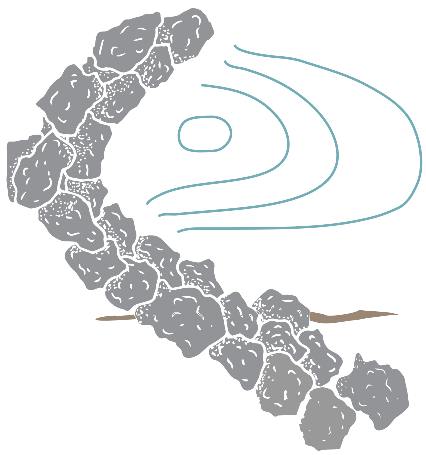
Fact Sheet Number 3



# Stream Restoration Series

## J-Hook Vane

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

**ALTERNATE NAMES:**

j-vane

**STRUCTURE TYPE:**

**rigid structure; flow deflector; river training structure**

J-hook vanes are flow deflection structures that dissipate energy, deflect stream flow to the center of the channel, reduce streambank erosion, and create pools. The original j-hook vane differs from the similar single-arm vane in that it extends beyond the vane tip at approximately right angles to downstream flow. This extension is the "hook" which gives this vane type its characteristic "J" shape. Particularly in smaller streams, the j-hook structure can be modified to span the channel to provide grade control (Figure 1). J-hook vanes may be constructed of wood (logs), stone (boulders), or a combination of both materials.

Where applicable, the j-hook vane is a more ecologically beneficial alternative to traditional bank armor, such as riprap. The j-hook vane deflects flows away from the bank and creates turbulence, dissipating energy. The flow deflection and resulting drop in applied shear stress improves the establishment of protective vegetation on bare or newly regraded banks. By protecting the bank from fluvial erosion, this structure promotes the overall stability of the stream cross-section.

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. The scour hole formed downstream of a j-hook vane is typically deeper than the pool formed by a single-arm vane, as the hook induces stronger turbulence in the region of scour.

In modified j-hook vanes, the hook extends across the entire baseflow channel, such that it resembles a cross vane without one vane arm. The modified j-hook structure provides grade control in two ways. First, the footer rocks extend below the expected scour depth to prevent upstream migration of knickpoints. A knickpoint is point along the channel where there is a sharp change in the stream bed elevation, which creates a small waterfall that can erode upstream. Second, the vane creates an elevation change in the channel longitudinal profile, which allows lower bed slopes upstream and downstream of the vane, decreasing the forces driving channel erosion.

**CAUTION:** If the forces driving bank erosion are not those addressed by the function of the j-hook vane, vane installation is unnecessary and will likely be ineffective, such as when bank erosion or instability is caused by overland surface runoff or seepage. J-hook 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 to protect infrastructure or to prevent channel migration and/or downcutting (modified j-hook only).

J-hook vanes can also increase flow diversity in uniform channels. Water ponded upstream of modified vanes induces gravel deposition. By forcing the flow over a drop and concentrating it in the center of the channel, these structures cause the formation of a scour pool downstream of the vane, further increasing flow diversity. In this way, a single modified j-hook vane creates a single riffle-pool structure while a series of vanes develops a riffle-pool sequence.

Figure 1. Modified j-hook vane. (Project by Ecotone, Inc.)

## Application

The j-hook vane is effective for stream reaches which…

- are slightly-to-moderately meandering/sinuous;
- are actively incising;
- would naturally possess a riffle-pool sequence (i.e. Rosgen stream types A3-A4, B3-B4, C3-C4, F3-F4, and G3-G4 as described in Rosgen's 1996 text Applied River Morphology);
- have a moderate to high gradient;
- 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 j-hook 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 less than or equal to the design flood, and to improve pool habitat.

Consider use of the j-hook vane carefully for stream reaches which…

- have no site constraints which require the stream to remain stationary and not naturally migrate across the floodplain;
- are deeply incised or have a low width to depth ratio, as the arm slope may exceed recommended values;
- are experiencing substantial change in their cross-sectional geometry, as additional structural stabilization measures may be required;
- 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;
- have high bedload transport, as the longer span of a j-hook vane makes it more susceptible to aggradation than the single-arm vane; or,
- have beds of very fine, mobile material (fine sands and/or silt), which increases the risk of structural failure by undercutting.

**CAUTION:** Do not install a j-hook vane in streams which…

- are composed of bedrock;
- have a gradient greater than 3%;
- regularly experience heavy loads of very large sediment (cobbles and larger) or other large debris (i.e. large logs);
- already have a well developed riffle-pool system; or,
- have no design constraints which prevent natural lateral 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 Waterway Construction Guidelines (2000), Gordon et al. (2016), 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 recurrance 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 j-hook 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.

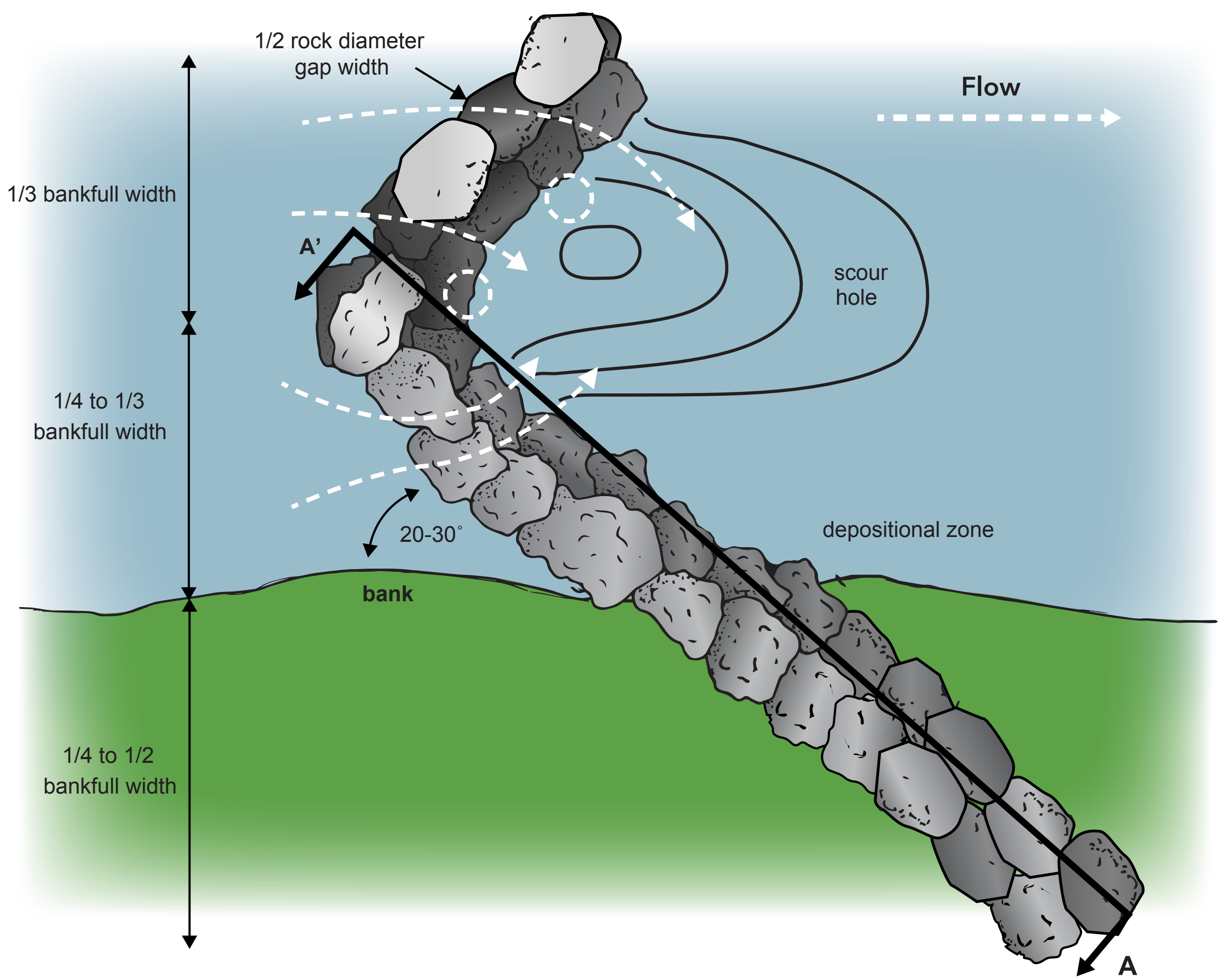



Figure 2. Plan view of traditional j-hook vane.

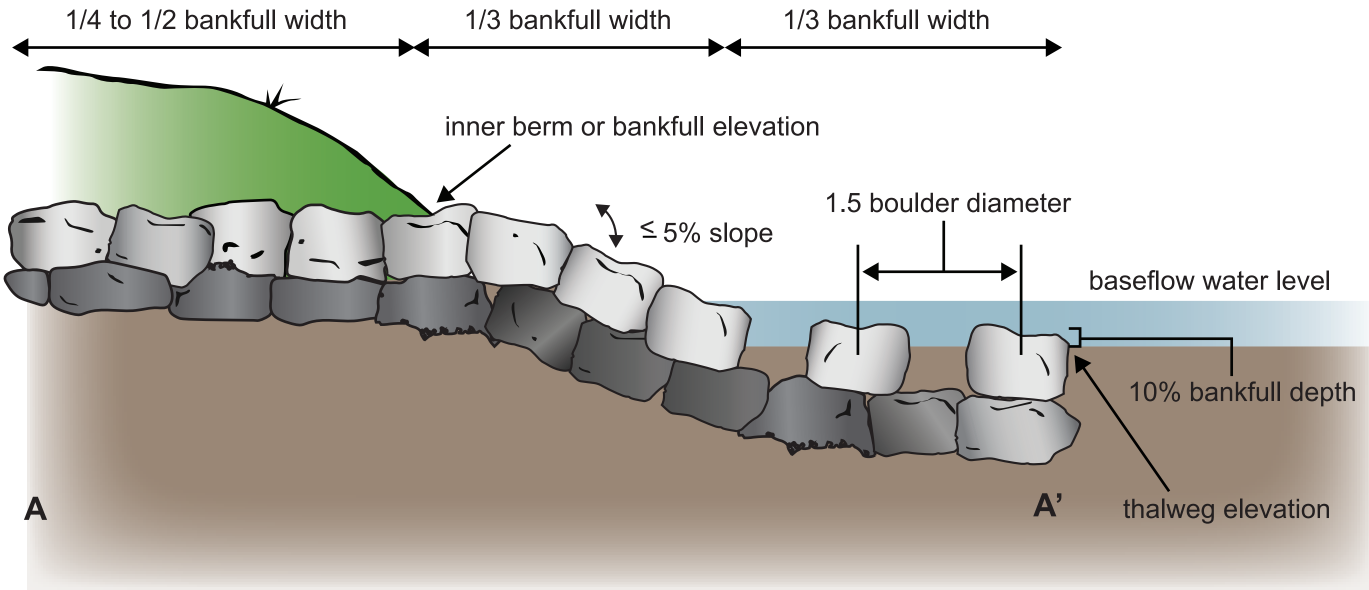



Figure 3. J-hook section A-A'.

## Material Selection

The choice between use of logs, rocks, or combination thereof for the j-hook vane should be made considering both the goals and requirements of a particular project, the materials which occur naturally in 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. However, logs are generally not recommended for use in grade control structures unless the stream would typically have a high occurrence of large in-stream woody debris. Since wood is a biological material, natural decay will significantly limit the life expectancy of a log j-hook vane. So if a longer SDL is required by the project, which is likely for a grade control structure, a modified j-hook vane constructed with logs 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 a series 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.

**CAUTION:** Use of log vanes in streams with highly variable flows (especially those in ultra urban settings) or for projects involving infrastructure protection is not recommended due to the lower durability of logs. In addition, log vanes are more easily undercut than rock vanes, so use caution when designing a log arm for a stream with fine, mobile bed material.

## Material Sizing

Material used for a j-hook vane must remain structurally sound during the design flow. However, the materials used must also be small enough to create the vane geometry described below. Selected material sizes may need to be altered based on the geometry and size of the stream to produce a j-hook vane which has the correct configuration. As a result, the design life of the structure may be reduced. Alternatively, the rocks can be grouted to increase vane strength.

When sizing woody material, note the size of material locally available and the size of material naturally occurring as debris in the stream or a reference reach, and select materials that will replicate a natural condition for the stream. 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 j-hook 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

**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.

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, the required diameter can be multiplied by 1.1-1.5 to add a factor of safety. Commonly, rocks used in j-hook vanes 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 vane 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

As water crosses over the vane arm, it will drop and impinge on the channel bed, causing a scour hole (plunge pool) to form. 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 downstream of the structure 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) and in Gordon et al. (2016). These methods frequently require knowledge of both the headwater and tailwater depths at multiple stream discharges; therefore, the design reach should be modeled using softwater such as HEC-RAS, as described in Gordon et al. (2016).

In designing structure footers, it is important to realize that the greatest scour will occur where there is the greatest drop height. Because the vane arm is sloped up from the hook, the greatest drop will occur along the vane arms, closest to the bank. However, this is also the area with the lowest footer depth (since the footers are parallel to the vane arm). To provide greater support along the arms, the footer depth can be extended or larger rocks can be used under the vane arm.

If a modified j-hook vane is being used to prevent the migration of a downstream knickpoint, it is important to estimate the maximum bed degradation that could occur at the structure due to the knickpoint. Footer depth should then be based on the greater of either the scour pool depth or the expected bed degradation due to the knickpoint. 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 feature, such as bedrock, is reached.

**CAUTION:** Be sure to estimate the expected scour depth prior to selecting a piling length (for log vanes) or number of tiers of footer rocks (for rock vanes). The expected scour depth can be easily determined using the methods described in Technical Supplement 14B ("Scour Calculations") of the NRCS Stream Restoration Design Handbook (NRCS, 2007).

### Placement within the Stream Cross-Section

Install the vane arm 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 1). A larger angle between the arm and the bank can protect 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.

**CAUTION:** Placing the vane arms at a larger angle to the bank (30 degrees) in a stream with a fine gravel or sand (highly erodible) bed may cause undesirable bed erosion as the scour depth immediately downstream of the vane increases with increasing horzinontal vane angle.

The vane should be keyed into the bank so that the vertical slopes of the arms do not exceed 5% for rock arms and 4% for log arms. As the verticle angle of the vane increases, so does the distance between the top of the vane arm and the bed, increasing the water drop height and the amount of scour that will occur. Although prior design guidance (Rosgen, 1996) indicated the vane should be keyed in at bankfull height, this may not be appropriate for every stream, and log vanes in particular should 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 the vane will protect from erosion.

Unlike the main arm of the vane, the hook of a traditional rock j-hook vane should not be straight, but should have a slight arc or curve to it. Additionally, the vane rocks along the hook should protrude slightly above the bed, a distance of approximately 10% of bankfull depth and should be spaced at a distance of 1.5 times the rock diameter to produce gaps approximately half the rock diameter wide. The hook portion provides additional turbulence, increasing the extent and depth of the scour pool.

For a modified j-hook, the j-portion is frequently straight, rather than curved. This section of the vane extends across the entire channel width and may also be keyed into the opposite bank. Similar to cross vanes, the rocks or logs forming the hook should be buried in the stream bed at approximately thalweg elevation to allow sediment transport and fish passage.

The length of the vane arm (excluding the hook) should not extend over more than 1/3 of the bankfull width, unless the channel is more than 20 feet (about 6 m) wide, in which case the vane may extend over as much as 1/2 of bankfull width. The vane length may be as short as 1/4 of bankfull width. With the addition of the hook, the entire j-hook structure may span as much as 60% of bankfull width. In general, the ratio of the structure length to bankfull channel width should decrease as the channel width increases. Note that a longer vane will protect a greater bank length from erosion.

### Placement within Stream Planform

Because j-hook vanes deflect flows away from a bank, they will also prevent natural migration of the channel across the floodplain. 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 infrastructure protection or grade control is not a project goal and the stream can be allowed to migrate naturally, j-hook vanes should not used.

To protect the outside of a meander bend in a slightly sinuous stream reach, place a vane or begin a vane series at the apex of the meander bend. If the stream is highly sinuous, move the vane location downstream from the meander apex about one bankfull channel width to avoid erosion in the zone of changing flow patterns at the apex.

Because bed material will deposit upstream of a modified j-hook vane and a scour pool will form downstream, modified j-hook vanes should be placed in a run on meandering channels.

Note that no modified j-hook vane should produce a bed elevation change of more than 2 ft. (0.6 m), to ensure the developed scour pool does not undermine the vane footers, as scour depth increases with increasing step height. Due to the lower durability of log arms and greater susceptibility to undermining, no modified log j-hook vane should create an elevation change in the bed of more than 0.5 ft. (0.15 m). The bed elevation change should also be limited to 0.5 ft. (0.15 m) if fish passage is a design goal.

J-hook vanes designed to protect infrastructure, such as bridges, should be installed at least two channel widths upstream from the bridge piers, to prevent pool formation at the structure. If applicable, the hydraulic behavior of the existing bridge should also be evaluated as part of the design.

## Construction

The most common failure modes for j-hook 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 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. 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 j-hook vane should fit together snugly, except those on the hook of a tradition rock j-hook. For the vane rocks of the hook, half the boulder diameter should be left. These gaps allow safe passage of fish and sediment, since the traditional j-hook vane, while not a stream-spanning structure, extends across a greater portion of the channel width than a single-arm vane. Since modified j-hook vanes extend across the entire channel, the hook/sill portion should be buried in the stream bed at approximately thalweg elevation to allow sediment transport and fish passage. The sill may also be keyed into the bank.

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 j-hook 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;
- regularly examine the vane for bed aggradation or degradation upstream of the structure; and
- ensure that modified j-hook vanes are not creating tailwater depths greater than upstream structure elevations (i.e. upstream structures are flooded at baseflow).

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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