Vermont Rivers & Roads Field Manual

Prepared by the Vermont Department of Environmental Conservation in cooperation with the Vermont Agency of Transportation

VERMONT
DEPARTMENT OF ENVIRONMENTAL CONSERVATION

VTrans Working to Get You There
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Information Resources

Rivers and Roads Training Program Materials
www.watershedmanagement.vt.gov/rivers.htm

ANR River Management Engineer and Permit Information
www.watershedmanagement.vt.gov/rivers/htm/
rv_management.htm

USGS Stream Stats Tool
http://water.usgs.gov/osw/streamstats/Vermont.html

ANR Natural Resources Atlas
http://anrmaps.vermont.gov/websites/anra/

The Cross-Vane and J-Hook Vane Structures, Dave Rosgen
www.wildlandhydrology.com/assets/cross-vane.pdf

Boulder Clusters Technical Note
http://el.erdc.usace.army.mil/elpubs/pdf/sr11.pdf

Vermont Aquatic Organism Passage Information
www.vtfishandwildlife.com/fisheries_AOP.cfm

VERMONT

Agency of Natural Resources
Department of Environmental Conservation
Watershed Management Division

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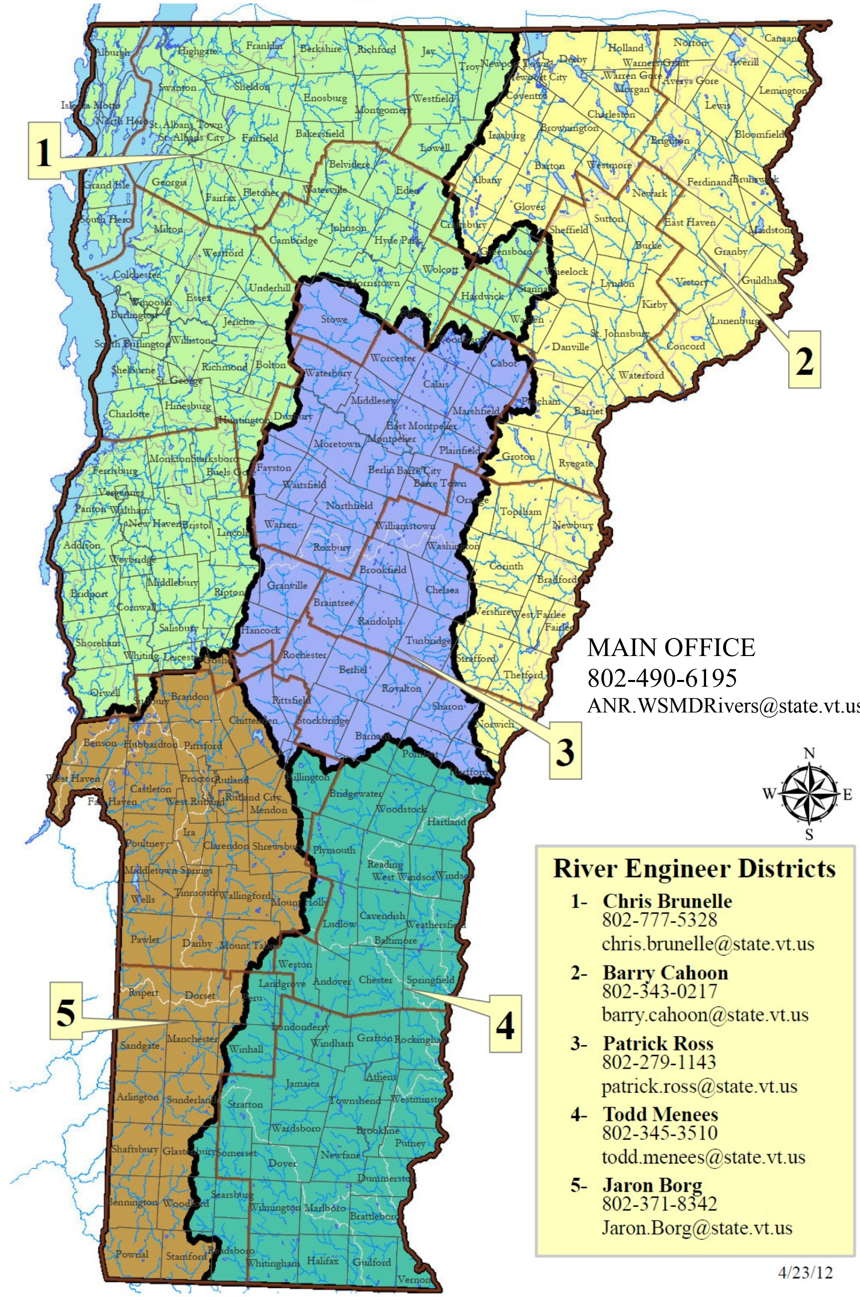
Introduction

Rivers are shaped by processes that result in general stability over time but periodic disturbances, both natural and human caused can temporarily destabilize a river. Unstable rivers represent a hazard to adjacent infrastructure and property. This field manual is a guide to recognizing river instability and restoring the river to a stable condition as part of road construction projects along rivers.

Contents

ANR River Management Engineer Districts



A Step-Wise Procedure for Building River Stability Into Road Construction

1. **Determine the expected river morphology:** Use available information.
    - Valley and River Types (use topographic maps)
    - Hydrologic and Sediment Regime Impacts (use online aerial photography)
    - Drainage Area (use USGS Stream Stats)
    - Channel Dimensions (use VT Channel Dimensions Table)

2. **Determine the existing morphology:** Make the following observations and measurements.
    - Observations
        - Bed Features
        - Deposition Patterns
        - Nick-Points
        - Bank Erosion
        - Stabilizing Features
    - Measurements
        - Bankfull Stage
        - Bankfull Dimensions
        - Entrenchment
        - Incision

3. **Analyze the instability:** Compare the existing morphology to the expected morphology and determine the type and cause of instability.

4. **Design:** Use your understanding of the expected condition, channel evolution and stabilization structures to return the river to a configuration that is as close to the equilibrium condition as possible.

Expected Morphology

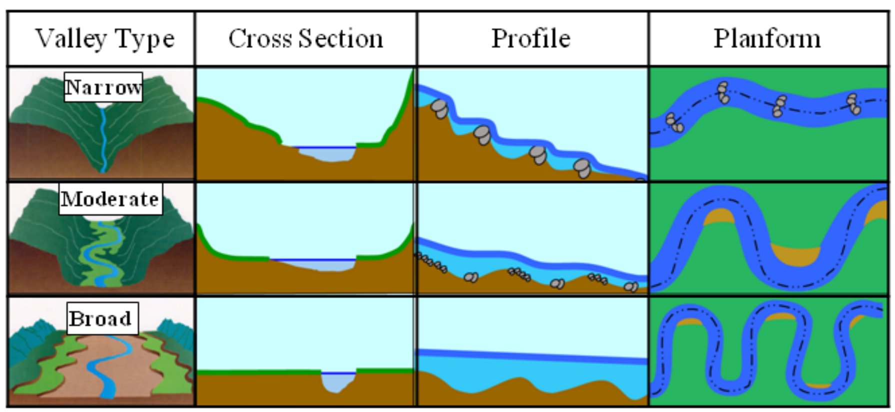
Use available information to determine the expected river morphology.

Valley and Stream Types

The valley type will tell you what the cross-section, profile and planform morphology of the channel should be.

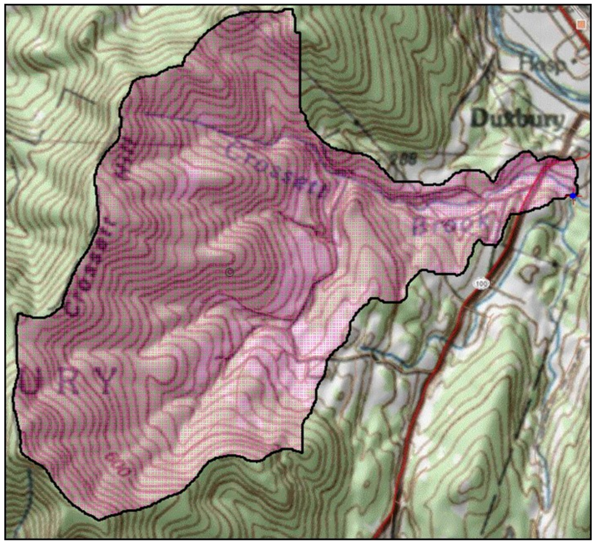
Typical Channel Types of Vermont

	Steep Narrow Valley	**Moderate Slope and Width Valley**	**Flat and Wide Valley**
Channel Slope	2% and Greater	Less than 2%	Less than 2%
Sinuosity	Low	Medium	High
Entrenchment	1.4 – 2.2	Greater Than 2.2	Greater Than 2.2
Width / Depth	12 - 20	20 - 30	Less Than 12
Bed Forms	Cascade and/ or Step-Pool	Riffle-Pool	Ripple-Dune
Bed Material	Gravel, Cobble and Boulder	Sand, Gravel and Cobble	Sand



Expected Morphology

Drainage Area and Hydrologic and Sediment Regimes



Use the USGS Stream Stats tool to measure drainage area and channel slope. (http://streamstats.usgs.gov/Vermont.html)

Use aerial photography to get a sense of the amount of hydrologic and sediment regime alteration in the watershed.

Expected Morphology

Use the table below to determine the approximate expected bankfull width and depth of the river. Expect natural variability. Steep rivers tend to be slightly wider and flat rivers tend to be slightly narrower than values predicted by the tables. Use the table to get you in the ball-park.

Vermont Bankfull Channel Dimensions Table

Drainage Area (mi^2)	Bankfull Width (ft.)	Bankfull Depth (ft.)	Drainage Area (mi^2)	Bankfull Width (ft.)	Bankfull Depth (ft.)
5	27	1.6	110	104	3.9
10	36	1.9	115	106	4.0
15	43	2.2	120	108	4.0
20	49	2.4	125	110	4.1
25	54	2.5	130	112	4.1
30	59	2.7	135	113	4.2
35	63	2.8	140	115	4.2
40	66	2.9	145	117	4.3
45	70	3.0	150	119	4.3
50	73	3.1	155	121	4.4
55	76	3.2	160	122	4.4
60	79	3.3	165	124	4.4
65	82	3.4	170	126	4.5
70	85	3.4	175	127	4.5
75	88	3.5	180	129	4.6
80	90	3.6	185	130	4.6
85	93	3.6	190	132	4.6
90	95	3.7	195	133	4.7
95	97	3.8	200	135	4.7
100	99	3.8	205	136	4.7
105	102	3.9	210	138	4.8

Drainage area can be measured using the U.S. Geological Survey Stream Stats Tool at http://streamstats.usgs.gov/Vermont.html

Existing Morphology

Make on-site observations and measurements to determine the existing morphology.

On-Site Observations

Features	Description
Nick-Points or Head-cutting	Steep to vertical and erodible drops in the channel bed? The banks downstream of the drops are significantly higher than the banks upstream.
Excessive Deposition	Large rapidly growing point bars and/or mid-channel bars. oarse bed materials and bed features buried by finer material. Generally loose, unarmored bed material.
Lack of bed features	A lack of stable steps on steep streams. A lack riffle-pool sequences on moderate and flat streams.
Rapid Bank Erosion	Freshly exposed roots and/or actively failing banks .
Stabilizing Features	Natural or manmade features such as bedrock or a stable culvert that could provide some degree of resistance to further bed or bank erosion.

On-Site Measurements

- Bankfull Stage
- Bankfull Width and Depth
- Entrenchment Ratio
- Incision Ratio

Note: See figures on pg. 13.

Existing Morphology

Identify the limits of the bankfull channel.

Bankfull Stage

- The discharge that shapes and maintains the channel over the long term is called the bankfull discharge because it typically fills a stable channel to the top of its banks. The height of the bankfull discharge is called the bankfull stage.
- The bankfull discharge is a moderate size flow that occurs every-other year on average, typically during spring runoff.
- The bankfull discharge creates visual evidence of its height that remains long after the water has receded.
- The bankfull stage provides a consistent benchmark for measuring width and depth that is independent of the water surface.

Determining the Limits of the Bankfull Channel

1. Find 3-5 bankfull indicators along the channel and measure the height of each above the water surface.
2. If the height of most of the indicators are within half a foot of each-other, calculate their average. This is height of the bankfull discharge.
3. If the heights of the indicators are not within half a foot of each other continue identifying indicators until you find at least three that have the same height.
4. Use the bankfull height above water surface as a benchmark for measuring bankfull width and depth of the channel.

Bankfull Indicators

The bankfull discharge leaves evidence of its height in the form of flat landforms covered with sands and fine gravels that have been deposited by the river. Look for these features as indicators of the height of the bankfull discharge.

- **The nearly flat and vegetated top of stable point bars.** On stable meandering rivers the tops of point bars usually mark the bankfull stage. Don't use the tops of large bars made up of coarse materials. These are often rapidly growing and don't provide good indicators of the bankfull stage.

- **Flat benches along the banks.** On straighter sections of river the bankfull stage is often marked by the top of flat benches that protrude out from higher banks.

- **Break in bank slope.** The point at which the steep bank transitions to a flatter slope often marks the bankfull stage.

- **Lower limits of trees.** Because bankfull flow occurs fairly often most trees cannot grow within the bankfull channel. Do not use trees that have slumped into the channel over time.

Existing Morphology

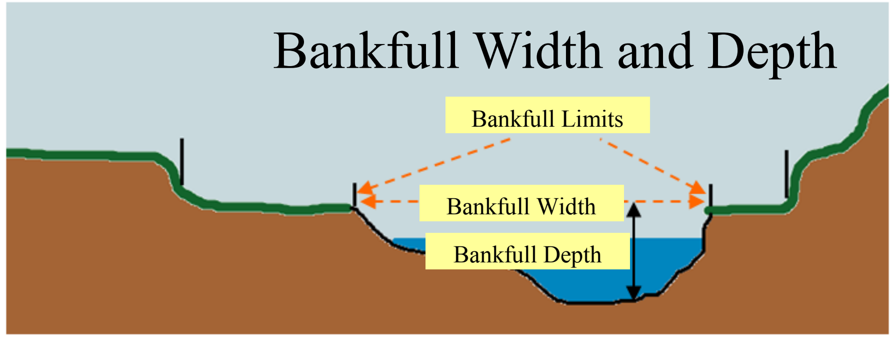
Example Bankfull Channels

Steep entrenched brook in a narrow valley

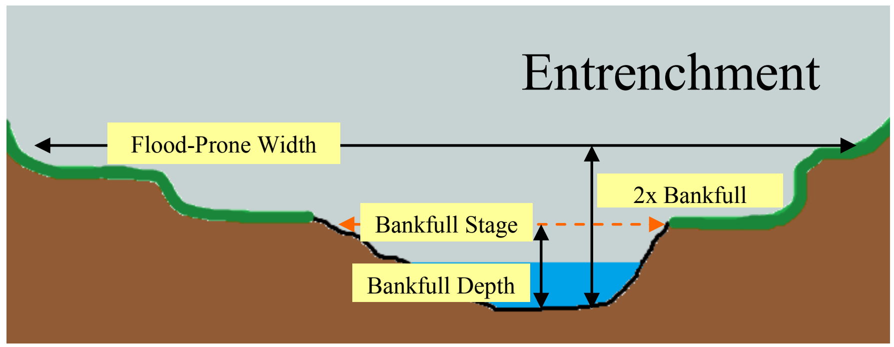
Moderate gradient non-entrenched brook in a broad valley

Low gradient non-entrenched brook in a broad valley

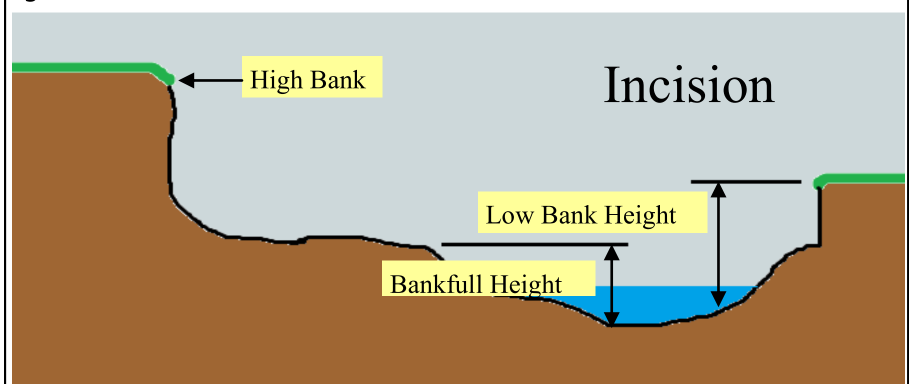
Existing Morphology



Measure bankfull width and depth at the elevation of the bankfull limits



Entrenchment is the ratio of flood-prone width to bankfull width. Moderate and broad valley rivers should have an entrenchment value greater than two.



Incision is the ratio of the height of the low bank to the bankfull depth. An incision ratio greater than 1.2 indicates channel incision.

Analyzing Instability

Compare the existing and expected morphology and use your observations to determine the type, degree and cause of instability and determine if stabilizing the river should be considered.

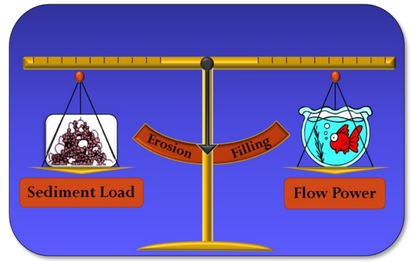
Analysis Questions

- Is the river less than 80% of the bankfull width?
- Has the river become incised (i.e., lost floodplain connectivity?)
- On step-pool rivers, have the steps been removed leaving no large boulders to create channel roughness?
- Is the river filling to the extent that the bankfull discharge would jump the banks and abandon the channel?
- Is the river eroding or filling to the extent that it has moved into channel evolution (see pgs 16 and 17)?

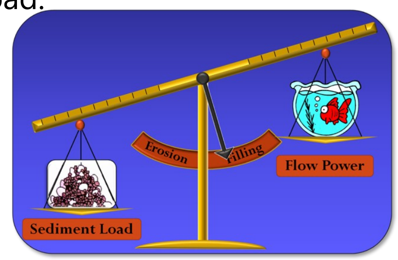
Causes of River Instability

Instability Type	Causes
Erosion (vertical and/or lateral)	Increased discharge, slope, or depth
	Decreased roughness (lost bed features)
Filling	Increased sediment load/size
	Decreased discharge, slope or depth

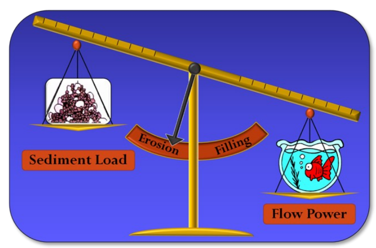
Analyzing Instability



This channel is stable. Width and depth are as expected for a moderate valley river and riffle-pool bedforms are in place. Flow power is in balance with channel resistance and sediment load.



This narrow valley channel was filled during a landslide. Flow power is overwhelmed by the sediment load. Restore by dredging to create a bankfull width and depth channel and rebuilding step-pool bedforms.

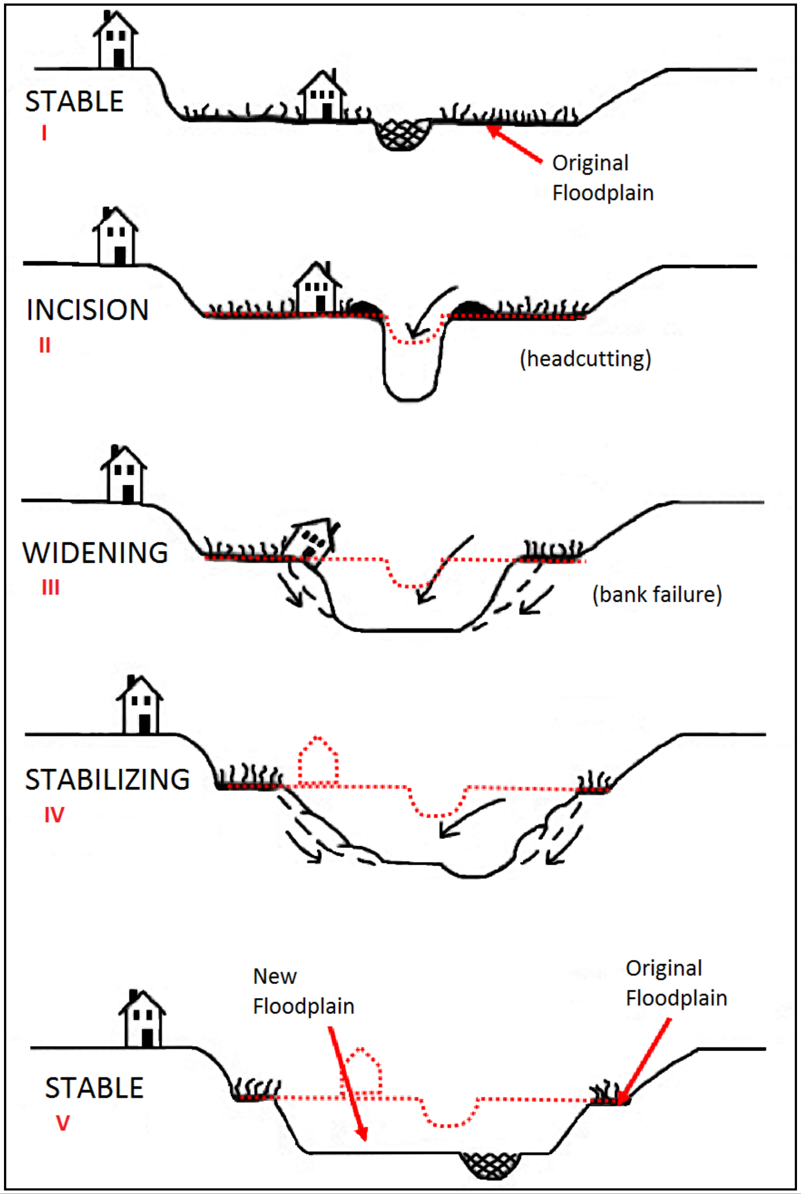


This broad valley channel has a greater width and depth than expected and no bedforms. It has incised over ten years. The flow power overwhelms the resistance of the channel and the sediment load. Restore by reconnecting the channel and floodplain, narrowing width, and restoring channel roughness.

Analyzing Instability

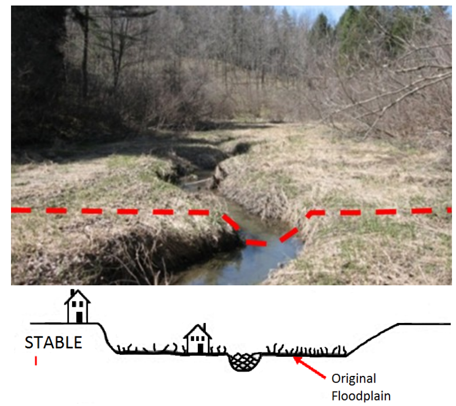
Channel Evolution

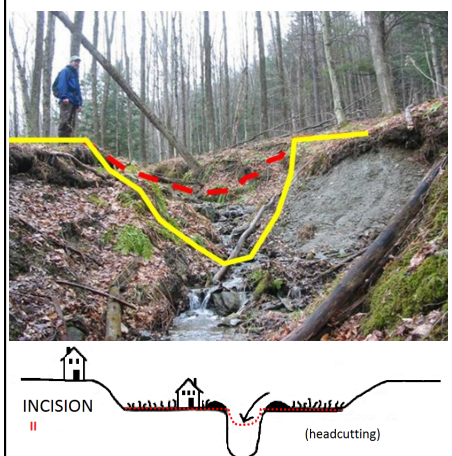
Channel Evolution can last for tens to hundreds of years. Recognize it and identify channel modifications that will advance the river toward the stable stage.

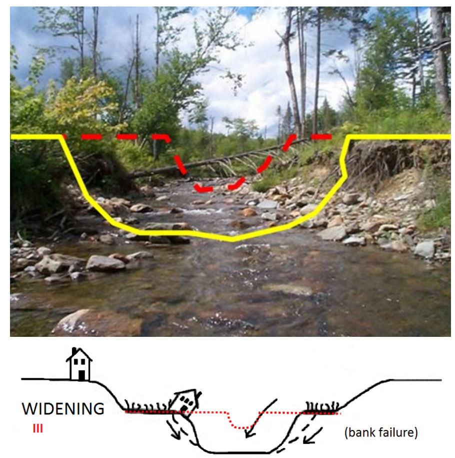


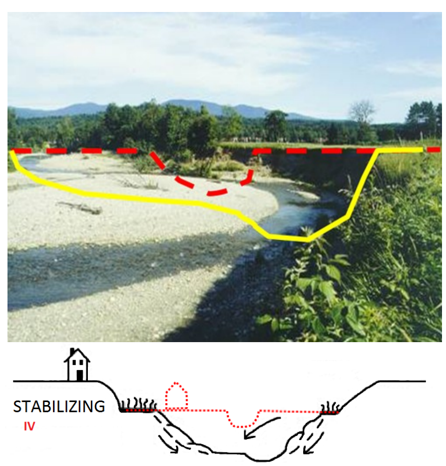
Stages of Channel Evolution

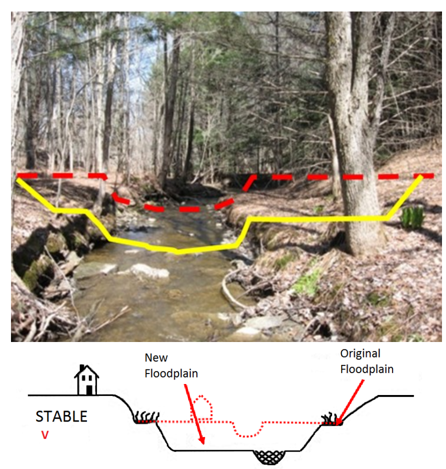
Examples from Vermont











Design

In general, think in terms of Channel Evolution and Equilibrium and take measures that move the river toward the stable condition.

General Design Considerations

- Restore the predicted or observed bankfull width and depth dimensions. Or, if the damaged reach lies between two altered but undamaged reaches, match the dimensions of the up and downstream reaches.

- Restore the expected degree of floodplain connectivity to the greatest extent possible.

- Leave in place or construct bed features to provide roughness and habitat.

- Stabilizing a channel that has incised can require significant design work. Consider getting technical assistance with solutions.

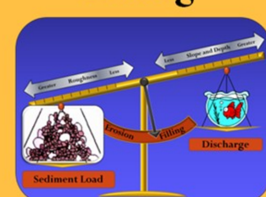
- If stabilization structures are required, follow the design specifications closely (see the next section of examples of commonly used stabilization structures).

- Keep in mind the likely channel response to the activities listed in the table on the following page and try to avoid them.

- Follow the Stream Alterations Culvert Standards when replacing culverts to ensure preservation of sediment and flow transport and overall river stability and aquatic organism passage.

Design

River and Road Maintenance Activities to Avoid

Activity		Resulting Change to Equilibrium Factors	Channel Response
Over Dredging	→	Increased Depth	Erosion 
Over Dredging	→	Decreased Resistance & Sediment Volume	
Channel Narrowing	→	Increased Depth	
Channel Berming	→	Increased Depth	
Channel Straightening	→	Increased Slope	
Increased Runoff Rate	→	Increased Depth & Slope	
Undersized Culvert	→	Decreased Slope Upstream	Filling 
Channel Widening	→	Decreased Depth	
Upstream Landslides	→	Increased Sediment Volume	

Stabilization Structures

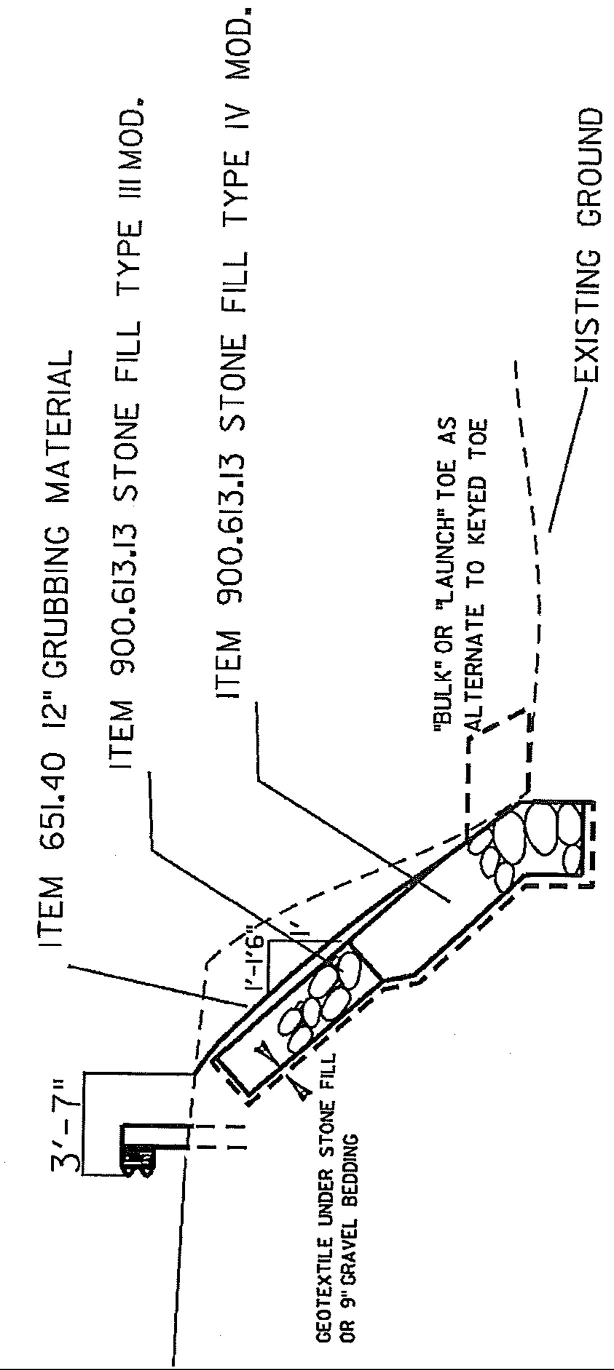
Rip-Rap

Figure 1. *Rip-Rap serves as an immobile surface that protects the underlying bank from erosion.*

CONSIDERATIONS

- Slope
- Material Gradation
- Thickness
    - Keyway (vertical and lateral)
    - Top Elevation (1 ft above low floodplain on opposite bank or Q50)
- Underlayment/Bedding

Stabilization Structures



Stabilization Structures

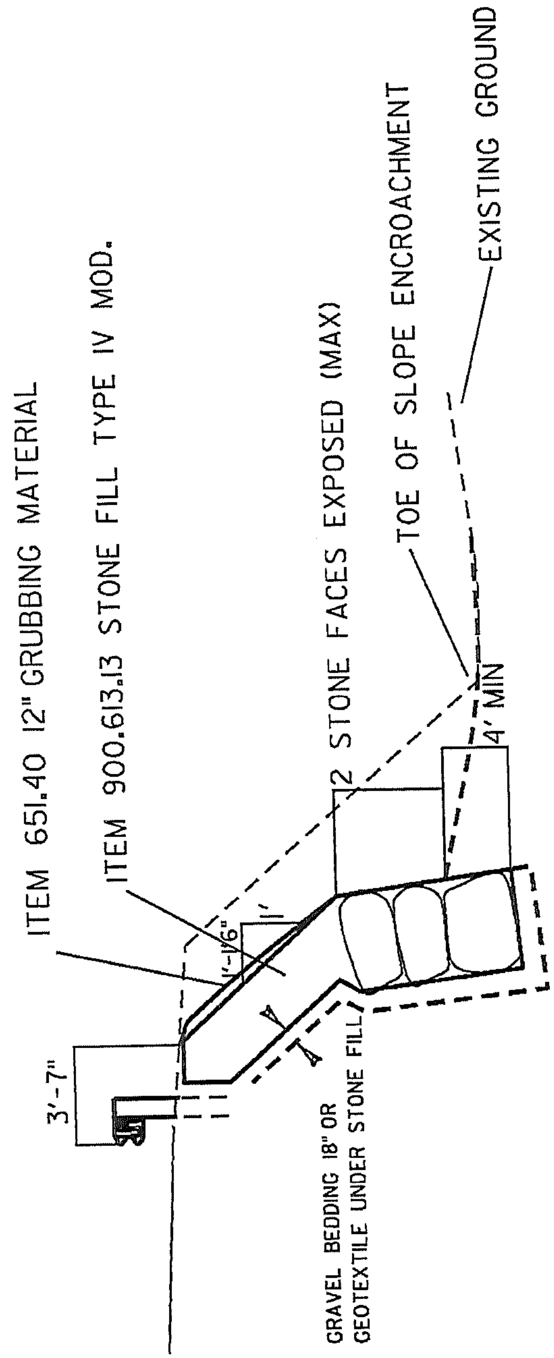
Stacked Wall

Figure 2. *Stacked walls provide an immobile surface to protect the underlying bank but because of their steep slope don't consume as much space between the road shoulder and the river as rip-rap.*

NOTES

1. Stone toe wall shall be constructed with stones of the specified size and in no cases shall the immediate dimension of any stone be less than 3'0".
2. Wall shall be constructed with staggered (ie. running) joints between rocks on adjacent tiers.
3. Footer rock shall be embedded below the channel a minimum of 4'0".
4. Contractor shall carefully select and place individual stones to maximize contact with adjacent stones.
5. To extent practical, stones shall dip toward embankment to better resist sliding.

Stabilization Structures



Stabilization Structures

Bed Armor

Figure 3. *Bed armor creates an immobile surface to protect the underlying bed from eroding downward.*

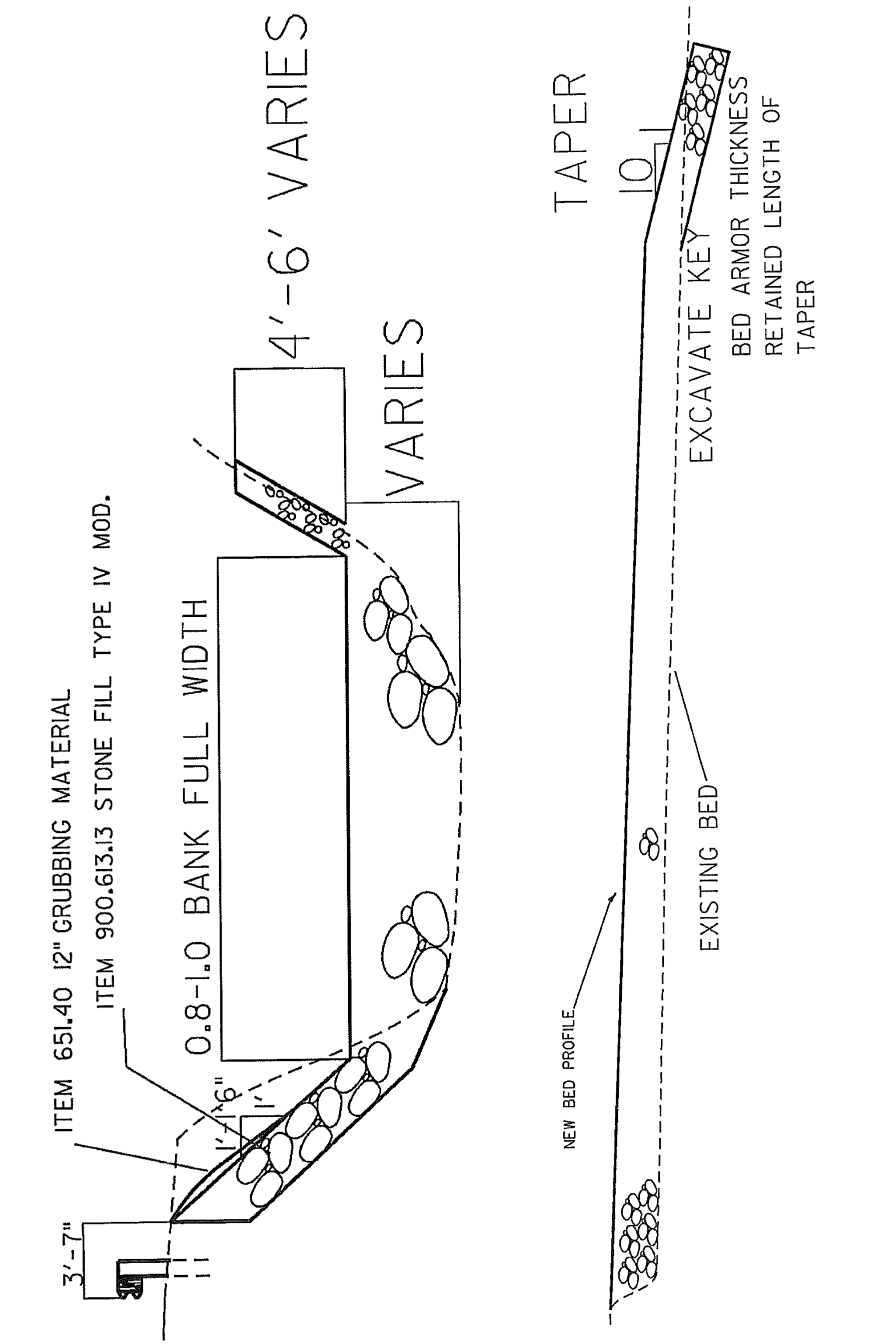
CONSIDERATIONS

- Channel Width and Depth
- Material Size and Gradation
- Thickness
- Up and Downstream Tapers into Channel Bed
- Availability of Bedload to Infill Gaps

NOTES

1. 90% of rock armor by volume must have at least 2 dimensions greater than the average dimension of any existing bed armor particles resistant to the flow.
2. Point of transition either away from toe of roadway embankment or alleviation of channel confinement.

Stabilization Structures



Stabilization Structures

Rock Weir

Figure 4. *Rock cross-vanes meet multiple objectives including bed and bank stabilization and sediment transport by creating a stable point in the channel that dissipates and redirects erosive energy as well as habitat by providing deep pools.*

NOTES

1. Rock size should be in the range of 3-5 ft.
2. The footer depth should be 3 times the height of the protrusion of the invert rock (see page 32).
3. The top course should be offset slightly upstream of the footer course to protect against scour at the base of the structure.

Stabilization Structures

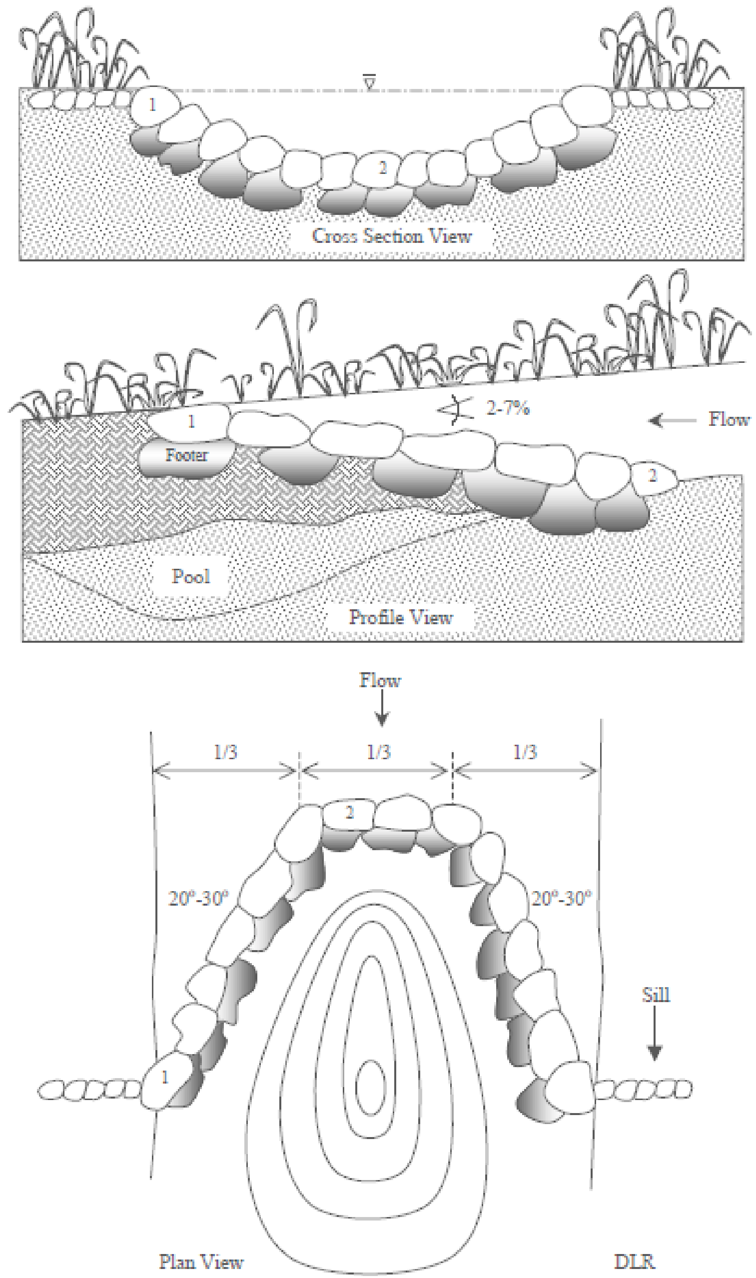


Figure 3. Cross section, profile and plan view of a Cross-Vane

Stabilization Structures

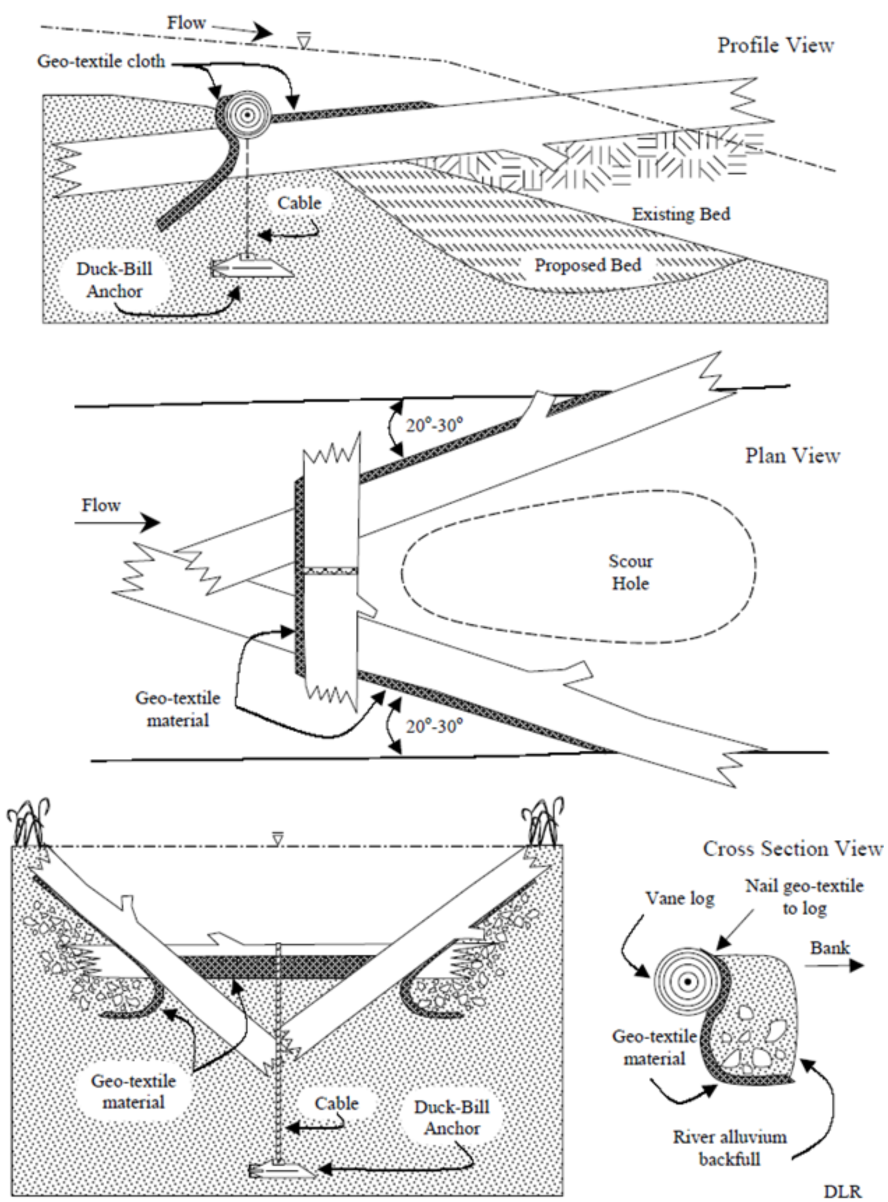
Log Cross Vane

Figure 5. *Log cross-vanes are an alternative to the rock cross-vanes and meet the same objectives but can be more difficult to construct and have a shorter life expectancy. However, in situations where large rock is unavailable they can be a viable alternative to the rock cross-vane.*

NOTES

1. The invert of the structure is secured using a duck-bill anchor or placement of a large boulder on the ends of the logs.
2. Geo-textile should be used to prevent piping of sediments and undermining of the invert.

Stabilization Structures



Stabilization Structures

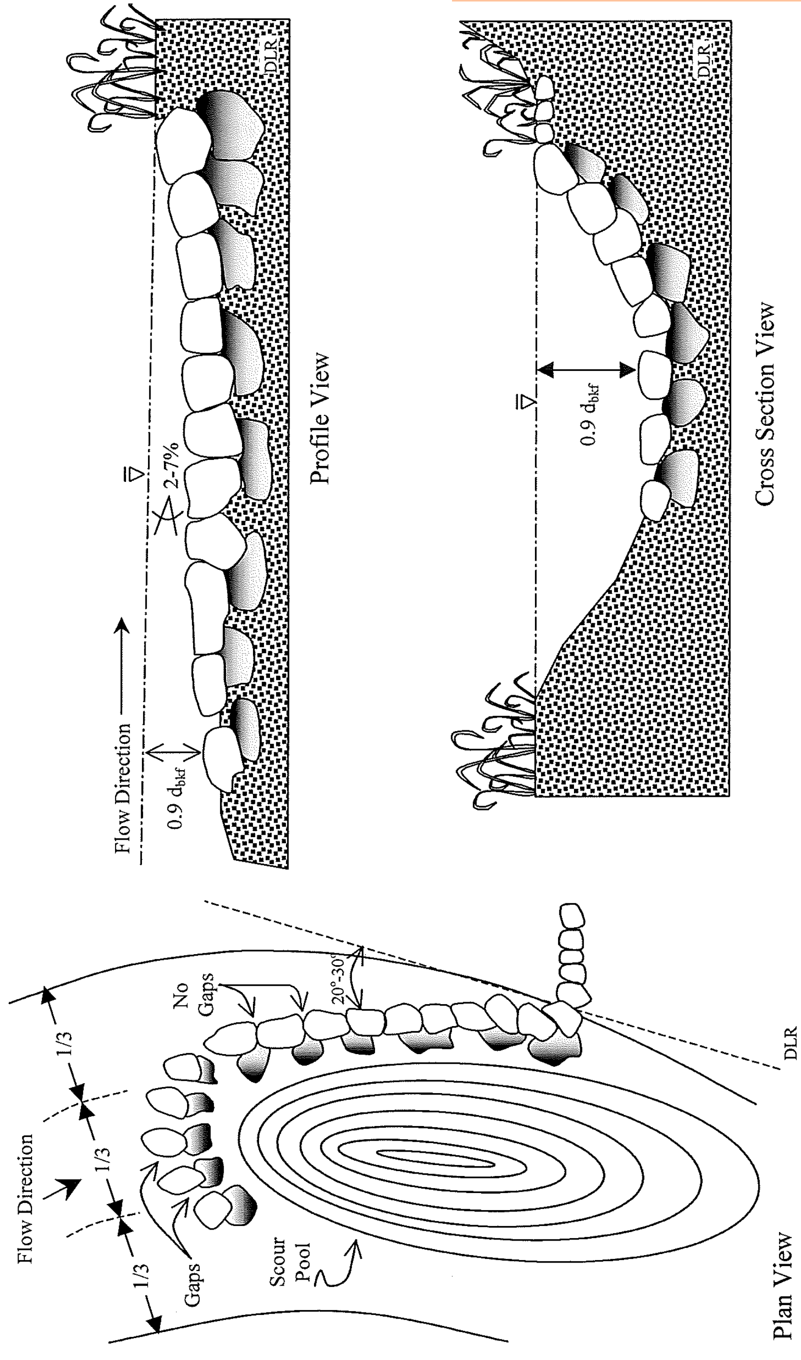
J-Hook Vane

Figure 6. *J-hook vanes meet multiple objectives including bank protection, sediment transport, channel capacity and habitat maintenance by dissipating and redirecting erosive energy into the center of the channel where a deep pool is created.*

NOTES

1. Rock size should be in the range of 3-5ft.
2. The footer depth should be 3 times the height of the protrusion of the invert rock (see page 30).
3. The top course should be offset slightly upstream of the footer course to protect against scour at the base of the structure.
4. Vanes can be constructed without the J-hook component.

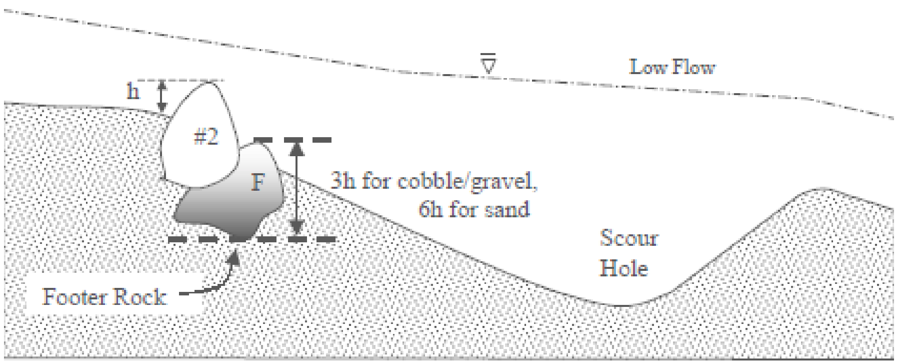
Stabilization Structures



Stabilization Structures

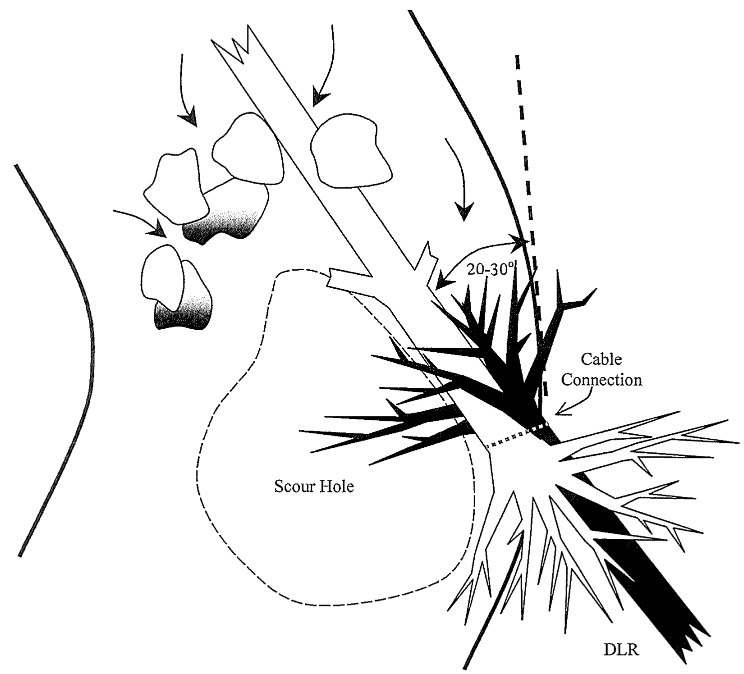
Rock Vane Structures: Footer Depth

For both the rock cross-vane and the J-hook vane the depth of the footer rock at the invert is 3 times the protrusion height (h) of the top invert rock (#2) in gravel and cobble bed streams. In sand bed streams the footer depth should be 6 times the protrusion height.



Log J-Hook Vane

Figure 6. *Log J-hook vanes meet the same objectives as the rock J-hook vanes but can be more difficult to construct and have a shorter life expectancy. However, in situations where large rock is unavailable they can be a viable alternative to the rock J-hook vane.*



Stabilization Structures

Random Boulder Placement

Figure 7. *Random boulder placement meets multiple objectives including channel stability and habitat maintenance by creating roughness that dissipates erosive energy in a way that results in the creation of small scour pools.*

NOTES

1. Boulder placements are suitable on streams where boulders would naturally occur but are absent.
2. Rock size should be 1 to 2 times the largest boulders that would naturally occur on the stream.
3. Clusters of 3 to 5 boulders with one boulder-width between boulders are most effective.
4. Boulders should occupy less than 10% of the bankfull cross-sectional area.

Designing Culverts for River Stability

Culverts sized to the bankfull channel width with sufficient opening height and embedment depth, have a slope similar to the up and downstream channel and horizontally aligned with the channel, will have minimal impact on the hydraulics of the sediment transporting flows and therefore provide for natural channel stability and aquatic organism passage through the structure.

For more information on designing and retrofitting culverts for better aquatic organism passage see the Vermont AOP Guidelines at: www.vtfishandwildlife.com/fisheries_AOP.cfm

Vermont General Permit Culvert Requirements	
Span Width	1.0 – 1.2 x Wbkf
Opening Height	4 x Dbkf
Embedded Depth	30% of Total Height
AOP	Provided

Structure Size Requirements for Channel with Width of 10 ft. and Depth of 1 ft.