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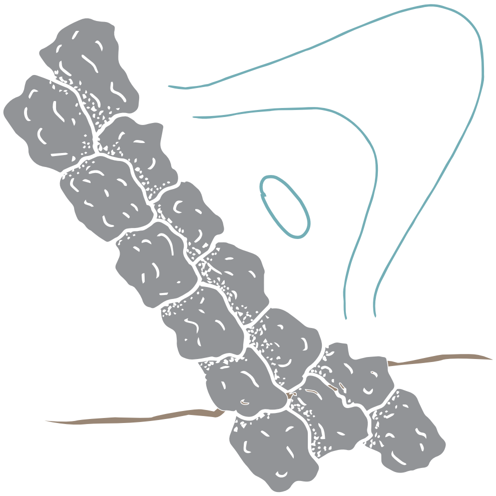
Fact Sheet Number 2



Stream Restoration Series

Single-Arm Vane

Authors: E.L. Hickman and T.M. Thompson, Biological Systems Engineering

ALTERNATE NAMES:

(single-arm) rock vane,

(single-arm) log vane, single-wing vane, straight vane

STRUCTURE TYPE:

rigid structure; flow deflector; river training structure

Single-arm vanes are flow deflection structures that dissipate energy, deflect stream flow to the center of the channel, reduce streambank erosion, and create pools. The single-arm vane deflects flows away from the bank and creates turbulence, dissipating energy. This new flow condition also causes the thalweg to migrate towards the center of the stream and a scour pool to form downstream of the vane, which can provide habitat for fish and other aquatic wildlife.

Where applicable, the single-arm vane may be used as a more ecologically sound alternative to traditional bank armor, such as riprap. Vanes may improve the establishment of protective vegetation on bare or newly regraded banks by deflecting flows away from vulnerable new plantings (Figure 1). By protecting the bank from fluvial erosion, this structure promotes the overall stability of the stream cross-section. Single-arm vanes can be constructed of wood (logs), stone (boulders), or a combination of both materials (Figure 2).

CAUTION: If the forces driving bank erosion are not those addressed by the function of the single-arm vane, vane installation is unnecessary and will likely be ineffective, such as when streambank erosion or instability is actually caused by overland surface runoff or seepage. Single-arm vanes are costly and have a relatively high risk of structural failure due to their position within the stream itself, so they should be installed only to protect infrastructure by preventing bank erosion.

Figure 1. Single-arm vanes redirect flows from banks, reducing erosion caused by high flows.

Figure 2. Single-arm vane, Paint Branch, College Park, Maryland.

Application

The single-arm vane is effective for stream reaches which…

- have no site constraints which would require that the stream not naturally migrate laterally across the floodplain;
- are slightly-to-moderately meandering/sinuous;
- would naturally possess either a plane-bed or a riffle-pool sequence (i.e. Rosgen stream types B2-B5 and C2-C4 as described in Rosgen's 1996 text Applied River Morphology);
- have coarse bed material (small boulders/cobbles to coarse sand), which is mobile enough for scour pool formation; and,
- have few or no regions of stagnant water or backwater.

Use a single-arm vane to halt or prevent bank erosion or lateral migration in situations where it is desirable for the stream cross-section to remain constant at flows equal to or less than the SDF.

Consider use of the single-arm vane carefully for stream reaches which…

- are deeply incised or have a low width to depth ratio, as the vane slope may exceed recommended values;
- are currently incising or experiencing substantial change in their cross-sectional geometry, as additional structural stabilization measures may be required;
- have beds of very fine, mobile material (fine sands and/or silt), which increases the risk of structural failure by undercutting; or,
- have an opposite bank which is also experiencing or in danger of undesirable erosion, especially in small or narrow streams where flows may be deflected directly into the opposite bank, causing higher erosion rates there.

CAUTION: Do NOT install a single-arm vane in streams which…

- are composed of exposed bedrock;
- have a gradient greater than 3%
- regularly experience heavy loads of large sediment (cobbles and larger) or other large debris (i.e. large logs) or
- otherwise have no sufficient justification for preventing natural lateral channel migration.

General Design Guidelines

The numerical guidance listed below represents rules-of-thumb that may not be strictly followed on a site-by-site basis and should not be substituted for actual design calculations and/or modeling. Please see the references section for a list of useful documents from which these numbers were obtained, most notably the Maryland's Waterway Construction Guidelines (2000) and Sotiropoulis and Diplas (2014).

Design Flow

It is important to consider a range of low and high flows in stream restoration design. At low flows, structures should concentrate flows to maintain sufficient depth for fish passage and survival of aquatic organisms. Stability analysis at high flows should be conducted to ensure the vane remains in place for flows up to a given recurrence interval (return period). The magnitude of the design flows will depend on project goals, as well as physical (site and valley), budget, regulatory, and other constraints.

One consideration in the selection of a high design flow is the desired structure design life (SDL). Inherently, the SDL indicates the likelihood that, in any given year, the vane might experience a flood event of greater magnitude than the design storm. The SDL is often determined by client needs or permitting requirements. In an urban watershed, in which structure failure may cause damage to nearby infrastructure or adjoining property, the acceptable level of risk is important to consider.

If the acceptable level of risk is provided in the form of a given recurrence interval, T, for the flow to be withstood by the structure, the SDL will be equivalent to that recurrence interval. For example, if local regulations require that all in-stream structures be designed to withstand a 50-yr flood event, then the SDL will be 50 years, and the design flow will be the 50-yr flood discharge. The probability of the design flood occurring in any given year is $P = 1/T * 100\%$. Thus, there is a 2% probability of the 50-year flood occurring in any given year.

The risk, R, of the structure experiencing a flow equivalent to the design flood during a given time period, m, is determined using the formula $R = 1-(1-1/T)^m$, where m is the time period of interest in years. Thus, a single-arm vane designed for an SDL of 50 years will have a failure risk of 18% over a 10-year period.

Alternatively, the SDL can be determined by calculating the flow that will produce an applied shear stress or other hydraulic parameter that the vane must resist and then determining the recurrence interval of the associated flow.

Material Selection

The choice between use of logs or rocks for the single-arm vane should be made considering both the goals and requirements of a particular project, the materials which occur naturally in

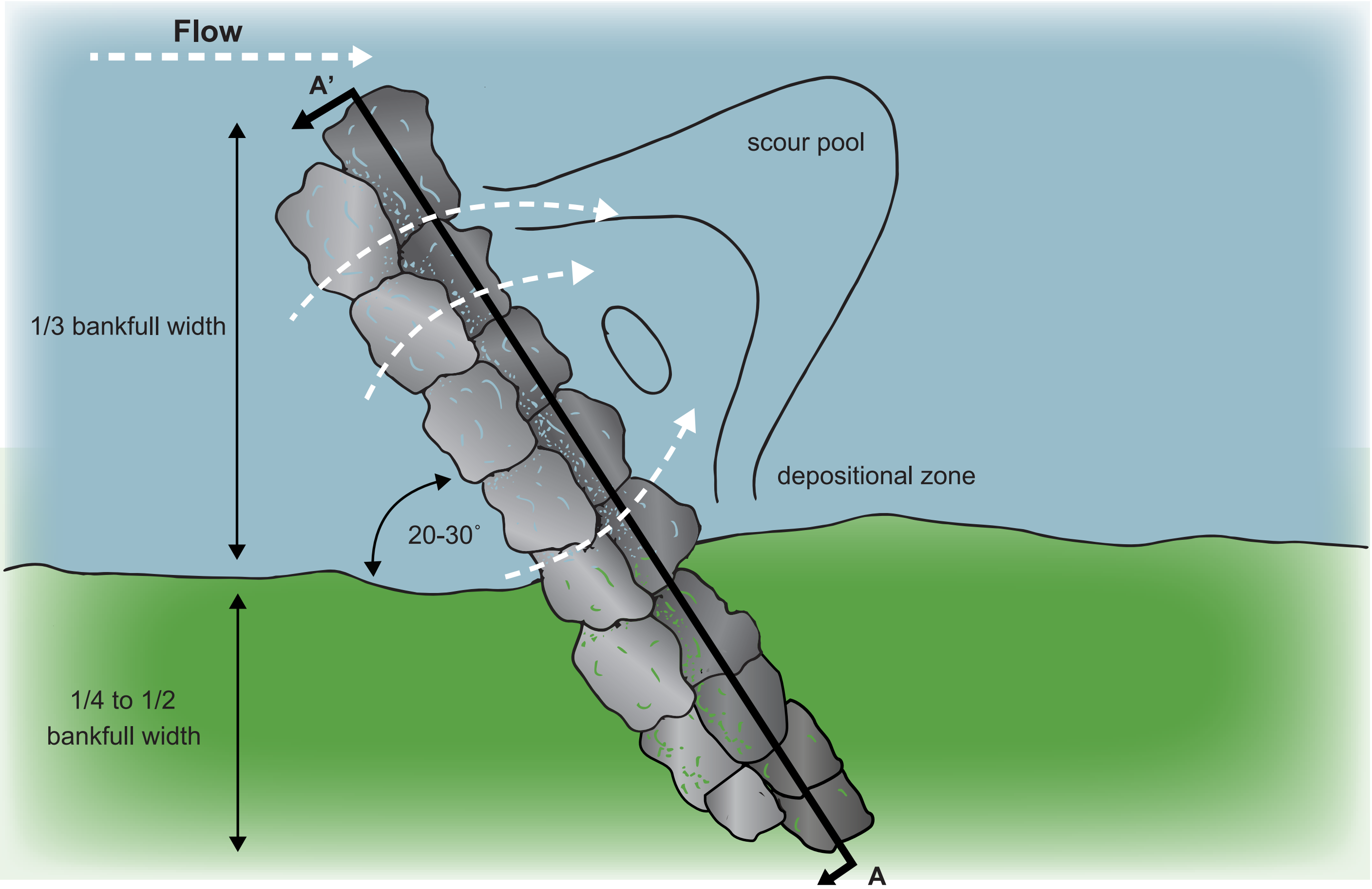


Figure 3. Single-arm vane plan view.

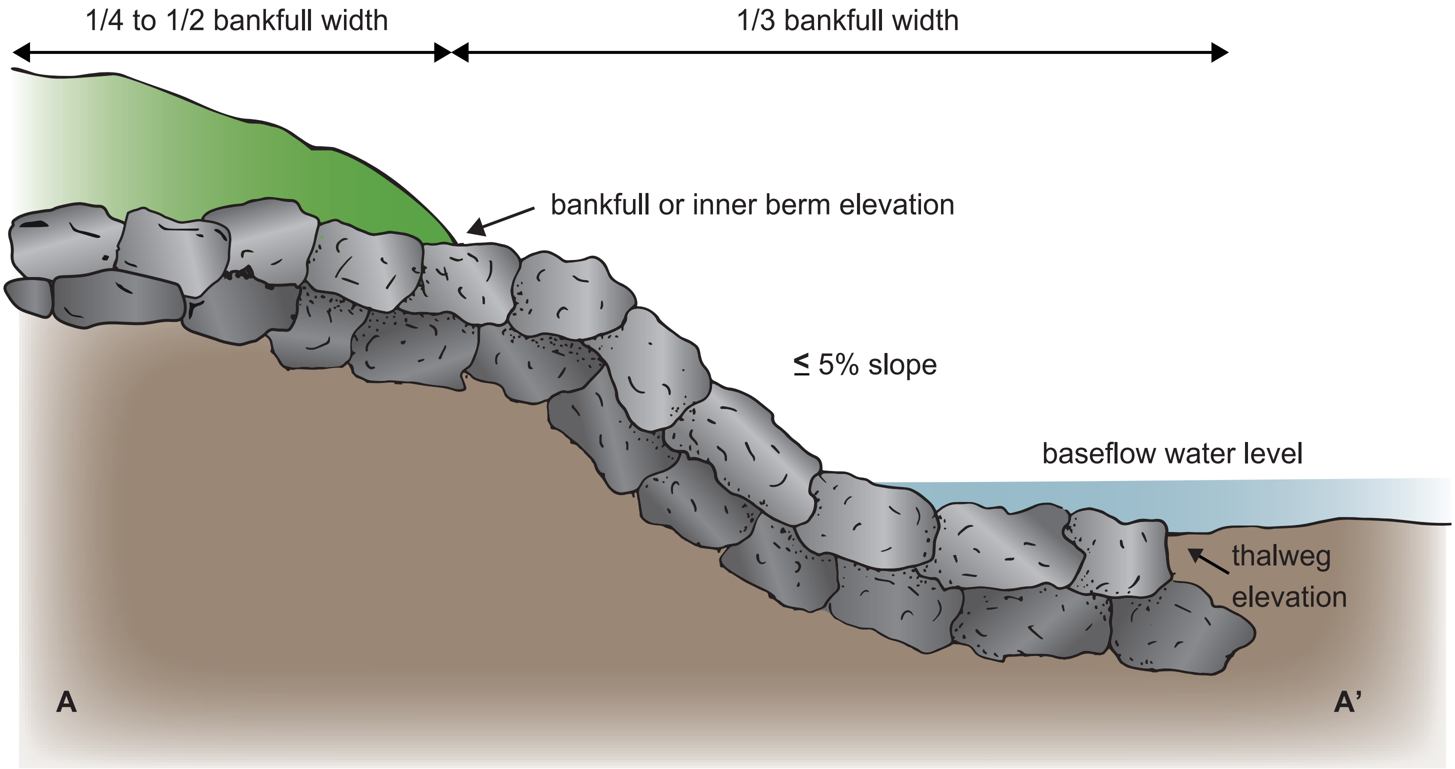


Figure 4. Single-arm vane cross section A-A'.

the stream (or a reference reach), and materials available on site.

Woody material (logs) is generally less expensive than rocks, and may be more readily available. Use of logs should be seriously considered in streams that naturally have a high occurrence of large in-stream woody debris, rather than large in-stream boulders. Since wood is a biological material, natural decay will significantly limit the life expectancy of a log-arm cross vane, so if a longer SDL is required by the project, a log vane may not be a viable option. Wood that is continuously submerged will have a greater life than wood exposed to wetting and drying.

Boulders are more expensive than logs, but are more durable, as their natural decay occurs over a much longer period of time. Rock vanes may also be easier to construct, as the key is made of multiple individual boulders, rather than the same single log as the vane. Rock vanes are particularly recommended for projects which require a long SDL or involve the protection of infrastructure, and for streams in which large boulders and rocks are normally found.

Material Sizing

Material used for a cross vane must remain structurally sound during the design flow. When sizing woody material for log arms, note the size of material locally available and the size of material naturally occurring as debris in the stream or a reference reach. In general, use of single logs less than 8 in. (20 cm) in diameter is not recommended. Additionally, logs should be long enough to key into the bank 1/4 to 1/2 bankfull width. Smaller logs may be used in a bundle if they are bolted together.

To size boulders for the single-arm vane, the minimum size rock which will remain in place during the design flow must be determined. The flow exerts a shear stress on any material in the channel; this is called the applied shear stress. The critical shear stress of a particle (boulder) is the shear stress at which it will likely be displaced. Because different channel cross section geometries can produce the same average flow velocity, it is important to assess the stability of the materials using shear stress, rather than an allowable velocity. Technical Supplement 14C Stone Sizing Criteria of the NRCS Stream Restoration Design Handbook (NRCS, 2007a) describes these calculations in greater detail. Designers should recognize that techniques used to size riprap may underestimate the size stone needed for in-stream structures because the vane rocks are more exposed to the flow than riprap. Once a material size is calculated, a factor of safety of 1.1-1.5 is commonly used. Rocks used in single-arm vanes typically are 2-4 ft. (60-120 cm) in diameter. Designers should also consider using stones which are large enough to prevent movement by vandals.

Choose rocks which have flat, rather than round, surfaces to allow the vane rocks to sit securely on the footer rocks and to line up with adjacent rocks. When placing rocks, remember that the rocks nearer the tip will experience the strongest hydraulic forces. In general, larger rocks will produce more turbulence, leading to a deeper scour pool. Also be sure to consider rock mineral composition, as rocks such as sandstone can have lower density and some minerals can experience high rates of weathering or chemical leaching. Use native stone when possible.

Footer Depth

The highest hydraulic stresses and the deepest part of the scour hole occur at the tip of the vane. While this scour hole increases bedform and flow diversity, if it becomes deeper than the footer materials, the structure can be undermined. Therefore, it is critical to estimate the scour depth over a range of flows to ensure the footers or piles for log vanes extend below the maximum predicted scour depth. The expected scour depth can be determined using the methods described in Technical Supplement 14B ("Scour Calculations") of the NRCS Stream Restoration Design Handbook (NRCS, 2007b). Once the maximum bed degradation is estimated, the footer depth or piling should extend 1.5-3.0 times this expected depth, or until a resistant layer, such as bedrock, is reached.

CAUTION: If the channel substrate has a high sand content, use the Wilcock-Kenworthy modification of the Shields number, as described in Wilcock et al. (2008), to determine the critical shear stress.

Placement within Stream Cross-Section

Install the vane arms at a 20° to 30° horizontal angle from the bank, such that the vane points upstream. Measure the angle between the vane and the upstream bank (see plan view diagram, Figure 3). A larger angle between the arm and the bank protects greater lengths of bank against erosion, but also results in more intense bed scour and greater risk of failure. In highly sinuous channels, a smaller horizontal angle reduces the risk of erosion just upstream of where the vane is keyed into the bank. However, because water will flow perpendicular to the vane arm, in smaller streams, smaller horizontal angles can direct flows into the opposite bank, causing bank erosion downstream of the structure. Each vane arm typically does not extend over more than 1/3 of the bankfull width.

CAUTION: Use of a large verticale angle in a stream with a bed of fine gravel or sand (highly erodible) may cause undesirable bed erosion as the scour depth immediately down stream of the vane increases with increasing vertical vane angle.

The in-stream vane tip should be submerged at all times. This condition requires the rocks at the vane tip (not just the footer rocks) or the log tip be buried in the stream bed at approximately thalweg elevation. In general, the steeper the vertical slope of the vane arm, the greater force the water gains as it passes over the vane, causing a greater scour depth downstream of the vane. The location at which the vane is keyed into the bank may be lowered if necessary, to ensure the vertical slope of the vane from bank key to tip does not exceed 5% for rock structures and 4% for log structures. Although prior design guidance (Rosgen, 1996) indicated the vane should be keyed in at bankfull height, this will not be appropriate for every stream, and log vanes in particular may be keyed in lower than bankfull height, as they generally require a lower vertical slope (B.A. Doll, personal communication, April 11, 2016).

CAUTION: The greater the vertical slope of the vane, the shorter the length of bank that is protected from erosion.

Placement within Stream Planform

Single-arm vanes are designed to prevent natural migration of the channel across the floodplain. If infrastructure protection is not a project goal and the stream has room to migrate naturally, it is best to design the stream without the use of an in-stream structure, as these structures will prevent natural channel migration.

If natural channel migration cannot be allowed, such as to protect infrastructure, a similarly confined reference reach can be used to inform structure spacing along the channel. In undisturbed meandering streams, pools commonly occur every 5 to 7 bankfull widths apart along the stream channel. If approximation of specific natural habitat conditions is desired, consult reference reaches to determine how far apart pools naturally form in the desired condition, and space vanes appropriately.

Single-arm vanes can be used to redirect flows upstream of bridges and culverts. The vane tip should be placed 1.5 to 2.0 times the bankfull width upstream of the upstream end of the bridge/culvert abutment. This location reduces the likelihood that the scour pool will form adjacent to the bridge foundation while still directing flows away from the embankment. For more information, see Johnson et al. (2002).

To protect the outer bank of a meander in a slightly sinuous stream reach, place a vane or begin a vane series at the apex of a meander bend, where flow impinges on the bank at an acute angle. If the stream is highly sinuous, move the vane location downstream from the meander apex about one bankfull channel width to avoid promoting erosion in the turbulent zone at the apex. In general, use of a series of vanes promotes better and longer-lasting bank protection than use of a single vane. Vector analysis can be used to determine vane spacing as a function of the radius of curvature of the bend [see Sotiropoulos and Diplas (2014)].

Construction

The most common failure modes for single-arm vanes are undermining of the structure, structure flanking, and loss of vane rocks.

Footer rocks/logs and wooden pilings are used to prevent scour from undermining the vane. One or more tiers of footer rocks may be used, depending on the susceptibility of the vane to structural failure by undercutting. During construction, slightly offset vane rocks into the flow (in the upstream direction), such that a bit of the footer rock is

Figure 5. Vane rocks should fit snugly together and be chinked with smaller rock with a wide range of sizes. (Design by Wetland Studies and Solutions, Inc.)

exposed on the downstream vane face. This offset prevents the creation of a scour hole directly on the downstream face of the vane which would undermine the structure, perhaps even causing vane rocks to collapse into the scour hole.

To prevent bank erosion where the vane is attached to the bank, it is important to "key in" the vane arms. Anchor the bank end of each arm into the bank a distance 1/4 to 1/2 bankfull width. Large boulders may be placed on the downstream side of the vane arms to increase structural stability (Figure 3). This increased support is provided along the downstream face where the vane is anchored into the bank.

Even though rocks may be sized correctly for the design flow, individual rocks may be dislodged due to turbulence around exposed rocks or flow between rocks. All rocks used in a single-arm vane should fit together snugly (Figure 5). Offset vane rocks from footer rocks such that each vane rock is centered on the intersection of two footer rocks, resting on half of each. To prevent sediment from eroding through gaps in the footer rocks, hand-chink any gaps that exist between rocks with gravel with a wide range of particle sizes and wrap the footer in geotextile fabric.

Post-Construction Monitoring

The function of most structures can be assessed using repeated visual observations and photographs. Some additional monitoring activities to evaluate vane function include the following:

- measure scour pool depth to ensure a pool is forming and the pool depth does not exceed the depth of pilings or footer rock layers;
- regularly examine the adjacent streambanks for erosion or a lack of vegetation establishment;
- examine the vane for rock displacement after storm events of a similar magnitude as the design storm, where displacement is defined as complete removal of the rock from its place, rather than minor shifting; and,
- regularly examine the vane for aggradation or bed degradation upstream of the structure.

If visual assessment of the structure indicates undermining, lateral erosion, or aggradation of the structure, additional assessments, such as cross section and longitudinal surveys, can be conducted to determine what corrective action may be needed.

Consider requesting help from local conservation or volunteer-based organizations for monitoring work that can be performed by laypeople, if resources for monitoring are unavailable or limited.

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References

Bernhardt, E. S., Sudduth, E. B., Palmer, M. A., Allan, J. D., Meyer, J. L., Alexander, G., Follastad-Shah, J., Hassett, B., Jenkinson, R., Lave, R., Rumps, J., & Pagano, L. (2007). Restoring rivers one reach at a time: results from a survey of US stream restoration practitioners. Restor. Ecol., 15(3): 482-493.

Cramer, M. L., ed. (2012). *Stream Habitat Restoration Guidelines*. Olympia, WA: Washington Department of Fish and Wildlife, Washington Department of Natural Resources, Washington Department of Transportation, Washington Department of Ecology, Washington State Recreation and Conservation Office, Puget Sound Partnership, US Fish and Wildlife Service.

Doll, B. A., Grabow, G. L., Hall, K. R., Halley, J., Harman, W. A., Jennings, G. D., and Wise, D. E. (2003). *Stream Restoration: A Natural Channel Design Handbook*. North Carolina Stream Restoration Institute. Raleigh, NC: North Carolina State University.

Fischenich, C. (2001). *Stability thresholds for stream restoration materials*. EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-29). U.S. Army Corps of Engineers Research and Development Center: Vicksburg, MS.

Johnson, P.A., Hey, R. D., Brown, E. R., & Rosgen, D. L. (2002). Stream restoration in the vicinity of bridges. *J. Am. Water Res. Assoc.* 38(1):55-67.

Maryland Department of the Environment. (2000). *Maryland's Waterway Construction Guidelines*. Baltimore, MD: Maryland Department of the Environment: Water Management Administration.

Natural Resources Conservation Service. (2007a). Technical Supplement 14C: Stone Sizing Criteria. In: *National Engineering Handbook 654: Stream Restoration Design*. Washington, D.C: United States Department of Agriculture, Natural Resources Conservation Service.

Natural Resources Conservation Service. (2007b). Technical supplement 14B: Scour calculations. In: *National Engineering Handbook 654: Stream Restoration Design*. Washington, D.C: United States Department of Agriculture, Natural Resources Conservation Service.

Radspinner, R. R., Diplas, P., Lightbody, A. F., & Sotiropolous, F. (2010). River training and ecological enhancement potential using in-stream structures. J. *Hydraul. Eng.*, 136(12): 967-980.

Rosgen, D. L. (1996). *Applied River Morphology* (2nd ed.). Fort Collins, CO: Wildland Hydrology.

Rosgen, D. L. (2001). The cross-vane, w-weir, and j-hook structures: their description, design, and application for stream stabilization and river restoration. *Proc. Wetlands Engineering and River Restoration Conference 2001*. Reston, VA: American Society of Civil Engineers.

Sotiropoulos, F. & Diplas, P. 2014. *Design Methods for In- Stream Flow Control Structures.* National Cooperative Highway Research Program Report 795. Washington, D.C.: Transportation Research Board.

Virginia Division of Soil and Water Conservation. (2004). *The Virginia Stream Restoration and Stabilization Best Management Practices Guide*. Richmond, VA: Virginia Department of Conservation and Recreation.

Wilcock, P., Pitlick, J., & Cui, Y. (2008). *Sediment transport primer: Estimating bed material transport in gravelbed rivers. General Technical Report*. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.