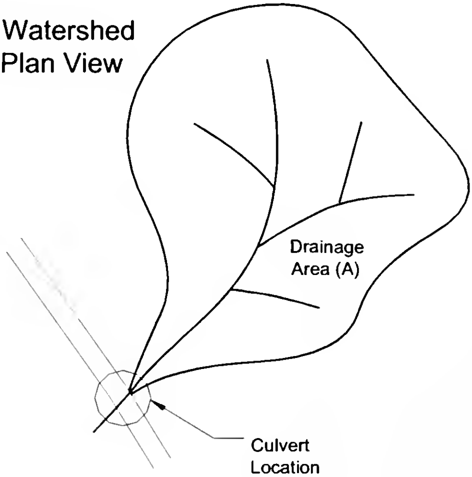
Box



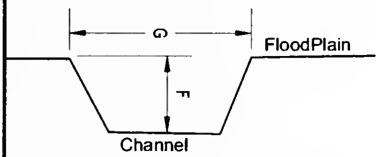
LAND & WATER CONSULTING, INC.	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
P O BOX 8254	PROJECT MANAGER	NOT TO SCALE	FILENAME	DRAWING TITLE Culvert Shapes
Missoula, MT 59807	DRAWN BY MW	CHECKED	FIGURE	

Culvert Sheet

Watershed Plan View

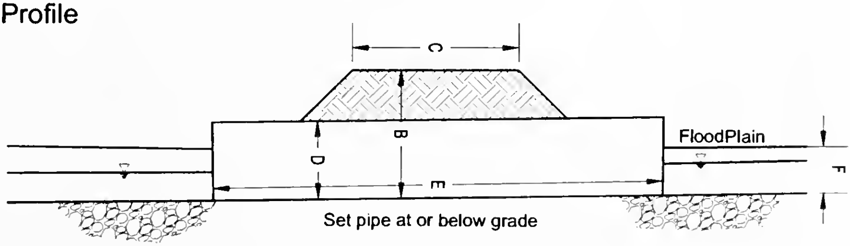


Cross Section



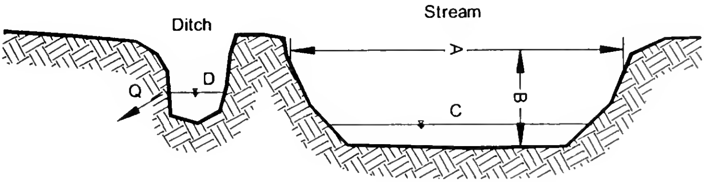
Drainage Area	A=__________	Culvert Length (C+(3xB))	E=__________
Precipitation (in)	ppt=__________	Channel Depth	F=__________
Design 25 yr. 100 yr. Flood	Q=__________	Channel Width	G=__________
Fill Height (ft) (Channel Bottom to Road)	B=__________	Culvert Type (Round, Arch, Box, __________)	
Road Width (ft)	C=__________	Culvert Diameter (in)	D=__________

Profile



LAND & WATER CONSULTING, INC. P O BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	NOT TO SCALE	FILENAME	DRAWING TITLE Willow Wattle Bank Reveg
	DRAWN BY MW	CHECKED	FIGURE	

Diversion Design



Cross Section

Channel Width A = ___________

Bankfull Depth B = ___________

Low Water Elevation C = ___________

Required Ditch Operating Level D = ___________

Headwater Requirement (D-C) ___________

Peak Ditch Diversion Rate (cfs) ___________

Channel Stability Lateral Good / Fair / Poor

Channel Stability Vertical Good / Fair / Poor

Bedload/Sediment Low / Moderate / High

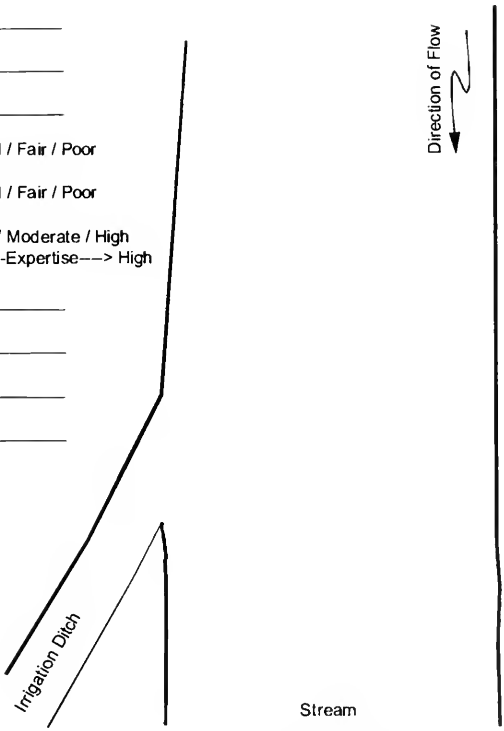
Low <---Expertise---> High

Diversion Structure Type ___________

Headgate Type ___________

Bank Protection Type ___________

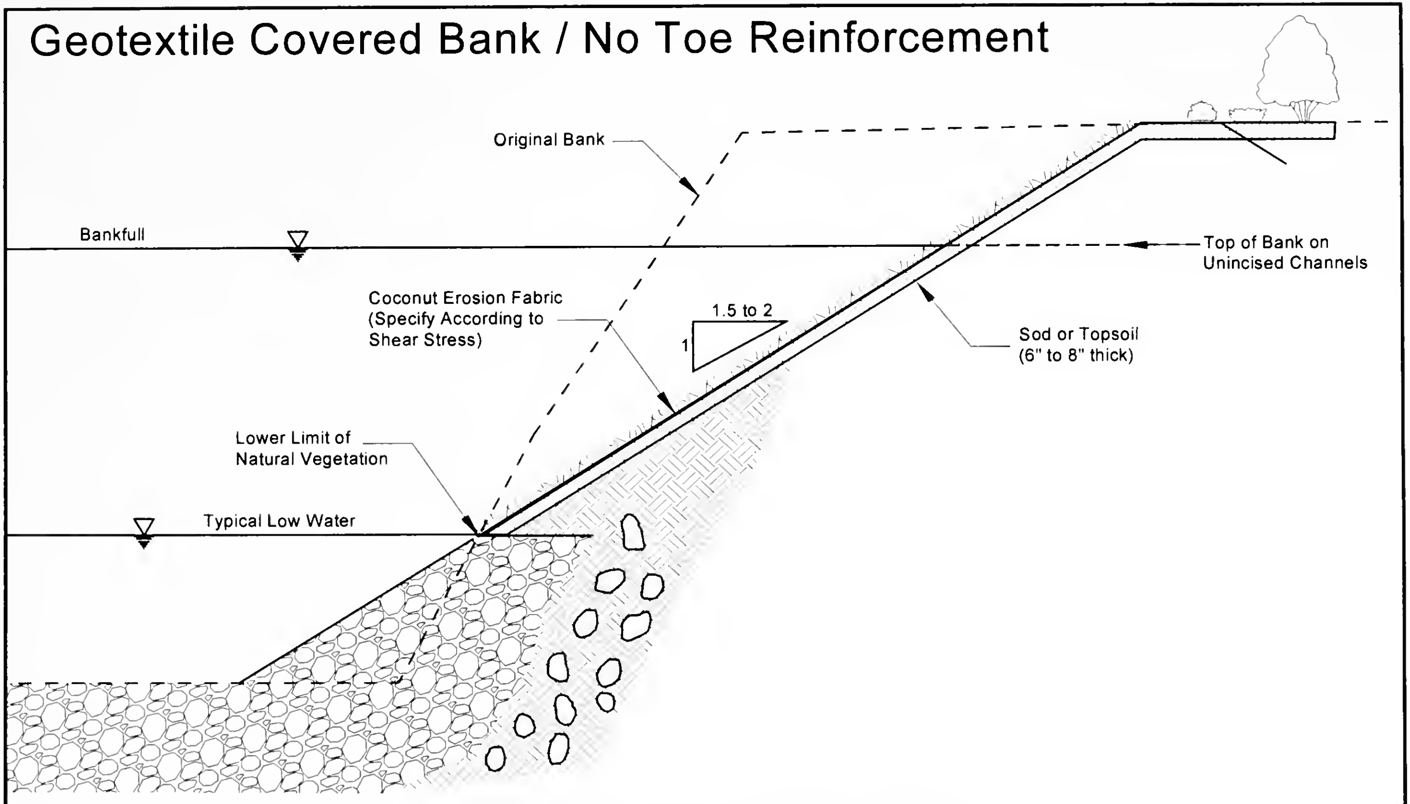
Provisions for Fish Passage ___________



Plan View
(Sketch Details)

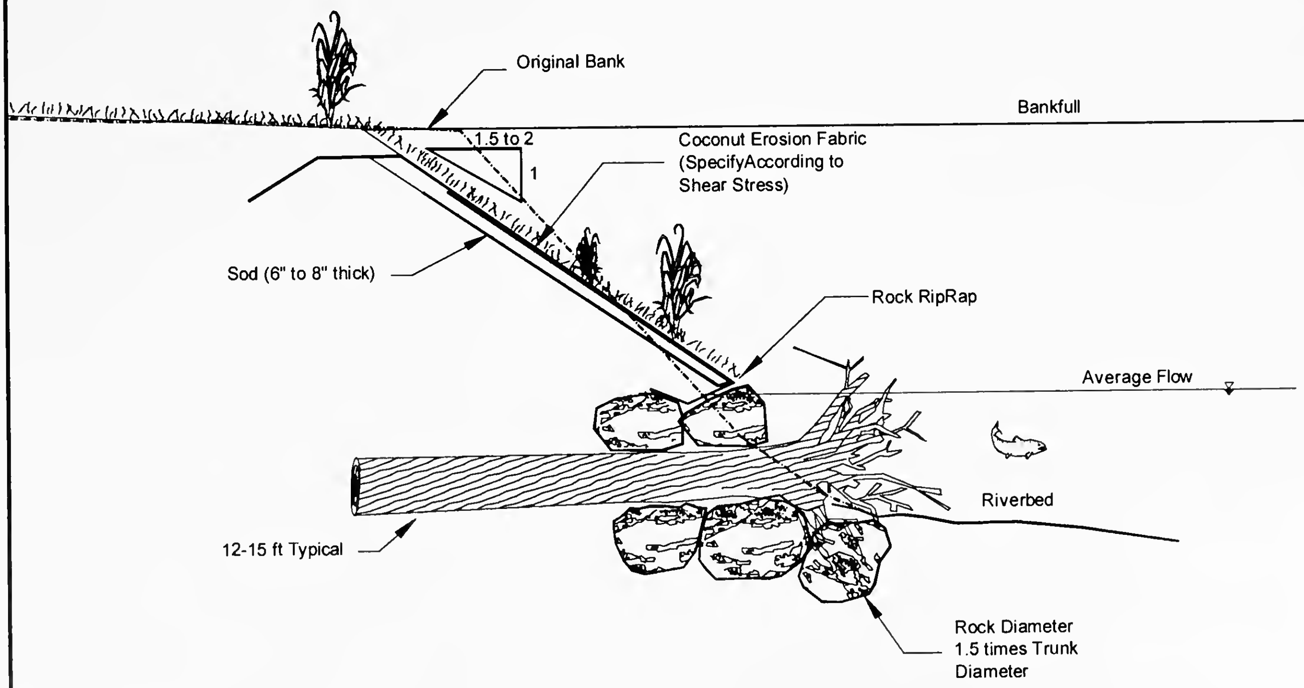
LAND & WATER CONSULTING, INC P.O. BOX 8254 Missoula MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	NOT TO SCALE	FILENAME	DRAWING TITLE Diversion Design
	DRAWN BY MW	CHECKED	FIGURE	

Geotextile Covered Bank / No Toe Reinforcement



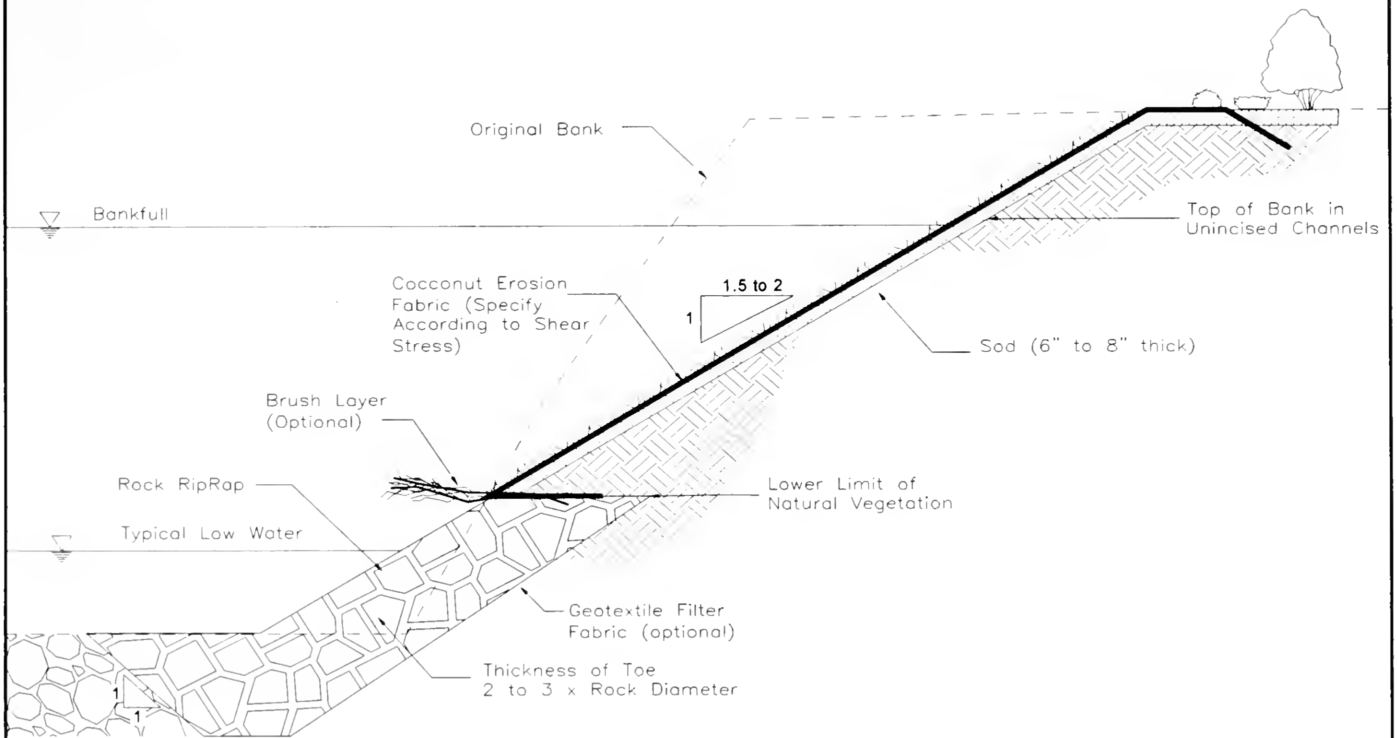
LAND & WATER CONSULTING, INC. P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Geotextile Covered Bank / No Toe Reinforcement
	DRAWN BY MP/MW	CHECKED	FIGURE	

Geotextile Covered Bank with Single Root Wad Footer



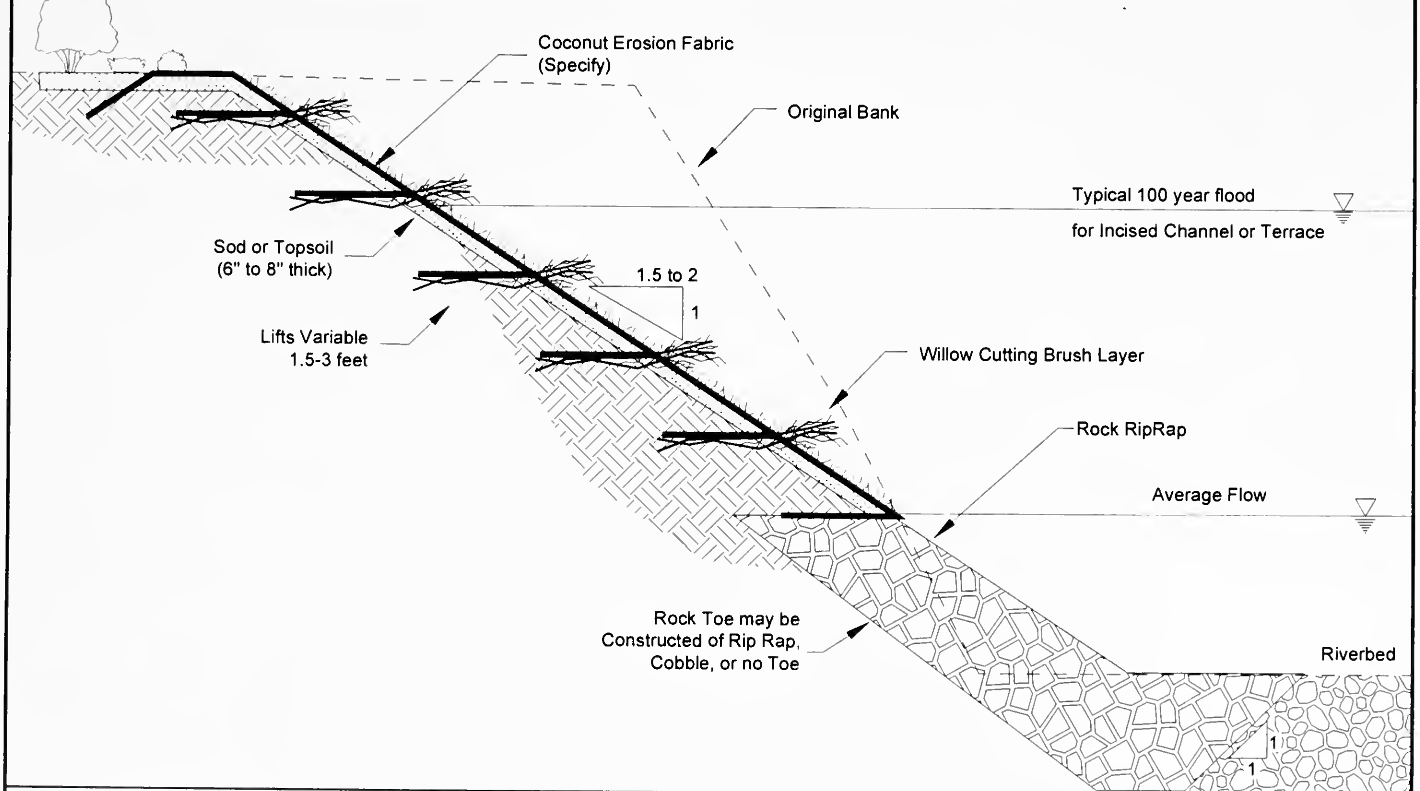
LAND & WATER CONSULTING, INC P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Geotextile Bank with Root Wad
	DRAWN BY MP/MW	CHECKED	FIGURE	

Geotextile Single Wrap Bank with Rip Rap Toe



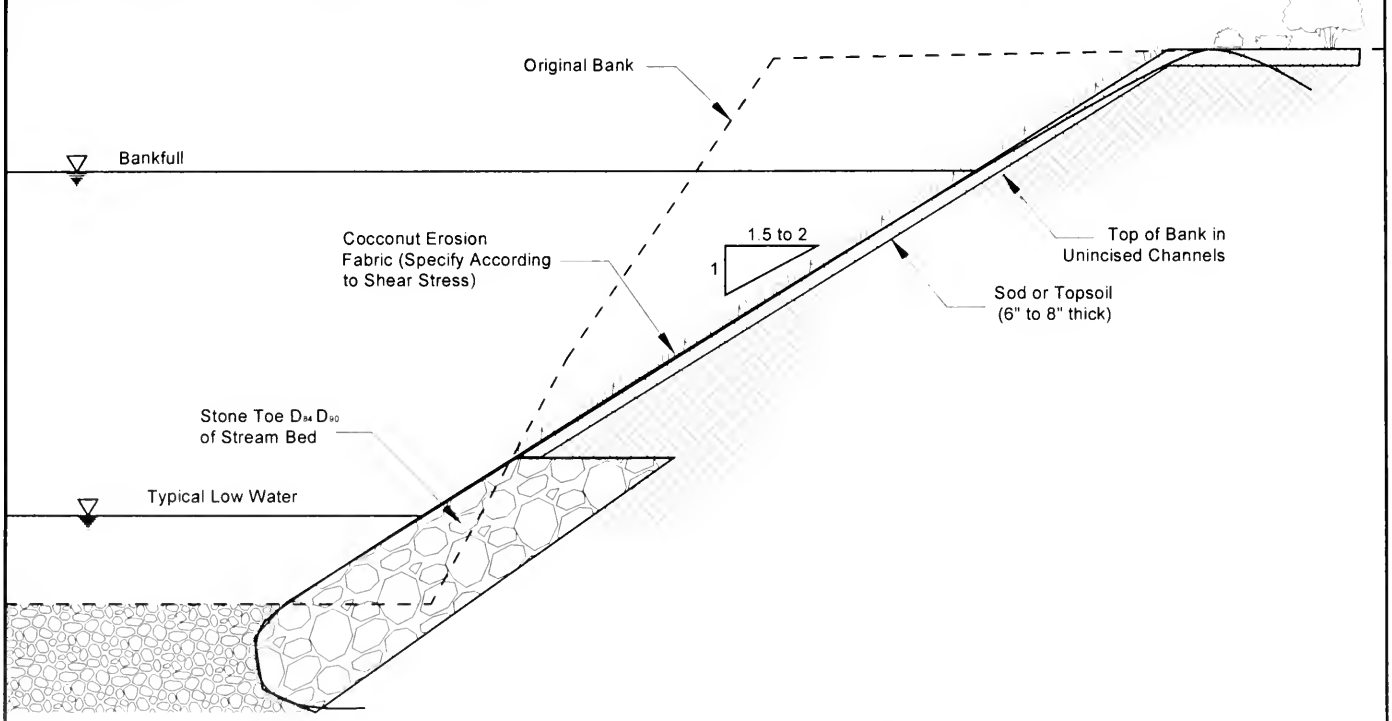
LAND & WATER CONSULTING, INC P.O. BOX 8254 Missoula, MT 59807	PROJECT NO H98-143	DATE Sept 98	LOCATION Missoula, MT	PROJECT NAME CD Manual
	PROJECT MANAGER B.Anderson	SCALE N/A	FILENAME GEO_RRToe	DRAWING TITLE Geotextile single wrap bank with Rip Rap Toe
	DRAWN BY MP	CHECKED	FIGURE 1	

Geotextile Encapsulated Soil / Willow Bank



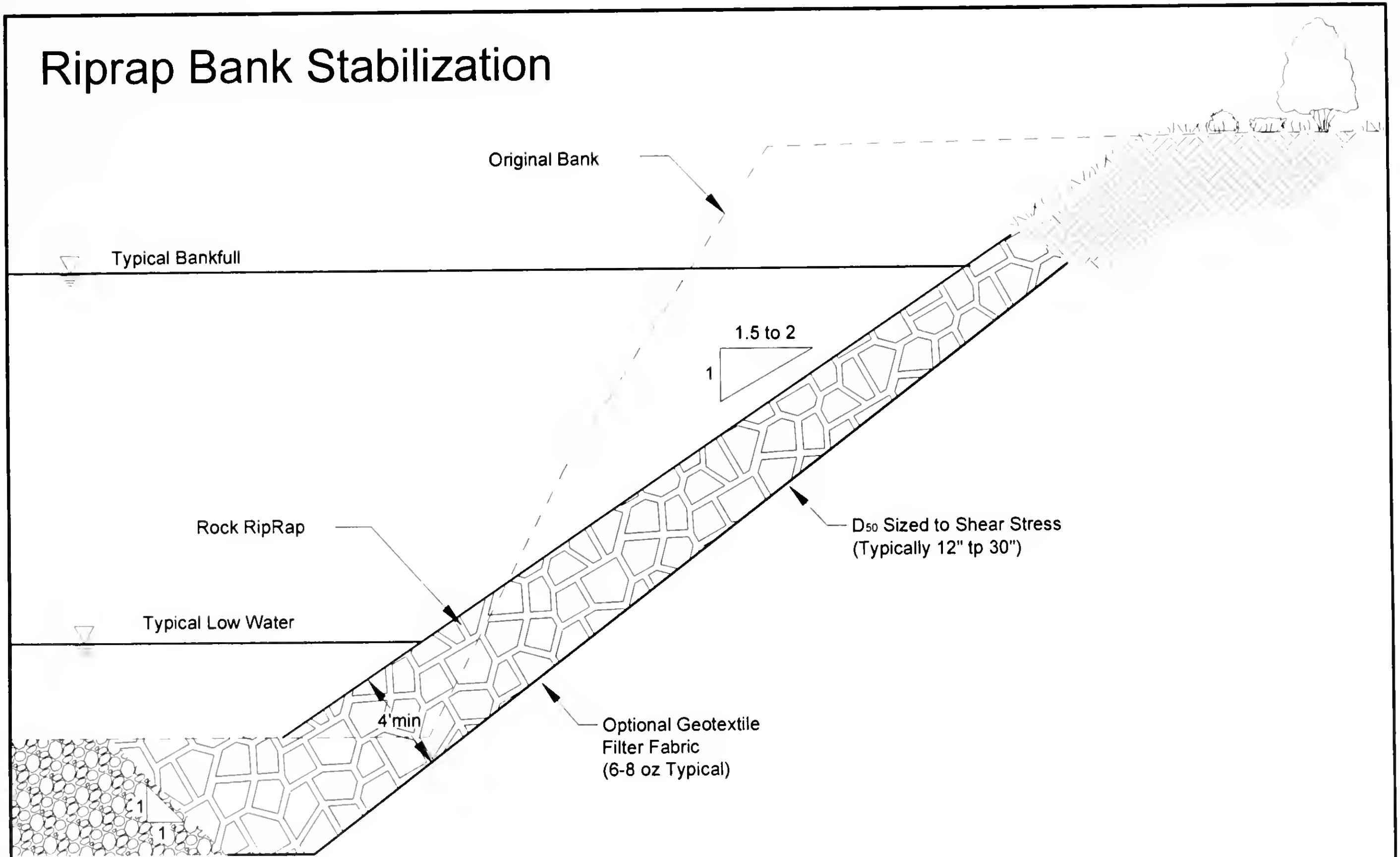
LAND & WATER CONSULTING, INC. P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Geotextile Encapsulated Soil / Willow Bank
	DRAWN BY MP/MW	CHECKED	FIGURE	

Geotextile Single Wrap Bank with Stone Toe Wrap



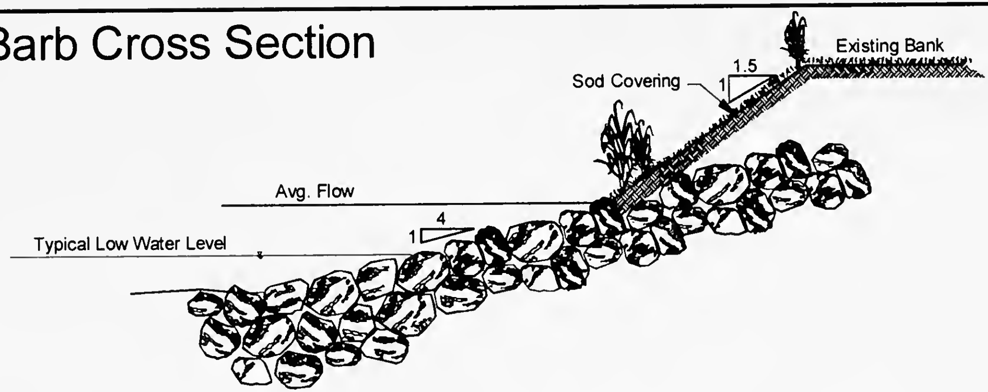
AND & WATER CONSULTING, INC P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Geotextile single wrap bank with Stone Toe Wrap
	DRAWN BY MP/MW	CHECKED	FIGURE	

Riprap Bank Stabilization

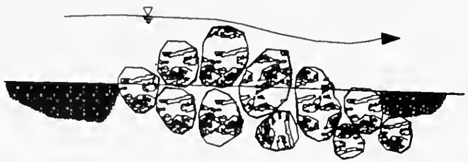


LAND & WATER CONSULTING, INC P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Riprap Bank Stabilization
	DRAWN BY MW	CHECKED	FIGURE	

Rock Barb Cross Section

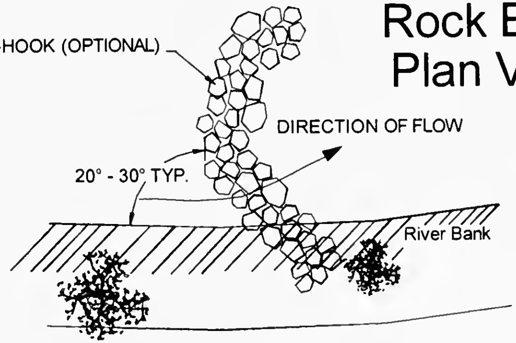


Rock Barb Cross Section



Rock 2-4 ft Diameter Typical

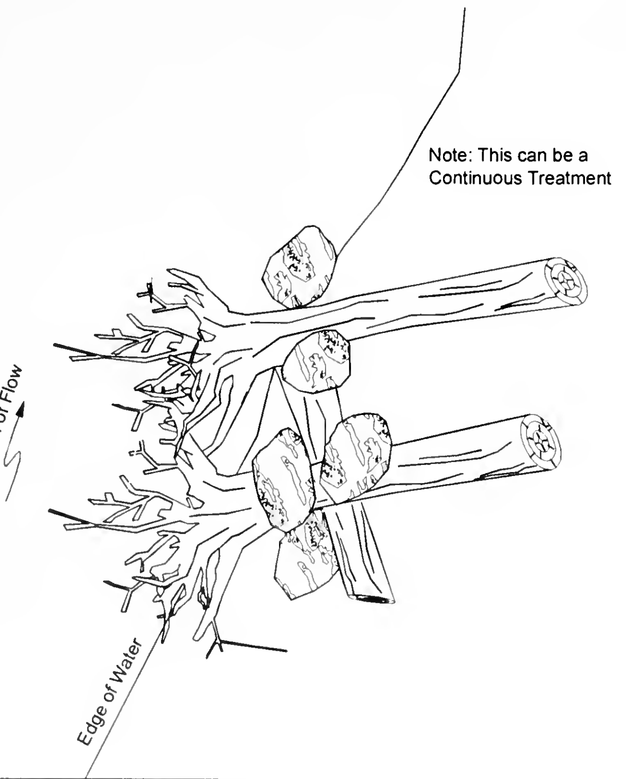
Rock Barb Plan View



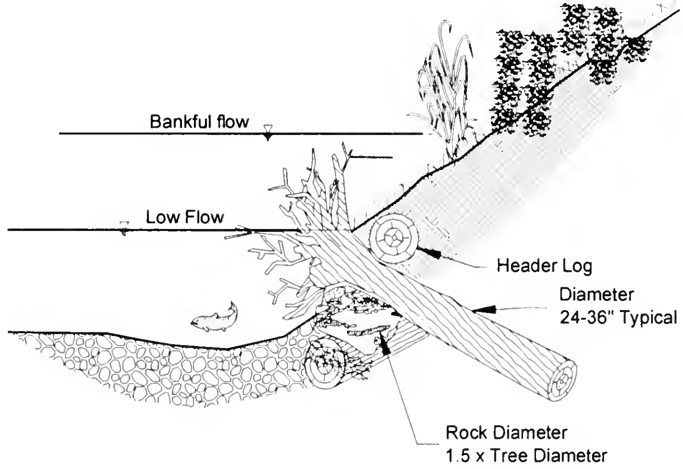
Top of Existing Bank

LAND & WATER CONSULTING, INC. P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Rock Barb
	DRAWN BY MW	CHECKED	FIGURE	

Root Wad Detail Plan View

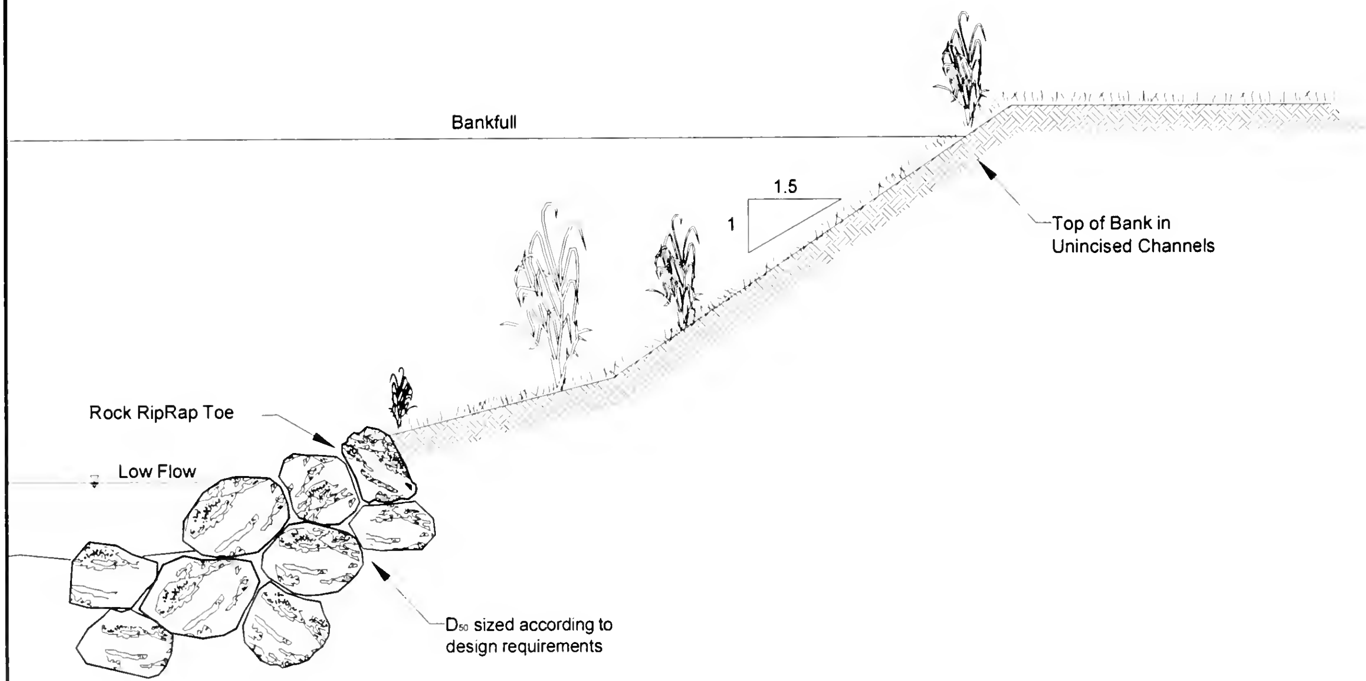


Root Wad Detail Cross Section



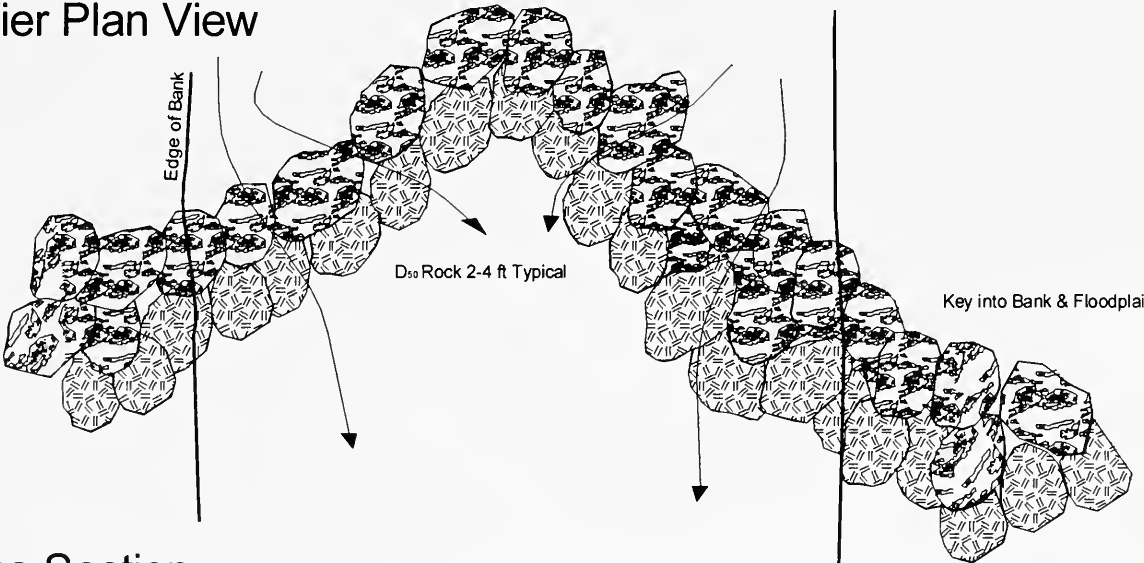
LAND & WATER CONSULTING, INC. P.O. BOX 8254 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Rootwad Detail
	DRAWN BY MW	CHECKED	FIGURE	

Stone Toe

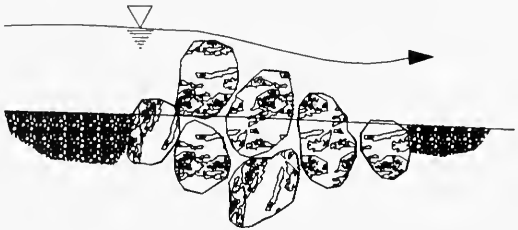


LAND & WATER CONSULTING, INC P.O. BOX 8264 Missoula, MT 59807	PERMIT NO	DATE	LOCATION	PROJECT NAME CD Manual
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE Stone Toe
	DRAWN BY MW	CHECKED	FIGURE	

V Wier Plan View



Cross Section



LEGEND
Exposed Rock
Footer Rock
Direction of Flow

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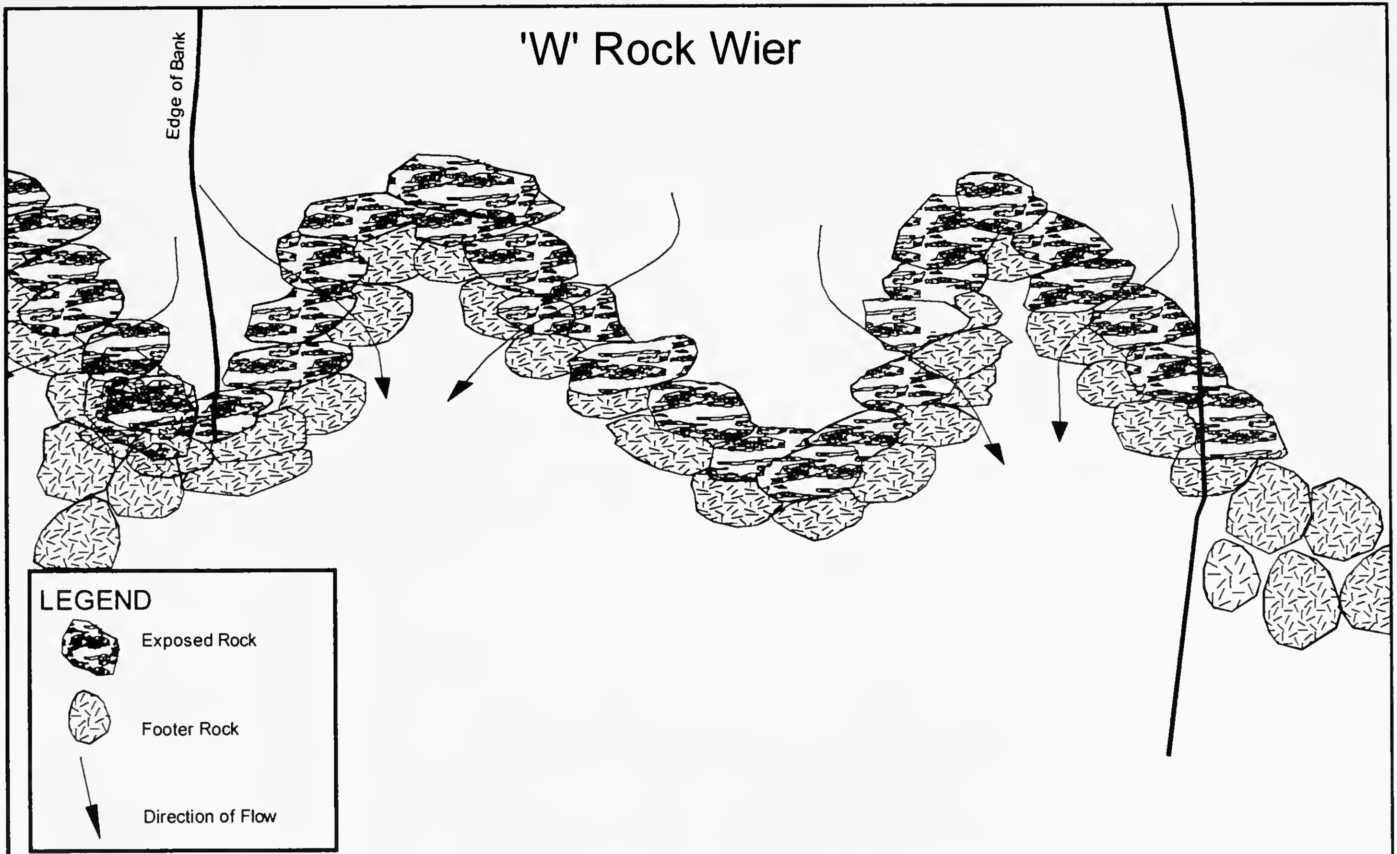
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE "V" Rock Weir
	DRAWN BY MW	CHECKED	FIGURE	

'W' Rock Wier



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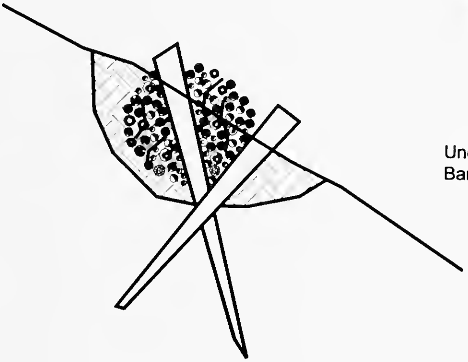
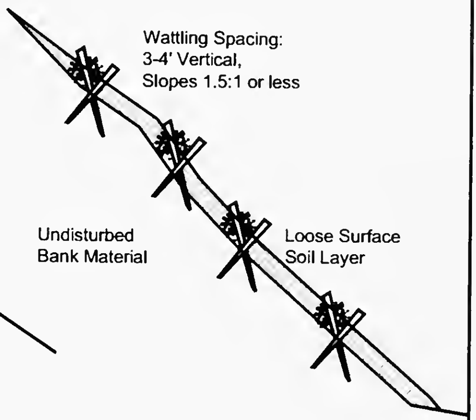
	PROJECT MANAGER	SCALE Not to Scale	FILENAME	DRAWING TITLE "W" Rock Weir
	DRAWN BY MW	CHECKED	FIGURE	

Willow Wattling Bank Revegetation

Cross Section Installation Detail



Bank Installation



Willow Wattle Detail

Stems 1/2" to 1 1/2" Diameter 12-18 per a Bundle
3-8 ft Long, 50% Dead Brush can be used

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	DRAWN BY MW	CHECKED	FIGURE	