River Restoration Toolbox
Practice Guide 1

Grade Control

Iowa Department of Natural Resources

April, 2018

Table of Contents

LIST OF TABLES

LIST OF DRAWINGS

LIST OF PHOTOS

Executive Summary

Grade control provides vertical stability in a restored stream. Such practices can also prevent relatively stable sections of upstream channel from becoming degraded, which can lead to years or even decades of excessive erosion. In western Iowa's deep loess areas alone, the Hungry Canyons Alliance attributes more than $1 billion of infrastructure damage related to vertical channel instability in the 20th century, and the associated loss of aquatic life and habitat are incalculable. Grade control techniques include a variety of in-stream structures including vanes, weirs, steps, and riffles. The following techniques are detailed in this guide:

1. Rock Arch Rapids
2. Cross Vane
3. W-weir
4. Step-Pool
5. Rock and Log Riffle
6. Rock Riffle
7. Grouted Grade Control

The *River Restoration Toolbox Practice Guide 1: Grade Control* has been developed to assist with the presentation of design and construction information for stream restoration in Iowa. It is intended to provide guidance to:

- Those responsible for reviewing and implementing stream restoration,
- Engineers responsible for the design of stream restoration projects,
- Others involved in stream restoration at various levels who may find the information useful as a technical reference to define and illustrate grade control techniques.

The Practice Guide includes a written assessment of the grade control practice and describes a variety of grade control techniques. Each technique includes drawings, design guidelines, a specifications list, and photographs.

The information in the Practice Guide is intended to inform practitioners and others and define typical information required by the State of Iowa to be included with the use of grade control techniques. The information and drawings are not meant to represent a standard design method for any type of technique and shall not be used as such. The Practice Guide neither replaces the

need for site-specific engineering designs nor precludes the use of information not included herein.

The Practice Guide may be updated and revised to reflect up-to-date engineering, science, and other information applicable to Iowa streams and rivers.

1.0 INTRODUCTION

Grade control, either natural or constructed, provides vertical stability in a restored stream. Channel degradation is a common problem in impaired streams, and the potential for degradation is also a consideration for long-term stability when implementing restoration techniques.

Grade control can be accomplished using a variety of in-stream structures, including vanes, weirs, steps, and riffles, all of which can be modified or adapted to site-specific conditions and constraints. Grade control techniques may be needed in many restoration circumstances such as when a channel is downcutting, degrading, or head-cutting; when raising a channel bed and tying in downstream at a lower elevation; or in tangents (cross-overs between meander bends) when a channel is constructed on a new alignment.

Due to the complexity of appropriately siting grade control and the engineering considerations required for selecting and sizing grade control structures, the techniques included in this practice generally require design by a professional. In addition, these structures require precise placement of materials during construction and require an experienced contractor.

The design guidelines provided in this document are general and are not a comprehensive design manual. It is the responsibility of the designer to understand the design approach and the feasibility of using these techniques on a case-by-case basis. The criteria in the following sub-sections and throughout this Practice Guide in no way replace design discretion, experience, and training, and cannot incorporate every scenario. They are intended to flag common errors, promote empirically stable design ranges, assist designers and reviewers in communication, and adapt tested designs to Iowa conditions.

1.1 GEOMORPHIC DESIGN CONSIDERATIONS

A thorough understanding of a stream's geomorphic condition is needed prior to implementing grade control techniques. For example, the spacing between multiple grade control structures in high gradient streams (e.g., cross vanes) is based on a relationship between the channel's bankfull slope and width. Similarly, the location of grade control structures in low-gradient streams (e.g., rock and log riffles) is dependent upon bankfull width and stream pattern parameters like meander length, belt width, and curve radius. In addition, the stream's position vertically in the landscape should be considered; stream's that are incised and/or entrenched may not benefit from the implementation of grade control techniques alone.

In Iowa, grade control techniques can generally be successfully implemented in channels with a range of width to depth ratios. Also, if the stream remains entrenched (Entrenchment Ratio [E.R.] less than 1.4) under design conditions, a conservative approach to restoration is to excavate additional bankfull (between 1 to 2-year recurrence) floodplain and plant with appropriate species for additional stability (see *Practice Guide 2: Vegetative Restoration*) in addition to implementing grade control techniques.

1.2 HYDROLOGIC AND HYDRAULIC COMPUTATIONS

Stream restoration designs that prescribe even minimal work, such as minor bank shaping, adding one or two in-stream structures, revegetation of stream banks, etc., influence the flow of the water in the channel. Calculation of the amount of water flowing in the channel (hydrology), and the characteristics of that flow (hydraulics), are needed to verify stability and understand flow depth, flow rate, velocity, etc.

Bankfull cross-sectional area should correspond to ranges observed in nearby, free-flowing natural riffles (i.e., not impounded) analyzed with measured (e.g., USGS stream gage data) or computed (e.g., various hydrologic equations/models) ~1.5 year recurrence interval discharge (flow rate). Additionally, bankfull cross-sectional area should be within ranges presented on regional curves. The Minnesota regional curve for bankfull cross-sectional area is an accepted resource for use in Iowa (http://files.dnr.state.mn.us/eco/streamhab/geomorphology/cross-section.pdf)

Hydraulic calculations to determine shear stress should be incorporated for any type of grade control practice using un-grouted methods. These calculations are performed to verify that the size of materials used will remain competent (in place) in the stream under the range of flows. In Iowa, frequent, small (1- to 2-year recurrence interval) flows should be considered; large (100-year and greater recurrence interval) flows or flows that submerge the grade control structure should also be analyzed so that a full range of shear stress values can be calculated and considered when designing grade control.

Analysis to determine depth of scour is needed to verify that grade control structures placed on footings will not be undermined. General guidance indicates that in gravel- and cobble-bed streams, footing boulders should extend 3 times deeper into the stream bed than the heading boulders protrude above the stream bed; in sand-bed streams the footings should extend 6 times deeper into the bed (Rosgen 2006).

Any headwater stage (depth) increase caused by the grade control structure should be reviewed so as not to be excessive (flooding of adjacent land, structures, infrastructure, etc.). Also, a structure crests that are built too high can divert water across the floodplain frequently. In addition, if the structure is not submerged once flows are out of the channel banks, water may flow around the structure with enough velocity and force to create an initial side channel and eventually the entire river can take a new route around the designed structure.

1.3 MATERIALS

1.3.1 Rock Materials

Designers should consider quality of economically available stone. In general, in Iowa, granitic field stone (sometimes known as “glacial erratic” stone) and quarry-run Sioux quartzite are sufficient to remain stable for many years and are not subject to decay from freeze thaw cycles. Where quarry-run limestone is used, a specific gravity of 2.6 or greater should be required in bid documents, which will result in durable, high manganese dolomite stone. Waste concrete may be used as footing stones, provided they are buried and not visible, are properly sized, and do not contain protruding rebar.

1.3.2 Filter Fabric

Filter fabric is a component of many grade control structures and is intended to prevent some seepage through the structure or sub-surface flow. It may be preferable to exclude fabric from features (such as by chinking or otherwise hand-placing smaller stones into voids) with appropriate stream bed materials when some initial seepage of water and fines is acceptable. Silt, fine sand, and coarse sand are common bed and transport materials in Iowa streams and "seating" by these particles through natural processes is likely for some features.

1.4 FLOODPLAIN (CUT-OFF) SILLS OR KEYWAYS

Many grade control, and other, in-stream structures are connected to their floodplains with sills. Also called floodplain sills, cut-off sills, and keyways, these structure components are placed into trenches excavated into the floodplain, oriented perpendicular to flow. Generally, a "keyway" refers to the trench being filled with rip rap, while "sill" generally means the trench is lined with boulders or logs. Sills are used to assure elevation of the floodplain, and to prevent cut-off chutes from forming in the floodplain while it is being vegetated.

Location and size of sills is a site-specific decision based on hydrology, existing bank shape, elevation of bankfull versus low terrace. Sills are commonly used in constructed floodplains and low floodplains, although they may be necessary in other locations where out-of-bank flows might cause floodplain erosion or wash around the structure.

1.5 FISH PASSAGE

Lower energy-gradient slope correlates to both project stability/longevity and better fish passage for all types of grade control techniques. For general Midwest fish passage conditions, Iowa DNR recommends:

- Bankfull slope does not exceed 5 percent,
- Roughness no lower than Manning's n of 0.035, and
- Head loss of individual steps or drops not exceed 0.8 feet.

Specific species' criteria should be considered at stream restoration sites. For example, a head loss of 0.8-ft may still block movement of many species of Iowa fish; "water jumps" of as little as 0.2-ft can be problematic for prairie fish species. Additional detail or variations may be necessary for specific structure designs to ensure that grade structures do not act as barriers under low flow conditions, including:

- Structures with gaps allow fish movement even with greater head loss

- Tight (no gap) structures with areas of head loss connected by slopes of 20:1 (or flatter), except for with Grouted Grade Control structures, which can be constructed at a 15:1 (or flatter) slope and still allow for fish passage.

2.0 GRADE CONTROL TECHNIQUES

2.1 FREESTANDING ROCK ARCH RAPIDS

2.1.1 Narrative Description

Freestanding rock arch rapids are a grade control structure often used in larger streams and rivers to provide stable elevation drop (e.g., following dam removal, etc.), while still allowing fish passage and safer recreational vessel travel. Use of properly-sized natural substrates such as boulders is important in the design of this structure for resiliency against steep slopes and higher shear stresses.

Luther Aadland of the Minnesota DNR developed the rock arch rapids, building off early rock ramp designs with the goal of converting low-head dam sites to stable natural channels passable by fish (Aadland, 2010). The structure improves a general rock ramp by adding boulder weirs in a step configuration that dissipates energy and flattens the slope between weirs. The weirs also direct flow to the center of the channel, reducing near bank stress and maintaining pools for habitat and fish passage. In addition, the weirs direct ice and debris to the center, where depths of water can reduce damage to the freestanding rock arch rapids structure that may occur during snowmelt/runoff.

2.1.2 Technique Information

- **Use:** Intended to be used for grade control, either to prevent bed degradation, or where infrastructure protection is an objective. Provides a stable, naturalized grade transition, passable by fish. Establishes a steep, stable channel section, that will not shift, using natural materials. Also reduces near-bank shear stress, velocity, and stream power.

- **Other uses:** Can exhibit habitat like that found in natural rapids and may also be designed to meet objectives for aesthetics and aquatic recreation such as fishing and kayaking.

- **Best applications:**

    - Streams and rivers with low head dams or perched culvert outlets. Slope must accommodate no more than a 0.8-ft. head loss measured from water surface to water surface at thalweg over the boulder weirs for Iowa fish passage.

    - Best planform stream position is in a straight stream section, downstream of grade (elevation) differential.

- **Variations:**

  - Combining with stream bank stabilization (e.g. Rock Toe Protection, Root Wad, etc.). See Streambank Toe Protection Practice for more information.
  - Combining with geomorphic channel design principals. See Geomorphic Channel Design practice.

- **Computations:** Computations are necessary and should accompany any design using freestanding rock arch rapids. Freestanding rock arch rapids require design by a professional.

  Hydrologic and hydraulic computations aid in verifying that the appropriate conditions exist for use of the rock arch rapids. Geometric calculations are required to properly size and situate the structure within the context of its individual location. Hydraulic analysis is required to determine how the freestanding rock arch rapids will distribute energy at various flow stages and to determine size, thickness, and/or depth of building materials that will resist becoming dislodged or undermined.

  <u>Freestanding rock arch rapids properties:</u> The base stone layer's median particle size (D50) should be sized to resist mobilization during bankfull flow. Shear stress shall not exceed 14 lbs/ft^2 (70 kg/m^2) through the rapids.

- **Key Features:**

  - The freestanding rock arch rapids structure is constructed at an abrupt grade change, a grade instability, or infrastructure element that requires protection. The upstream end of the rapids is generally set at the elevation of the stream bed at the beginning of the grade change, instability, or at the infrastructure element. The downstream end of the rapids is generally set on the stream bed at an elevation lower than that of the next stable natural riffle downstream. The structure is straight, has a steep slope, and a U-shaped cross section.
  - The freestanding rock arch rapids is designed with a pavement and sub-pavement layer. The sub-pavement layer (or wedge) is designed to fill in the transition between the up- and downstream elevations. The base stone layer is placed as the main pavement layer of the structure over the sub-pavement (wedge) layer.
  - Voids for both layers are filled with chokestone to prevent subsurface flow and people's feet from fitting in the openings of the voids. Over time organic matter and silts will also fill in these voids. The use of filter fabric is not recommended.
  - Large boulders are embedded into the base stone, forming arch-shaped boulder weirs across the entire channel. Large boulders are also embedded into the pavement layer, between the weirs, as partial weirs. Boulders within the weirs are buttressed against each other in an arch shape to add stability. The arch-shaped configuration also directs flow away from the banks, into the center of the channel.

- The weirs are spaced, and the boulder components are placed, to promote low flow-condition velocity vectors and eddies to accommodate fish passage. Gaps between the boulders comprising the weirs can assist with maintaining fish passage.

- The arch-shaped boulder weirs are tied-in to and extended beyond the stream bank as a cut off sill (keyway) to prevent out-of-bank flows from washing around the weir.

2.1.3 Detail Drawings and Data Table

The following data table and drawings depict information that should be included in construction plans for freestanding rock arch rapids. The data table includes design guidelines and sources, where applicable.

Table 1. Required Design Data for Freestanding Rock Arch Rapids[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
A	Bankfull width	Feet	≥15 feet; mid-sized to large streams	The channel width at bankfull stage, often where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain
B1	Low-flow trough width	Feet	Width based on analysis of median discharge for month of August, a low flow trough depth=±1’, and roughness that considers weir stone protrusion (±0.5’)	Width of a small, pilot channel to concentrate low flows. Also, “fish trench.”
B2	Low-flow trough depth	Feet	Approx. 1’-- Maintain trough depth by adjusting trough channel width for base stone and weir stones. Target spilling out into channel base on outsides of trough.	Depth of a small, pilot channel to concentrate low flows. Also, fish trench.

Table 1. Required Design Data for Freestanding Rock Arch Rapids[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
C	Channel base width	Feet	--	Width of the existing channel bottom from toe of bank to toe of bank as defined by a break in slope between the steeper channel bank and the flatter channel bottom. This can also be defined by the width typically submerged by tailwater on smaller dams.
D	Boulder weir spacing	Feet	Spacing calculated based on overall head loss and not exceeding 0.8-ft. drop per weir	Spacing between arched boulder weirs measured from water surface to water surface at thalweg
E	Rock arch rapids length	Feet	Length between up- and- downstream tie-in points such that slope is ≤5%	Length between upstream end of elevation drop (e.g. -at dam, culvert outlet, headcut, other instability) and downstream limits of the installation
F	Weir angle	Degrees	20-30°; a more acute angle can be used to resolve steeper side slopes	Angle between the bank and upstream from the tangent line where the arched boulder weir intercepts the bank
G	Cut-off sill (keyway) length	Feet	½ Bankfull Width	Boulder weirs that extend beyond the point where they intercept the stream bank; this helps prevent out-of-bank flows from washing around the weirs

Table 1. Required Design Data for Freestanding Rock Arch Rapids[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
H	Weir drop	Feet	≤0.8 ft; measured from water surface to water surface at thalweg for Iowa fish passage	Height difference between the successive arched boulder weirs that does not exceed the physical mobility limitations of subject fish species
I	Base stone layer thickness	Feet	≥2 x D100 of select base stone; 2.5 feet minimum and must be thicker than D50 calculation.	Thickness of select base material
J	Volume of rock and/or waste concrete	Cubic yards	Convert to tons for contractor bidding.	The volume to fill in the sub-pavement (wedge) between the upstream and downstream ends of the rapids up to the subgrade on which the base stone (pavement) is placed.
K	Centerline slope	Percent	≤5%	Slope along the center (thalweg) of the rock arch rapids, from the upstream grade control to end of the rock arch rapids' tie-in to the downstream channel bottom.
L	Side slope	Ratio	1:1 maximum	Slope of the stream bank down to a point 1/3 across the channel bankfull width

Table 1. Required Design Data for Freestanding Rock Arch Rapids[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
M	Weir boulder length	Feet	3.5 ft. average; ideally weir boulders should be longer than they are wide and thick (“flat-shaped”), to resist rotation, tumbling, and be of a durable composition. They should be large enough to resist movement due to shear stress generated by concentrated flow (including ice and debris) thru the rapids.	One of three measurements to describe size of weir boulder building materials, the length is typically the largest dimension
N	Weir boulder width	Feet	3.0 ft average; ideally weir boulders should be longer than they are wide and thick (“flat-shaped”), to resist rotation, tumbling, and be of a durable composition. They should be large enough to resist movement due to shear stress generated by concentrated flow (including ice and debris) thru the rapids.	One of three measurements to describe size of weir boulder building materials, the width is typically the median dimension

Table 1. Required Design Data for Freestanding Rock Arch Rapids[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
O	Weir boulder thickness	Feet	1.5 ft minimum; ideally weir boulders should be longer than they are wide and thick (“flat-shaped”), to resist rotation, tumbling, and be of a durable composition. They should be large enough to resist movement due to shear stress generated by concentrated flow (including ice and debris) thru the rapids.	One of three measurements to describe size of weir boulder building materials, the thickness is typically the smallest dimension
P	Base Stone	Feet	A D50 based on hydraulic and shear stress relationships at various discharges can conservatively be used as a minimum stone size. Voids can be filled with chokestone to help base stone resist movement (become dislodged), due to shear stress generated by flow over the rapids. Rock base material should also have particles large enough to wedge in between the gaps of the weir boulders.	This layer forms the main pavement of the structure.
Q	Weir boulder protrusion	Feet	0.5 ft. – to maximum ½ weir boulder thickness. Generally, less protrusion toward the center of channel and more protrusion as the weirs reach the banks is advisable.	Distance that weir boulders protrude out of the base stone layer.

Table 1. Required Design Data for Freestanding Rock Arch Rapids[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
R	Weir boulder fish gap	Feet	0.4 to 1 ft.; 0.3 to 0.6 ft. in low flow trough of every weir that extends 0.5' lower than the tailwater surface. Some weir boulders should be placed with gaps. Often, using irregularly-shaped, narrower parts of the stone for the top, with the broader, flatter part of the boulder at the bottom, yields the gap at the water surface even though the bottoms are snugged together. Base stone material has particles large enough to become wedged in the gaps. Special care should be given to ensure there are gaps in the low-flow trough corresponding (fish trench). 0.3' to 0.6' wide gaps should be created at least one place in the low flow trough. Some randomness can be introduced by putting the gap in different cross sectional positions. Place an additional weir stone 1' downstream of the gap, with its top elevation at or slightly below the low-flow water surface. Then, create a minimum 2' to 3' deep trench through the base stone about an excavator bucket width wide connecting each fish passage gap.	Distance between selected surface boulders intended to provide specific flow path through rapids structure.

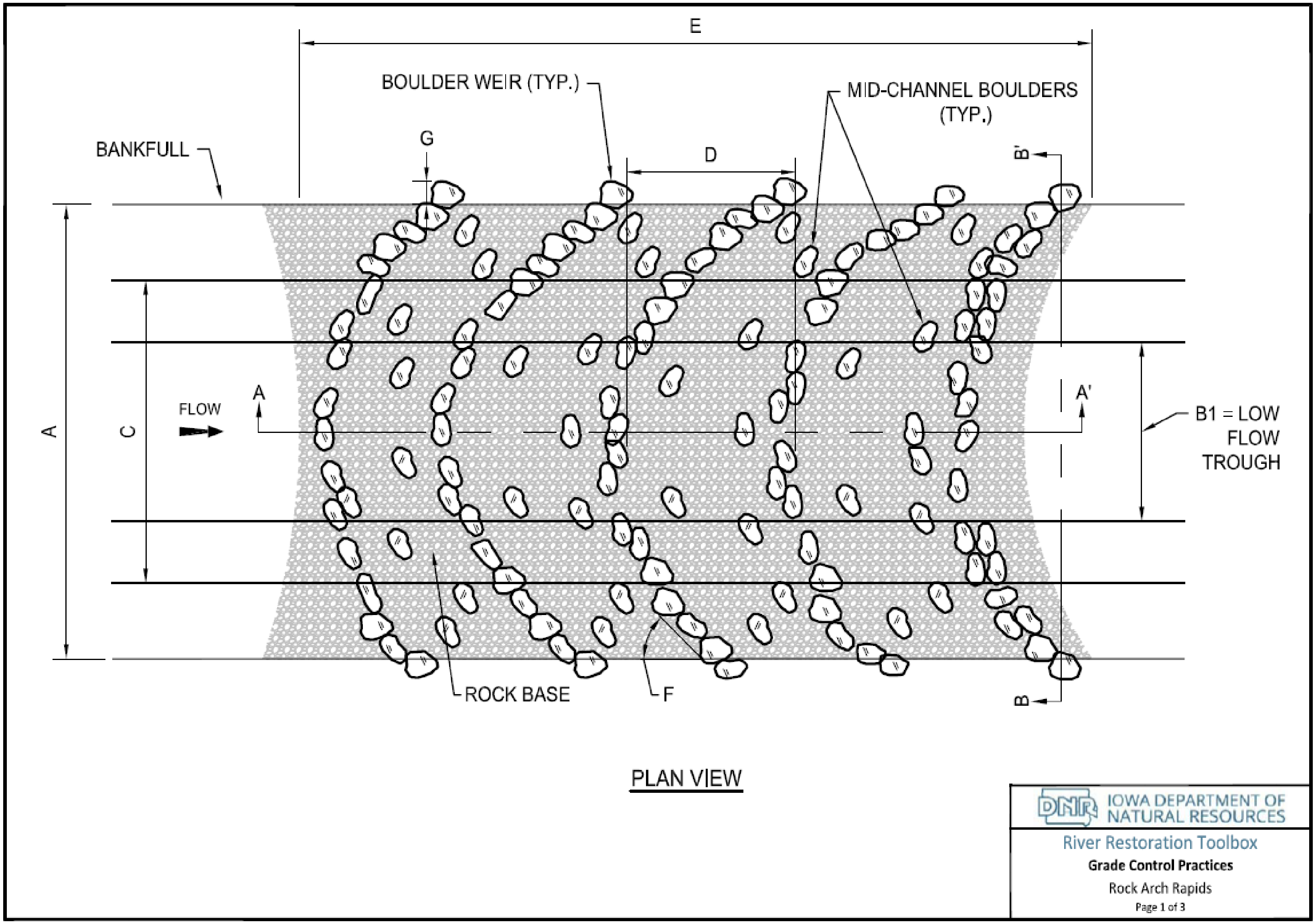
Table 1. Required Design Data for Freestanding Rock Arch Rapids[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
S	Choke stone size	Inches	3/8" to 6"	Stone to fill-in voids in subpavement and base stone layer for each 2 feet of thickness.

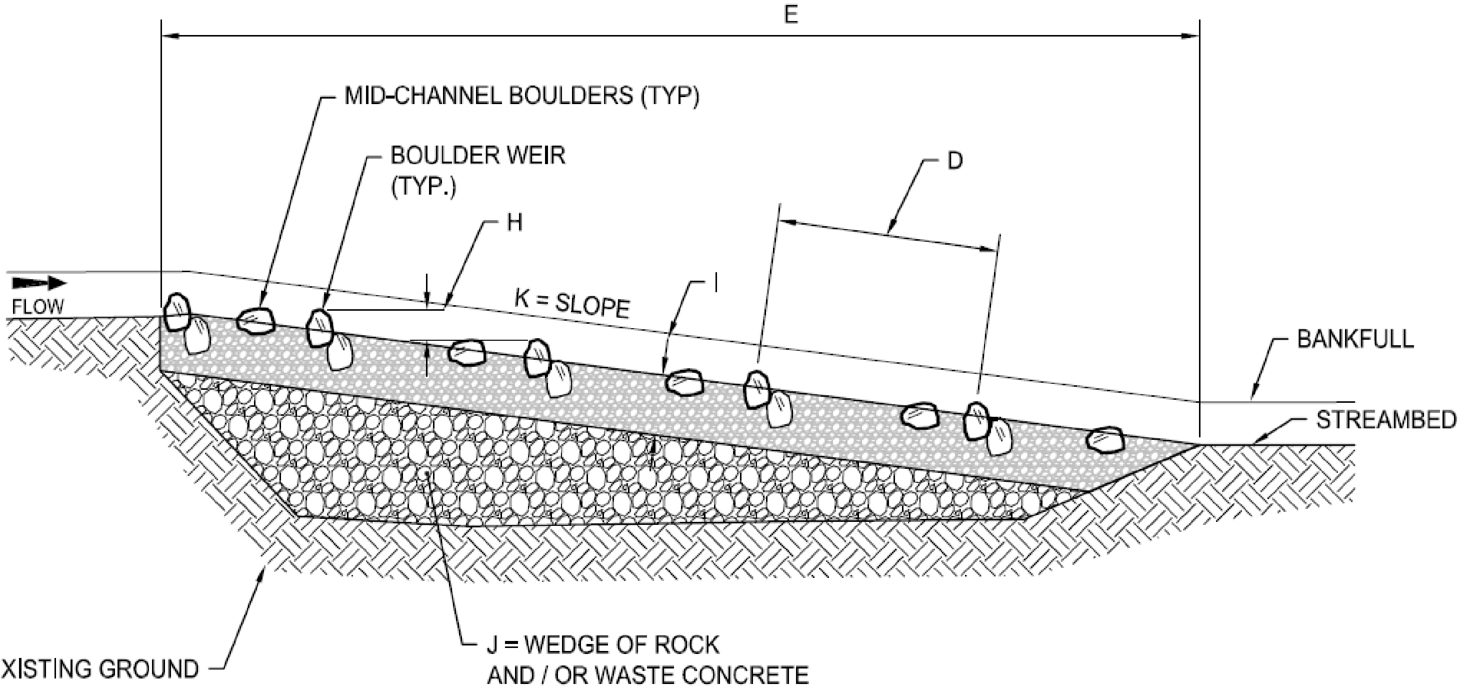
Notes:

1. Data are for rock arch rapids constructed of boulders.
2. Some dimension labels are referenced in the detail drawings.
3. Common guidance, values, or ranges are given unless they require computation using site-specific input.

Drawing 1. Freestanding Rock Arch Rapids



Version 1.0 2/17/2017



SECTION A-A'

IOWA DEPARTMENT OF
NATURAL RESOURCES

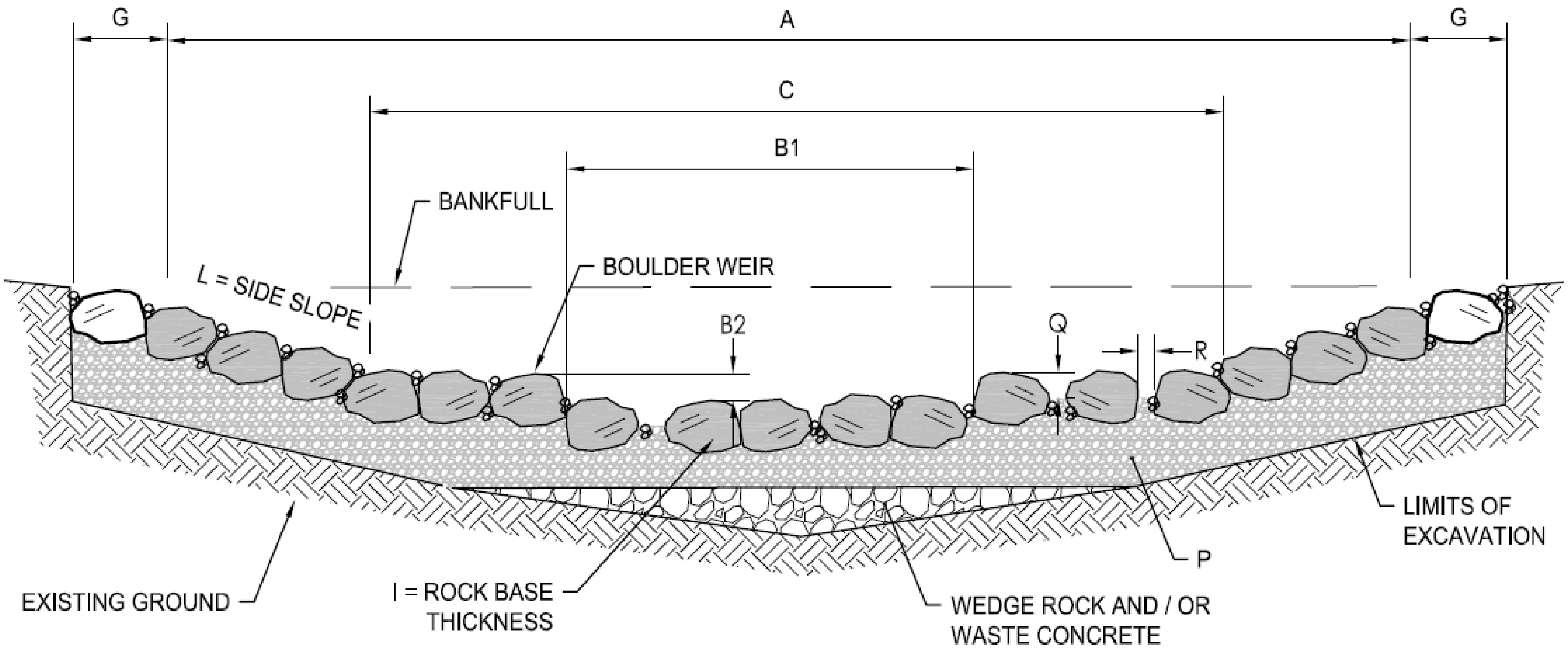
River Restoration Toolbox

Grade Control Practices

Rock Arch Rapids

Page 2 of 3

Version 1.0 2/17/2017



SECTION B-B'

IOWA DEPARTMENT OF NATURAL RESOURCES
River Restoration Toolbox
Grade Control Practices
Rock Arch Rapids
Page 3 of 3

Version 1.0 2/17/2017

2.1.4 Specifications

In addition to general information presented in Section 1.0 Introduction, the following information should be developed into specifications to accompany the use of freestanding rock arch rapids:

- Materials:
    - Boulders (rock)- Headers, footings, and sills (keyways) are typically boulders of durable limestone, dolomite, sandstone, granite, quartzite, etc., and be angular, flat, or cubed and have minimum average dimensions as specified by design. Boulders should be free of shale, cracks, and other defects. Slag or recycled aggregate should be rejected.
    - Pavement (base) material - Gravel and cobble with a D50 and specified gradation by design, typically durable limestone, dolomite, sandstone, granite, quartzite, etc., mined from the project site or an approved location (gravel pit, quarry, etc.). Slag or recycled aggregate should be rejected.
    - Sub-pavement material - Gravel and cobble with a D50 and specified gradation by design, typically durable limestone, dolomite, sandstone, granite, quartzite, etc., mined from the project site or an approved location (gravel pit, quarry, etc.). Waste concrete if available and needed to accommodate sites with large wedge volume should be clean and free of rebar or other unsuitable material.
    - Select chokestone - A typical gradation of 3/8" to 6" stone can be required. Typically, approximately 20 percent of the total tonnage of base stone and sub-pavement is used. Gradation of chokestone may need to be adjusted based on angularity of larger stone being used. Chokestone with a D50 and specified gradation by design, typically durable limestone, dolomite, sandstone, granite, quartzite, etc., mined from the project site or an approved location (gravel pit, quarry, etc.). Slag or recycled aggregate should be rejected.
- Equipment - The designer should specify that rock arch rapids be constructed using an excavator with a hydraulic thumb to assist with precise placement of boulders.
- Sequence – Place subpavement (wedge), then base stone (pavement), and then fill-in and manipulate voids with chokestone. The weirs and partial weirs are constructed last, in a downstream succession.
    - If the freestanding rock arch rapids can be top-dressed with at least a 2.5' thick layer of natural stone (i.e. pavement, base stone layer), the sub-pavement layer (wedge) can be constructed of rock and/or waste concrete.
    - Voids for both layers are filled with chokestone. Chokestone material is backfilled or mixed-in with the wedge and pavement layers to fill in voids to prevent subsurface flow and people's feet from fitting in the openings of the voids. If

    chokestone is backfilled (versus being mixed in ahead of placement in the structure), the contractor should take care to "knuckle-in" and use water to force the chokestone between voids for every ~2' of thickness. Over time organic matter and silts will also fill in these voids. The use of filter fabric is not recommended.

  - Large boulders are embedded into the base stone, forming arch-shaped boulder weirs across the entire channel. Large boulders are also embedded into the pavement layer, between the weirs, as partial weirs. Boulders within the weirs are buttressed against each other in an arch shape to add stability. The arch-shaped boulder weirs are configured to direct flow away from the banks, into the center of the channel.

  - The weirs are spaced, and the boulder components are placed, to promote low flow-condition velocity vectors and eddies to accommodate fish passage. Gaps measuring 0.4' to 1' wide, that extend 1' below low-flow water surface, in between the boulders comprising the weirs can assist with maintaining fish passage. Also, partial weirs can be added between full-width weirs.

  - The arch-shaped boulder weirs are tied-in and then extended beyond the stream bank as a cut off sill (keyway) to prevent out-of-bank flows from washing around the weir.

- Workmanship - The finished surface of the rock arch rapids should be naturalistic and in accordance with the lines, grades, cross sections, and elevations of the design. If used, no concrete debris should be visible and any rebar should be cut flush prior to placement.

- Measurement - A construction precision (tolerance) of 0.1 foot should be specified.

2.1.5 Photographs

Photo 1. Rock Arch Rapids at Vernon Springs Dam site. Source: Howard County, IA, Economic Development.

Photo 2. Rock Arch Rapids at Vernon Springs Dam site. Source: Howard County, IA, Economic Development.

Photo 3. Rock Arch Rapids at Quasqueton Dam Removal site. Source: Iowa DNR

Photo 4. Rock Arch Rapids at Vernon Springs Dam site. Source: Iowa DNR.

2.2 CROSS VANE

2.2.1 Narrative Description

Cross vanes are in-stream structures used to establish grade control and direct flows and energy toward the center of the channel. The structure is typically built using boulders or, less frequently, logs. Filter fabric is often used in the structure to prevent scour around, between, or under the rocks or logs. An additional weir, or step, is often added to the cross vane to improve fish passage, and to reduce energy dissipation at a single point by breaking a relatively large drop into two or three smaller drops.

Cross vanes reduce bank erosion by directing flows to the center of the channel, where a deep pool is maintained. The structure has been described by Rosgen (2006) and used extensively in natural channel designs.

2.2.2 Technique Information

- **Use:** Intended to establish grade control and stabilize the channel bed, creating a long-term elevation control that will not shift, using natural materials. Also reduces near-bank shear stress, velocity, and stream power.

- **Other Uses:** Addresses objectives of aquatic habitat improvement and recreation (e.g.- boating and fishing). An additional weir, or step, can be added to reduce the height between the stream bed above and below the structure, thus accommodating the passage of fish over the cross vane and reducing the energy at a single drop location.

- **Best applications:**

    - Small to mid-sized streams with slope to accommodate no more than a 0.8-foot head loss at thalweg over cross vane for Iowa fish passage.

    - Best planform stream position is when a structure is used to set the elevation of downstream riffle in larger stream systems. Normally positioned in glide/tail-out portion of pool. In small streams the use of a cross vane for grade control may not be the best option; however, if used it is often placed at the end of the riffle [point of curvature (PC) of bend].

- **Variations**

    - Combining with aquatic habitat features. See Aquatic Habitat Practice for more information.

    - Combining with stream bank stabilization (e.g. Rock Toe Protection, Root Wad, etc.). See Streambank Toe Protection Practice for more information.

    - Combining with geomorphic channel design principals. See Geomorphic Channel Design practice.

- **Computations:** Computations are necessary and should accompany any design using cross vanes. Cross vanes require design by a professional.

  Hydrologic and hydraulic computations aid in verifying that the appropriate conditions exist for use of the cross vane. Geometric calculations are required to properly size and situate the structure within the context of its individual location. Hydraulic analysis is required to determine how the cross vane will distribute energy at various flow stages and to determine size, thickness, and/or depth of building materials that will resist becoming dislodged or undermined.

- **Key Features:**

  - Floodplain cutoff sills connecting each vane arm at the point where it intercepts the stream bank are required to prevent out-of-bank flows from washing around the cross vane.

  - The structure requires footings to prevent shifting of the structure due to bed scour.

  - All header and footing boulders should be touching (no gaps). If the boulders are irregularly shaped and have gaps, the designer should specify that smaller stones (such as those from the select backfill material) that cannot slip through the gap be hand-placed in the gaps on the upstream side of the cross vane (“chinked”).

  - Header and footing boulders should be placed so they are angled slightly downward in the upstream direction to help them resist movement.

  - A non-woven geotextile (filter fabric) is usually used upstream of the boulders to prevent upstream bed materials and/or select backfill materials from washing through the boulders.

  - If logs are used to construct the cross vane, the logs should be tied-down with an anchor (e.g.-duck-bill anchor) or ballasted with boulders to prevent the logs from becoming dislodged.

2.2.3 Detail Drawings and Data Table

The following data table and drawings depict information that should be included in construction plans for a cross vane. The data table includes design guidelines and sources, where applicable.

Table 2. Required Design Data for Cross Vane with Step[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
A	Bankfull width (W_{bkf})	Feet	5 ft > W_{bkf} > 50 ft. It is often impractical to geometrically situate cross vanes in very narrow or very wide streams.	The channel width at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
B	Sill length	Feet	Minimum ½ W_{bkf}	Length of floodplain cutoff sills connecting each vane arm at the point where it intercepts the stream bank. Sills are required to prevent out-of-bank flows from washing around the cross vane.
C	Vane arm length	Feet	Based on equations for predicting ratio of vane length/bankfull width as a function of bankfull width, radius of curvature, and departure angle (Rosgen, 2006).	Length of cross vane arm; this feature connects the invert of the cross vane to the stream bank.

Table 2. Required Design Data for Cross Vane with Step[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
D	Vane arm angle	Degrees	20-30°. Measured upstream from the tangent line where the vane arm intercepts the bank. Angle variation is used to adjust vane arm length and may be asymmetrical to meet certain structure design objectives, such as adjusting to stream pattern (curvature) or bridge abutments or roadway embankments that do not cross the stream at a right angle.	The angle between the vane arm and the stream bank
E	Cross vane invert	Feet (NAVD[4])	Cross vane inverts are typically set on the longitudinal profile of a stream at the end-of-riffle/beginning-of-run point. Invert elevation should not create a “drop” in water surface that exceeds the physical mobility limitations of subject fish species. Limited to 0.8-foot head loss measured from water surface to water surface at thalweg for Iowa fish passage.	Cross vane invert is the low point of the structure, situated in the streambed, and oriented perpendicular to flow
F	Maximum riffle depth	Feet	--	The channel maximum depth above the riffle at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.

Table 2. Required Design Data for Cross Vane with Step[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
G	Bankfull elevation	Feet (NAVD[4])	--	Elevation where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
H	Maximum pool depth	Feet	--	The channel maximum depth of pool at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
I	Vane arm slope	Percent	2-7; measured upstream along the surface of the vane from the vane arm-stream bank intercept down toward the stream bed. Defined by the ratio of bank height/vane length	Slope of cross vane arm; this feature connects the invert of the cross vane to the stream bank
J	Vane arm tie-in	Feet	½ d_{mbkf} - $d_{mbkf;}$ the structure extends no higher than bankfull stage elevation. More often the cross vane arm intercepts the stream bank between ½ bankfull stage elevation and bankfull stage elevation (½ d_{mbkf} - d_{mbkf}). A bankfull and/or inner berm bench should be integrated into the design if bank height is higher than bankfull	Elevation of cross vane arm tie-in to the stream bank
K	Select backfill width	Feet	≥ boulder width	Width of placement of select backfill (if used) on the upstream side of the cross vane.

Table 2. Required Design Data for Cross Vane with Step[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
L	Setback	Feet, inches	± ½ boulder width	Distance header boulder is set back in the upstream direction from the footing boulder.
M	Footing depth	Feet, inches	3 – 6 times protrusion height of invert boulder; minimum footing depth is associated with a ratio of the protrusion height of the invert boulder above the stream bed, and is dependent on bed material. In gravel and cobble bed streams, footings are 3 times the protrusion height; in sand bed streams, the minimum depth is doubled due to the deeper scour depths that occur	Depth of footings into the stream bed
N	Boulder length	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, header and footing boulders should be longer than they are wide and thick (“flat-shaped”) and be of a durable composition.	One of three measurements to describe size of cross vane boulder building materials, the length is typically the largest dimension

Table 2. Required Design Data for Cross Vane with Step[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
O	Boulder width	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, header and footing boulders should be longer than they are wide and thick ("flat-shaped") and be of a durable composition.	One of three measurements to describe size of cross vane boulder building materials, the width is typically the middle dimension.
P	Boulder thickness	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, header and footing boulders should be longer than they are wide and thick ("flat-shaped") and be of a durable composition.	One of three measurements to describe size of cross vane boulder building materials, the thickness is typically the smallest dimension. It is also the vertical dimension.
Q	Select backfill material D50	inches	Minimum size of the intermediate (middle) axis of in-situ stream bed materials excavated for footing placement or off-site material of sufficient gradation, size, and shape to resist becoming dislodged.	Coarse material placed around heading and footing boulders after placement.

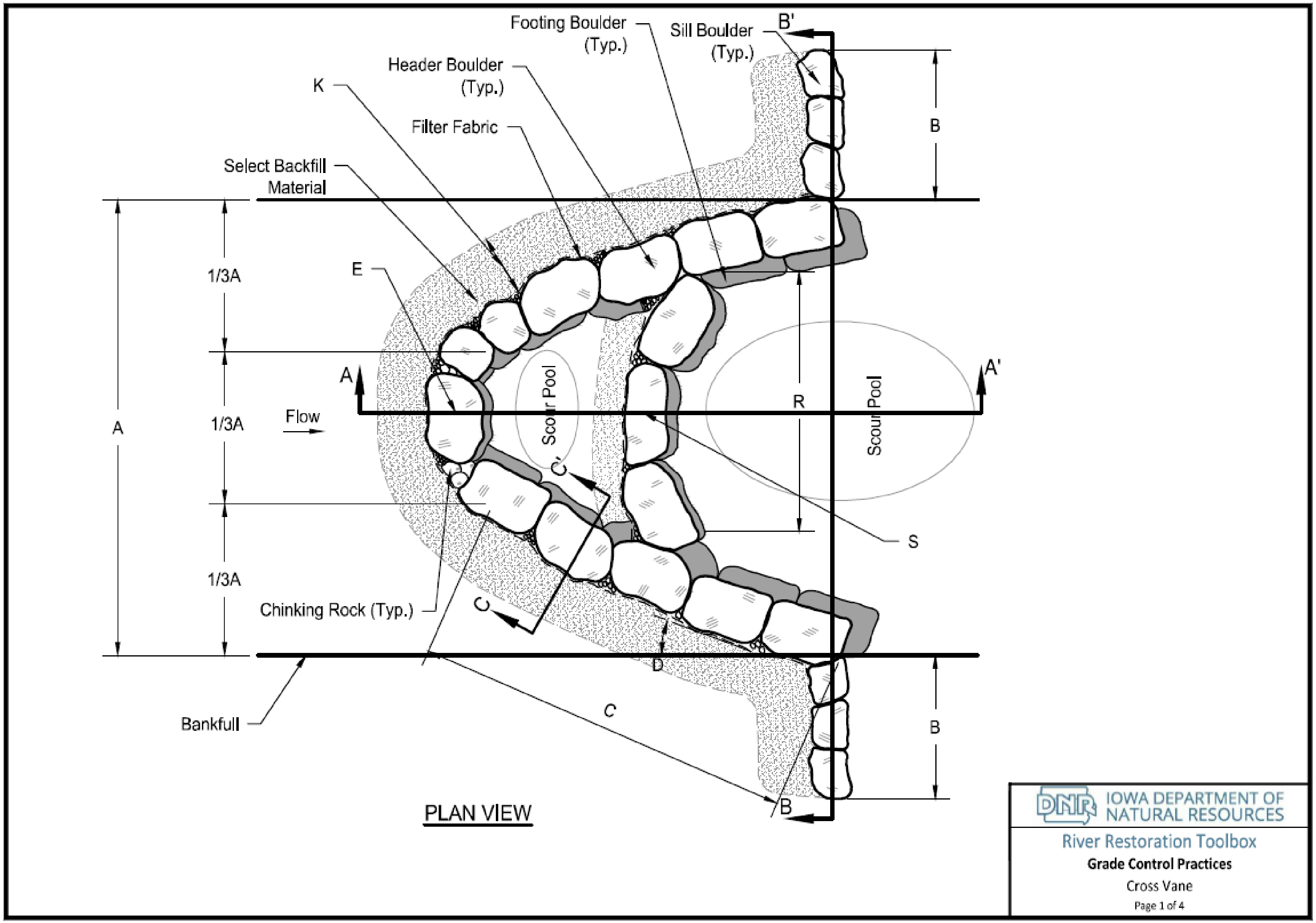
Table 2. Required Design Data for Cross Vane with Step[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
R	Step width	Feet	Optional; only if step is designed. Width is based on locating the step within the cross vane to create a small scour pool within the cross vane of sufficient size to accommodate the physical mobility requirements of subject fish species.	Width of step. Step is an additional cross vane invert located downstream of main invert.
S	Step invert	Feet (NAVD[4])	Optional; only if step is designed. Invert elevation is based on establishing a step height relative to the cross vane invert that does not exceed the physical mobility limitations of subject fish species.	Elevation of step. Step is an additional cross vane invert located downstream of main invert.
T	Step height	Feet	Optional; only if step is designed. Height difference between the cross vane and step inverts that does not exceed the physical mobility limitations of subject fish species. Limited to 0.8-foot head loss measured from water surface to water surface at thalweg for Iowa fish passage.	Difference in elevation between cross vane invert and step. Step is an additional cross vane invert located downstream of main invert.

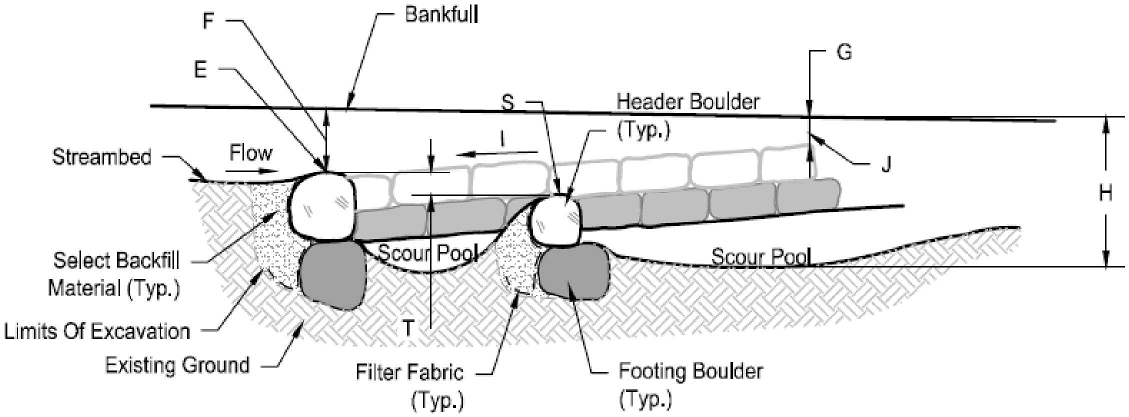
Notes:

1. Data are for cross vanes constructed of boulders, with or without a step. Additional and/or different data is required if logs are used.
2. Some dimension labels are referenced in the detail drawings.
3. Common guidance, values, or ranges are given unless they require computation using site-specific input.
4. NAVD – North American Vertical Datum or other, as appropriate. Elevations relative to local benchmark may also be used.

Drawing 2. Cross Vane with Step



Version 1.0 2/17/2017



CROSS SECTION A-A'

IOWA DEPARTMENT OF
NATURAL RESOURCES

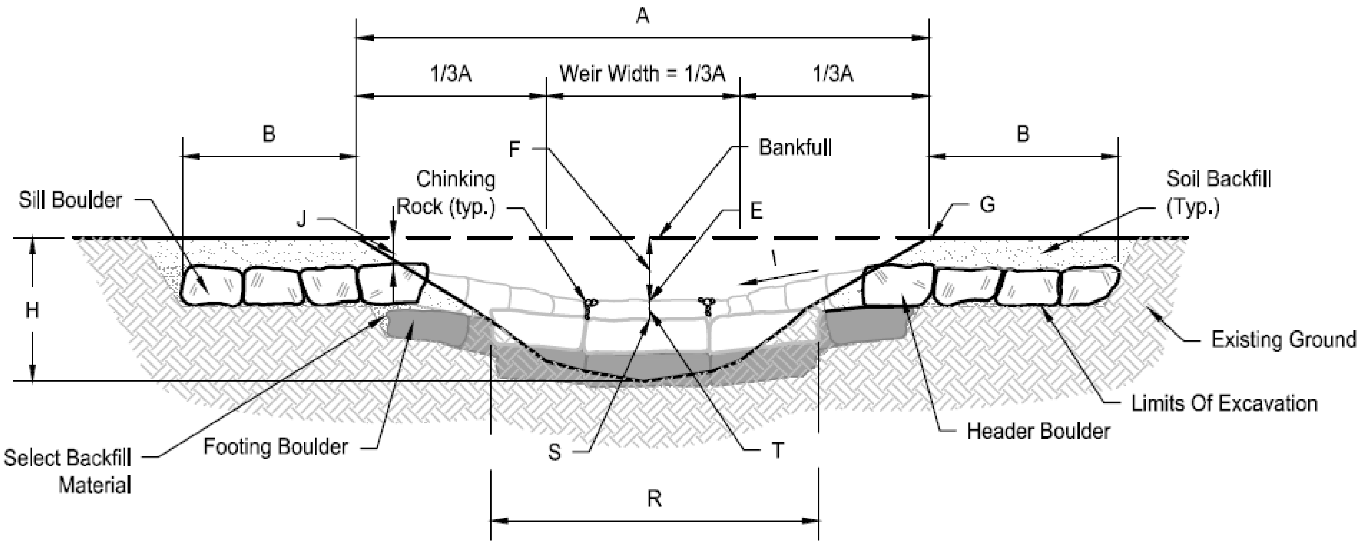
River Restoration Toolbox

Grade Control Practices

Cross Vane

Page 2 of 4

Version 1.0 2/17/2017



CROSS SECTION B-B'

IOWA DEPARTMENT OF
NATURAL RESOURCES

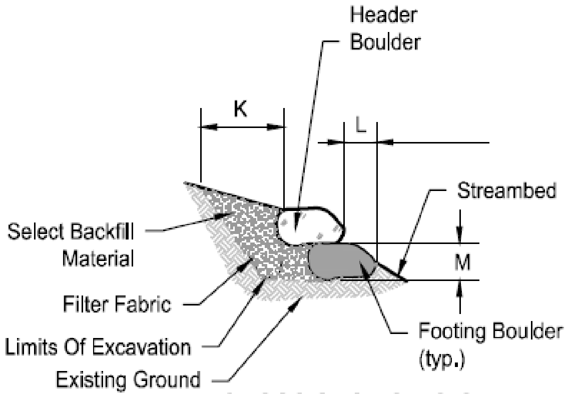
River Restoration Toolbox

Grade Control Practices

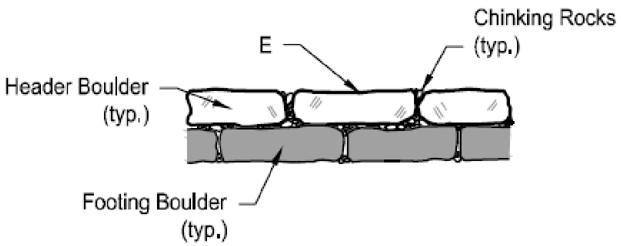
Cross Vane

Page 3 of 4

Version 1.0 2/17/2017



CROSS SECTION C-C'



CHINKING DETAIL

IOWA DEPARTMENT OF
NATURAL RESOURCES

River Restoration Toolbox

Grade Control Practices

Cross Vane

Page 4 of 4

Version 1.0 2/17/2017

2.2.4 Specifications

In addition to the information presented in Section 1.0 Introduction, the following information should be developed into specifications should accompany the use of a cross vane:

- Materials:
    - Boulders (rock) – Headers, footings, and sills (keyways) are typically boulders of durable limestone, dolomite, sandstone, granite, quartzite, etc., and be angular, flat, or cubed and have minimum average dimensions as specified by design. Boulders shall be free of shale, cracks, and other defects. Slag or recycled aggregate will be rejected.
    - Logs, as applicable – Logs shall be from trees free of rot and/or disease with minimum dimensions, with or without root ball attached, as specified by design. Logs shall be straight with limbs trimmed off, flush.
    - Filter fabric – Filter fabric shall be a non-woven geotextile that allows for filtration during stabilization and separation of materials.
    - Fasteners – Filter fabric attached to log using 2-inch galvanized roofing nails spaced 12 inches on center.
    - Anchors, if logs are used – Galvanized or stainless steel duckbill anchors with cable. Large flat rocks (ballast) can be substituted for the duckbill anchor and cable to keep the logs in place.
    - Select backfill – Gravel and cobble with a D50 and specified gradation by design, shall be durable limestone, dolomite, sandstone, granite, quartzite, etc., mined from the project site or an approved location (gravel pit, quarry, etc.). Slag or recycled aggregate will be rejected.
- Equipment – The designer should specify that cross vanes be constructed using an excavator with a hydraulic thumb to assist with precise placement of boulders and/or logs.
- Sequence – Multiple cross vanes are usually constructed in a downstream succession immediately following channel excavation. Individual structures are typically built as follows:
    - Excavate trench in stream bed to a depth equal to the total thickness of the heading and footing boulders.
    - Place footing boulders. There shall be no gaps between footings.
    - Install filter fabric.
    - Place select backfill behind the footing boulders.

  - Install heading boulders on top of and slightly set back from the footing boulders (such that part of the heading boulder is resting on the select backfill). Heading boulders should span the seams of the footing boulders. There should be no gaps between boulders.

  - Place select backfill behind heading boulders ensuring that any voids between the boulders are filled; hand placement or "chinking" may be necessary to ensure voids are filled and there is no sub-surface flow at the structure.

- Workmanship – The finished surface of the cross vane should be smooth and compact and in accordance with the lines, grades, cross sections, and elevations of the design. No loose ends of filter fabric should be visible.

- Measurement – A construction precision (tolerance) of 0.1-foot should be specified.

2.2.5 Photographs

Photo 5. Cross vane on the Rio Blanco. Source: Wildland Hydrology.

Photo 6. Cross vane arms tying in to bridge abutments. Source: Blue River, Wildland Hydrology.

Photo 7. Cross vane with step. Source: Trammel Creek, Stantec.

Photo 8. Cross Vane on Upper Coldwater Fork. Source: Stantec.

2.3 W-WEIR

2.3.1 Narrative Description

W-weirs are in-stream structures used to establish grade control and direct flows and energy. The structure is typically built using boulders. Filter fabric is used in the structure to prevent scour around, between, or under the boulders. An additional weir, or step, can be added to the w-weir to improve fish passage.

The w-weir reduces bank erosion by directing flows into two cells, where deep pools are maintained. The structure has been described by Rosgen (2006) and used extensively in natural channel designs on wide streams and rivers.

The w-weir is much like a cross vane; both near-bank sides are vanes that are directed from the stream bank, upstream toward the bed, with similar departure angles. The w-weir differs in that it directs flow into two flow paths. The structure forms a “W” shape when viewed in the downstream direction. The structure can provide grade control on larger streams and rivers, and is especially useful for protecting center bridge piers while increasing sediment transport and using natural channel materials. The w-weir maximizes fish habitat by providing multiple feeding lanes in the two thalwegs and pools. The structure can be adjusted to a Double W-Weir for very wide rivers or to direct flow around two central bridge piers through three flow paths.

2.3.2 Technique Information

- **Use:** Intended to establish grade control and direct flows, and can be used to protect center bridge piers. Stabilizes the channel bed, creating a long-term elevation control that will not shift, using natural materials. Also reduces near-bank shear stress, velocity, and stream power.

- **Other uses:** Can address multiple objectives of aquatic habitat improvement, recreation (e.g. boating and fishing), and irrigation.

    - An additional weir, or step, can be added to reduce the height between the stream bed above and below the structure, thus accommodating the passage of fish over the w-weir. Maximizes fish habitat by providing multiple feeding lanes in the two thalwegs and pools.

    - The head differential across the weir provides a variety of flow features (e.g. back eddies, hydraulic jumps, etc.) for kayakers, etc.

    - Can be used to develop irrigation diversion channels due to the flat slope of the vane leading to the stream bank.

- **Best applications:**

    - Larger rivers with slope to accommodate no more than a 0.8-foot head loss at thalweg over the weir for Iowa fish passage.

  - Best planform stream position depends on stream size and presence of bridges or culverts. Normally positioned in glide/tail-out portion of pool. Commonly placed upstream of double span bridges which have a pier mid-channel to provide an adequate transition and protect the bridge structure. The w-weir should be placed at a distance of $0.3xW_{bkf}$ upstream of the pier as a general guideline (Johnson, et al., 2002).

- **Variations:**

  - Combining with aquatic habitat features. See Aquatic Habitat Practice for more information.

  - Combining with stream bank stabilization (e.g. Rock Toe Protection, Root Wad, etc.). See Streambank Toe Protection Practice for more information.

  - Combining with geomorphic channel design principals. See Geomorphic Channel Design practice.

- **Computations:** Computations are necessary and should accompany any design using w-weirs. W-weirs require design by a professional.

  Hydrologic and hydraulic computations aid in verifying that the appropriate conditions exist for use of the w-weir. Geometric calculations are required to properly size and situate the structure within the context of its individual location. Hydraulic analysis is required to determine how the w-weir will redistribute energy away from the near-bank and any center bridge piers or other mid channel obstructions and to determine size, thickness, and/or depth of building materials that will resist becoming dislodged or undermined.

- **Key Features:**

  - Floodplain cutoff sills connecting each vane arm at the point where it intercepts the stream bank are required to prevent out-of-bank flows from washing around the w-weir.

  - The structure requires footings to prevent shifting of the structure due to bed scour.

  - All header and footing boulders should be touching (no gaps). If the boulders are irregularly shaped and have gaps, the designer should specify that smaller stones (such as those from the select backfill material) that cannot slip through the gap be hand-placed in the gaps on the upstream side of the w-weir (“chinked”).

  - Header and footing boulders should be placed so they are angled slightly downward in the upstream direction to help them resist movement.

  - A non-woven geotextile (filter fabric) should be used upstream of the boulders to prevent upstream bed materials and/or select backfill materials from washing through the boulders. No fabric should be visible on the surface of the completed structure.

2.3.3 Detail Drawings and Data Table

The following data table and drawings depict information that should be included in construction plans for a w-weir. The data table includes design guidelines and sources, where applicable.

Table 3. Required Design Data for W-weirs[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
A	Bankfull width (W_{bkf})	Feet	W_{bkf} > 30 ft; large streams	The channel width at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
B	Sill length	Feet	Minimum ½ W_{bkf}	Length of floodplain cutoff sills connecting each vane arm at the point where it intercepts the stream bank. Sills are required to prevent out-of-bank flows from washing around the w-weir.
C	Vane arm length	Feet	Based on equations for predicting ratio of vane length/bankfull width (VL) as a function of bankfull width, radius of curvature, and departure angle (Rosgen, 2006).	Length of w-weir arm; this feature connects the invert of the w-weir to the stream bank.
D	Vane arm angle	Degrees	20-30°. Measured upstream from the tangent line where the vane arm intercepts the bank. Angle variation is used to adjust vane arm length and may be asymmetrical to meet certain structure design objectives, such as adjusting to stream pattern (curvature) or bridge abutments or roadway embankments that do not cross the stream at a right angle.	The angle between the vane arm and the stream bank.

Table 3. Required Design Data for W-weirs[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
E	Weir invert	Feet (NAVD[4])	Elevation on the longitudinal stream bed profile, often corresponding to the end-of-riffle/beginning-of-run point. W-weir inverts are usually set at the same elevation at ¼ and ¾ bankfull width.	W-weir inverts are the low points of the structure, situated in the streambed, and oriented perpendicular to flow.
F	Maximum riffle depth	Feet	--	The channel maximum depth above the riffle at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
G	Bankfull elevation	Feet (NAVD[4])	--	Elevation where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
H	Maximum pool depth	Feet	--	The channel maximum depth of pool at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
I1	Vane arm slope, mid-channel vane arms	Percent	2-7%. Measured upstream along the surface of the vane from an elevation at ½ bankfull in the center of the channel down toward the stream bed. Defined by the ratio of bank height/vane length.	Slope of vane arms connecting the inverts of the w-weir to the stream banks.

Table 3. Required Design Data for W-weirs[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
I2	Vane arm slope, near-bank vane arms	Percent	2-7%. Measured upstream along the surface of the vane from the vane arm-stream bank intercept down toward the stream bed. Defined by the ratio of bank height/vane length.	Slope of vane arms connecting the inverts of the w-weir to the center point.
J1	Vane arm tie-in	Feet	¾ d_{mbkf} - d_{mbkf}. The structure extends no higher than bankfull stage elevation. More often, the w-weir arm intercepts the stream bank between ¾ bankfull stage elevation and bankfull stage elevation. A bankfull and/or inner berm bench may be integrated into the design.	Elevation of vane arms' tie-in to the stream banks
J2	Vane center point	Feet	Typically ½ d_{mbkf} or less. The center point of the structure is at an elevation typically half the bankfull max depth (when measured at the riffle).	Elevation of the w-weir center point
K	Select backfill width	Feet	≥ boulder width	Width of placement of select backfill (if used) on the upstream side of the w-weir.
L	Setback	Feet, inches	± ½ boulder width	Distance heading boulder is set back in the upstream direction from the footing boulder.

Table 3. Required Design Data for W-weirs[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
M	Footing depth	Feet, inches	3 – 6 times protrusion height of invert boulder. Minimum footing depth is associated with a ratio of the protrusion height of the invert boulder above the stream bed, and is dependent on bed material. In gravel and cobble bed streams, footings are 3 times the protrusion height; in sand bed stream the minimum depth is doubled due to the deeper scour depths that occur.	Depth of footings into the stream bed
N	Boulder length	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, header and footing boulders should be longer than they are wide and thick ("flat-shaped") and be of a durable composition.	One of three measurements to describe size of w-weir boulder building materials, the length is typically the largest dimension.
O	Boulder width	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, header and footing boulders should be longer than they are wide and thick ("flat-shaped") and be of a durable composition.	One of three measurements to describe size of w-weir boulder building materials, the width is typically the middle dimension.

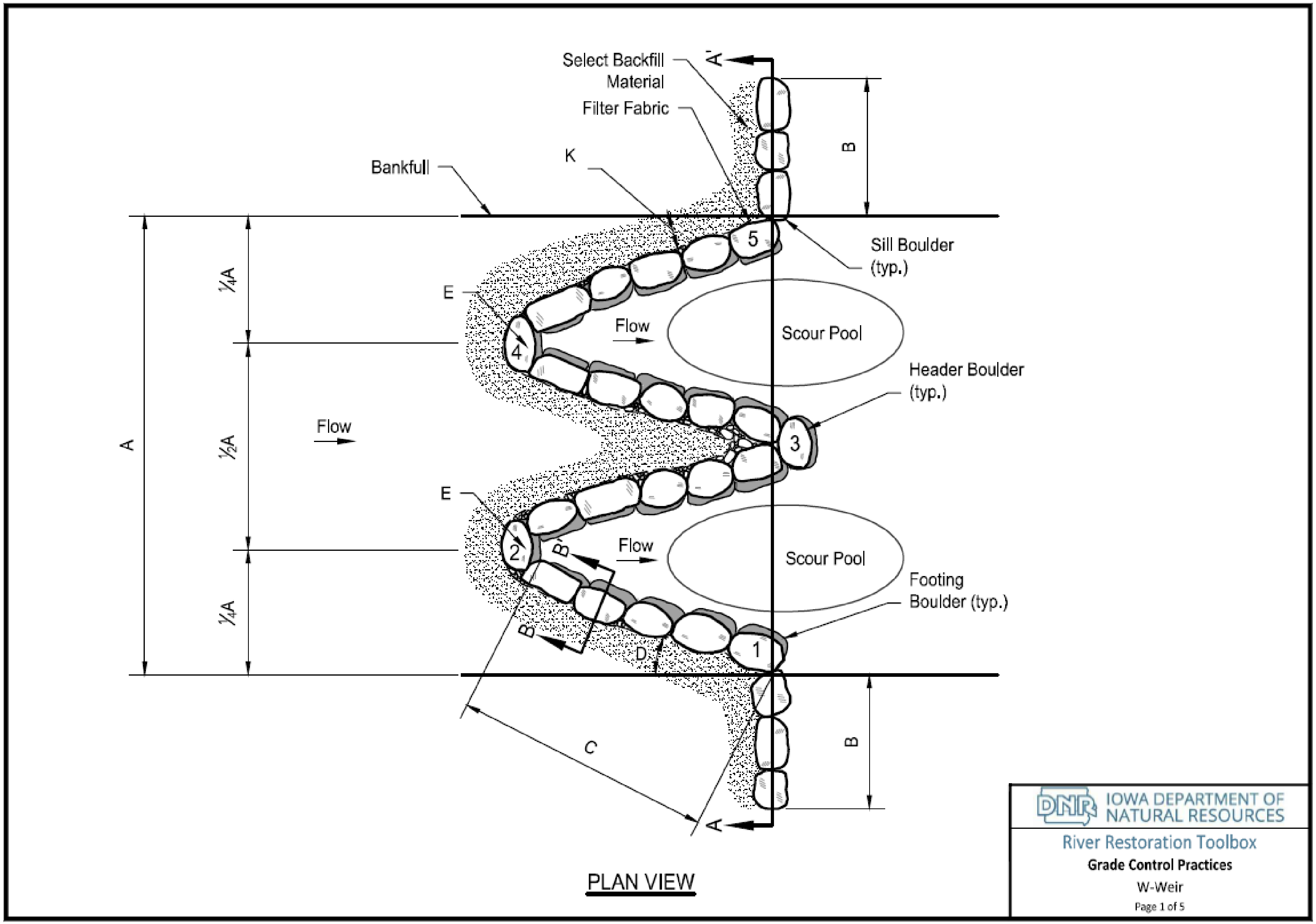
Table 3. Required Design Data for W-weirs[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
P	Boulder thickness	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally header and footing boulders should be longer than they are wide and thick ("flat-shaped") and be of a durable composition.	One of three measurements to describe size of w-weir boulder building materials, the thickness is typically the smallest dimension. It is also the vertical dimension.
Q	D50 of select backfill material	Inches	Minimum size of the intermediate (middle) axis of in-situ stream bed materials excavated for footing placement or off-site material of sufficient gradation, size, and shape to resist becoming dislodged.	Coarse material placed around heading and footing boulders after placement.

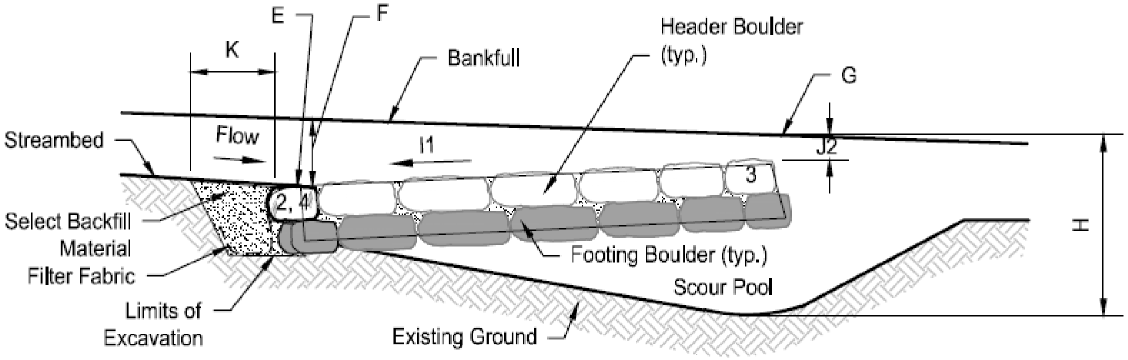
Notes:

1. Data are for W-weirs constructed of boulders.
2. Dimension label references detail drawings.
3. Common guidance, values, or ranges are given unless they require computation using site-specific input.
4. NAVD – North American Vertical Datum or other, as appropriate. Elevations relative to local benchmark may also be used.

Drawing 3. W-weir



Version 1.0 2/17/2017



PROFILE VIEW 1
MID-CHANNEL VANE

IOWA DEPARTMENT OF NATURAL RESOURCES

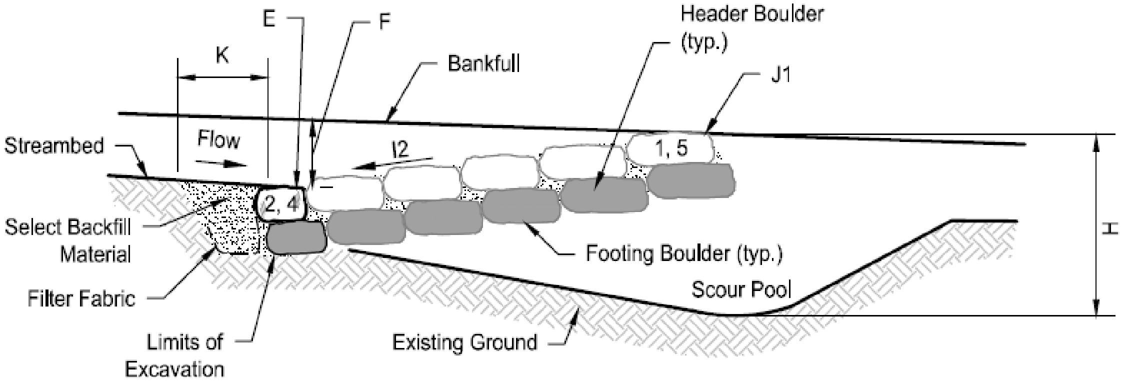
River Restoration Toolbox

Grade Control Practices

W-Weir

Page 2 of 5

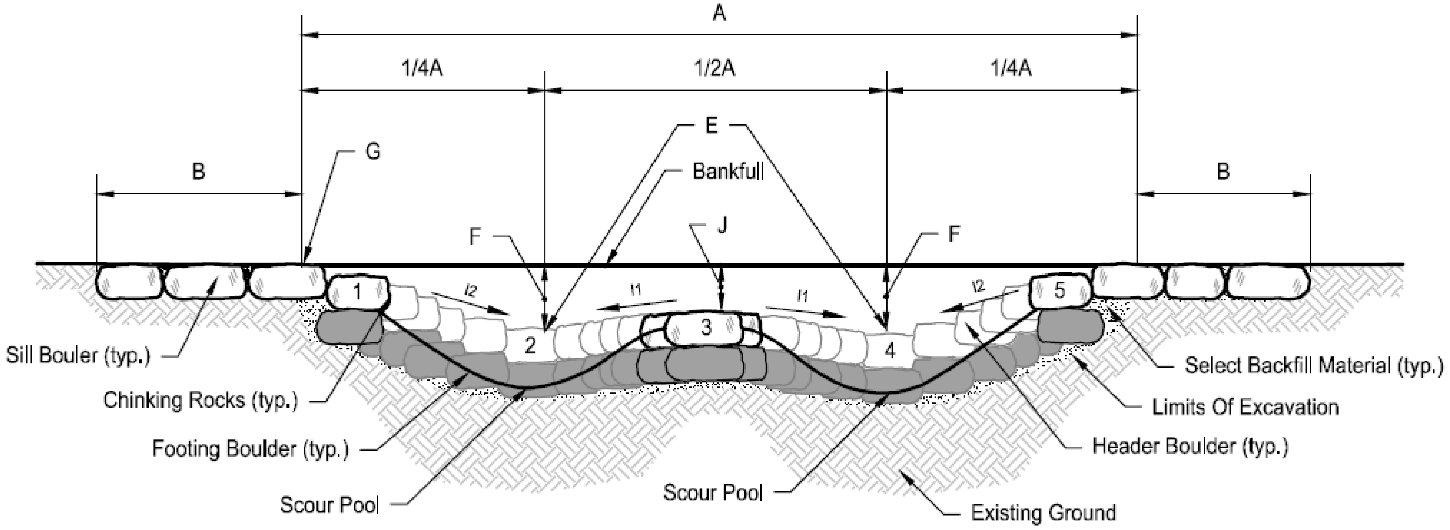
Version 1.0 2/17/2017



PROFILE VIEW 2
NEAR-BANK VANE

IOWA DEPARTMENT OF NATURAL RESOURCES
River Restoration Toolbox
Grade Control Practices
W-Weir
Page 3 of 5

Version 1.0 2/17/2017



CROSS SECTION A-A'

IOWA DEPARTMENT OF
NATURAL RESOURCES

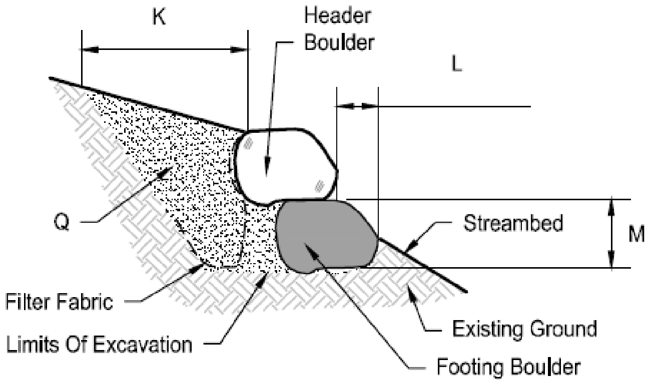
River Restoration Toolbox

Grade Control Practices

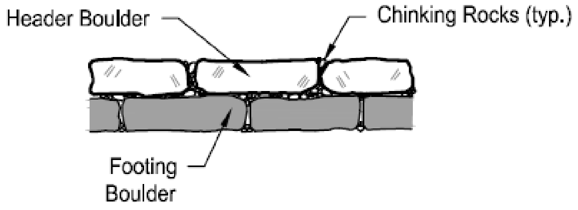
W-Weir

Page 4 of 5

Version 1.0 2/17/2017



CROSS SECTION B-B'



CHINKING DETAIL

IOWA DEPARTMENT OF
NATURAL RESOURCES

River Restoration Toolbox

Grade Control Practices

W-Weir

Page 5 of 5

Version 1.0 2/17/2017

2.3.4 Specifications

In addition to general information presented in Section 1.0 Introduction, the following information should be developed into specifications to accompany the use of w-weirs:

- Materials:
    - Boulders (rock) – Headers, footings, and sills (keyways) are typically boulders of durable limestone, dolomite, sandstone, granite, quartzite, etc., and be angular, flat, or cubed and have minimum average dimensions as specified by design. Boulders shall be free of shale, cracks, and other defects. Slag or recycled aggregate will be rejected.
    - Filter fabric – Filter fabric shall be a non-woven geotextile that allows for filtration during stabilization and separation of materials.
    - Select backfill – Gravel and cobble with a D50 and specified gradation by design, shall be durable limestone, dolomite, sandstone, granite, quartzite, etc., mined from the project site or an approved location (gravel pit, quarry, etc.). Slag or recycled aggregate will be rejected.
- Equipment – The designer should specify that w-weirs be constructed using an excavator with a hydraulic thumb to assist with precise placement of boulders and/or logs.
- Sequence –W-weirs are typically built as follows:
    - Excavate trench in stream bed to a depth equal to the total thickness of the heading and footing boulders.
    - Place footing boulders. There shall be no gaps between footings.
    - Install filter fabric.
    - Place select backfill behind the footing boulders.
    - Install heading boulders on top of and slightly set back from the footing boulders (such that part of the heading boulder is resting on the select backfill). Heading boulders should span the seams of the footing boulders. There should be no gaps between boulders.
    - Place select backfill behind heading boulders ensuring that any voids between the boulders are filled; hand placement or "chinking" may be necessary to ensure voids are filled and there is no sub-surface flow at the structure.
- Workmanship – The finished surface of the w-weir should be smooth, compact, and in accordance with the lines, grades, cross sections, and elevations of the design. No loose ends of filter fabric should be visible.

- Measurement – A construction precision (tolerance) of 0.1 foot should be specified.

2.3.5 Photographs

Photo 9. W-weir directing flow through bridge with center pier. Source: Unknown.

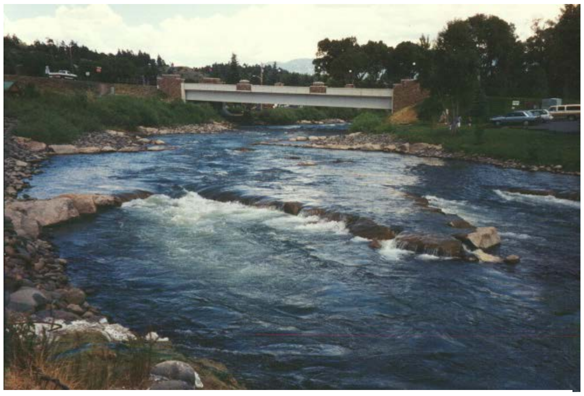


Photo 10. W-weir on the San Juan River. Source: Wildland Hydrology.

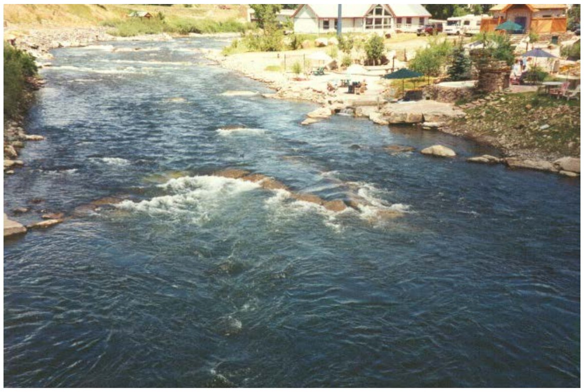


Photo 11. W-weir on the San Juan River. Source: Wildland Hydrology.

Photo 12. W-weir on the San Juan River. Source: Wildland Hydrology.

2.4 STEP-POOL STRUCTURE

2.4.1 Narrative Description

Step-pools are grade control structures used to dissipate energy and control elevation drop. They are typically used in stream reaches with relatively steep slopes. The structure also maintains a scour pool below each step which can hold water during dry periods in ephemeral and intermittent channels, thereby improving aquatic habitat availability in steep reaches.

The structure is adaptable; the step can be constructed from logs or rocks depending on channel conditions and materials available at the site, and may be constructed in single-step, double-step, riffle-step, or cascade-step configurations. Filter fabric is used in the structure to prevent scour under the rocks or logs.

2.4.2 Technique Information

- **Use:** Intended to establish grade control, dissipate energy, and control elevation drop, especially in relatively steep gradient channel reaches.

- **Other uses:** Can address aquatic habitat objectives by mimicking stable natural steep watercourses. The use of natural materials to build the step-pool structure, and the maintenance of scour pools during dry periods, creates important macroinvertebrate habitats in a newly constructed stream.

- **Best applications:**

  - Small streams with steep slopes. Step-pool structures are especially useful to connect smaller, headwater, ephemeral, intermittent, and perennial channels to main-stem stream reaches (e.g. a small catchment draining a developed area into a larger, perennial stream). They are useful in urban settings with limited sediment supply due to storm water drainage and locations where aesthetics and children's play areas are a project goal.

  - Best planform stream position is where straight channel sections connect small drainage areas to larger watersheds and between low gradient stream reaches separately by bedrock, faults, etc.

- **Variations:**

  - Combining with bank shaping and/or multi-stage channels. See Floodplain Restoration Practice for more information.

  - Combining with geomorphic channel design principals. See Geomorphic Channel Design practice.

- **Computations:** Computations are necessary and should accompany any design using step-pool structures. Step-pool structures require design by a professional.

  Hydrologic and hydraulic computations aid in verifying that the appropriate conditions exist for use of the step-pool structure. Geometric calculations are required to properly size and situate the structure within the context of its individual location. Hydraulic analysis is required to determine size, thickness, and/or depth of building materials that will resist becoming dislodged or undermined.

- **Key Features:**

  - Floodplain cutoff sills connecting each step at the point where it intercepts the stream bank are required to prevent out-of-bank flows from washing around the step-pool structure.

  - The structure requires footing boulders to prevent shifting of the structure due to bed scour.

- All header and footing boulders should be touching (no gaps). If the boulders are irregularly shaped and have gaps, the designer should specify that smaller stones (such as those from the select backfill material) that cannot slip through the gap be hand-placed in the gaps on the upstream side of the step ("chinked"). Gaps are created in a third course of boulders (surface boulders) to direct flow over each step in one or more relatively discrete locations.
- Header, footing, and surface boulders should be placed so they are angled slightly downward in the upstream direction to help them resist movement.
- A non-woven geotextile (filter fabric) should be used underneath the entire step-pool structure to prevent the structure from becoming undermined from scour. No fabric should be visible on the surface of the completed structure.

2.4.3 Detail Drawings and Data Table

The following data table and drawings depict information that should be included in construction plans for a step-pool structure. The data table includes design guidelines and sources, where applicable.

Table 4. Required Design Data for Step-Pool Structures[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
A	Bankfull width (W_{bkf})	Feet	< 30 ft; small to mid-sized streams	The channel width at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
B	Sill length	Feet	Minimum ½ W_{bkf}	Length of floodplain cutoff sills connecting each step at the point where it intercepts the stream bank. Sills are required to prevent out-of-bank flows from washing around the step-pool structure.
C	Step length	Feet	±0.3 x structure length; step features comprise approximately 30% of the total step-pool structure length	Length over the step portion of the structure
D	Pool length	Feet	±0.7 x structure length; pool features comprise approximately 70% of the total step-pool structure length	Length of the pool portion of the structure

Table 4. Required Design Data for Step-Pool Structures[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
E	Step spacing	Feet	0.5-4 x $W_{bkf;}$ step spacing is inversely proportional to the slope and is used to design elevation loss across the structure.	Distance between steps
F	Gap width	Feet	0.4 to 1 ft.; 0.3 to 0.6 ft. in low flow trough; gaps in the surface boulders should provide one or more flow paths across each step. Some of the surface boulders should be placed with gaps. Often, using irregularly-shaped, narrower parts of the stone for the top, with the broader, flatter part of the boulder at the bottom, yields the gap at the water surface even though the bottoms are snugged together. Select backfill material has particles large enough to become wedged in the gaps. Special care should be given to ensure there are gaps at low flow. Some randomness can be introduced by putting the gap in different cross sectional positions.	Distance between selected surface boulders intended to provide specific flow path through step-pool structure.

Table 4. Required Design Data for Step-Pool Structures[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
G	Step invert elevation	Feet (NAVD[4])	Step-pool inverts are typically set on the longitudinal profile of a stream in a riffle and/or run bed feature. Invert elevations should not create a “drop” in water surface that exceeds the physical mobility limitations of subject fish species. Limited to 0.8-foot head loss measured from water surface to water surface at thalweg for Iowa fish passage.	The step invert is the low point of each step of the structure
H	Maximum riffle depth	Feet	--	The channel maximum depth above the riffle at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
I	Pool depth	Feet	--	The channel maximum depth of pool at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.

Table 4. Required Design Data for Step-Pool Structures[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
J	Select backfill material thickness	Feet	≥2 x D100 of select backfill material; the thickness of select backfill should ensure no material becomes dislodged.	The thickness of material placed under the step footing boulders and lining the stream bed
K	Pool spacing	Feet	0.5-4 x $W_{bkf;}$ pool spacing is inversely proportional to the slope and is used to design elevation loss across the structure	Distance between individual pools of the step-pool structure
L	Boulder offset	Feet, inches	±0.2 ft.; placement of boulders should approximate the general cross-sectional parabolic shape of the stream bed	Height difference between adjacent boulders placed to form the step
M	Boulder length	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, surface, header, and footing boulders should be longer than they are wide and thick (“flat-shaped”) and be of a durable composition.	One of three measurements to describe size of the boulder building materials for the steps, the length is typically the largest dimension.

Table 4. Required Design Data for Step-Pool Structures[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
N	Boulder width	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, surface, header, and footing boulders should be longer than they are wide and thick ("flat-shaped") and be of a durable composition.	One of three measurements to describe size of the boulder building materials for the steps, the width is typically the middle dimension.
O	Boulder thickness	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, surface, header, and footing boulders should be longer than they are wide and thick ("flat-shaped") and be of a durable composition.	One of three measurements to describe size of the boulder building materials for the steps, the thickness is typically the smallest dimension. It is also the vertical dimension.

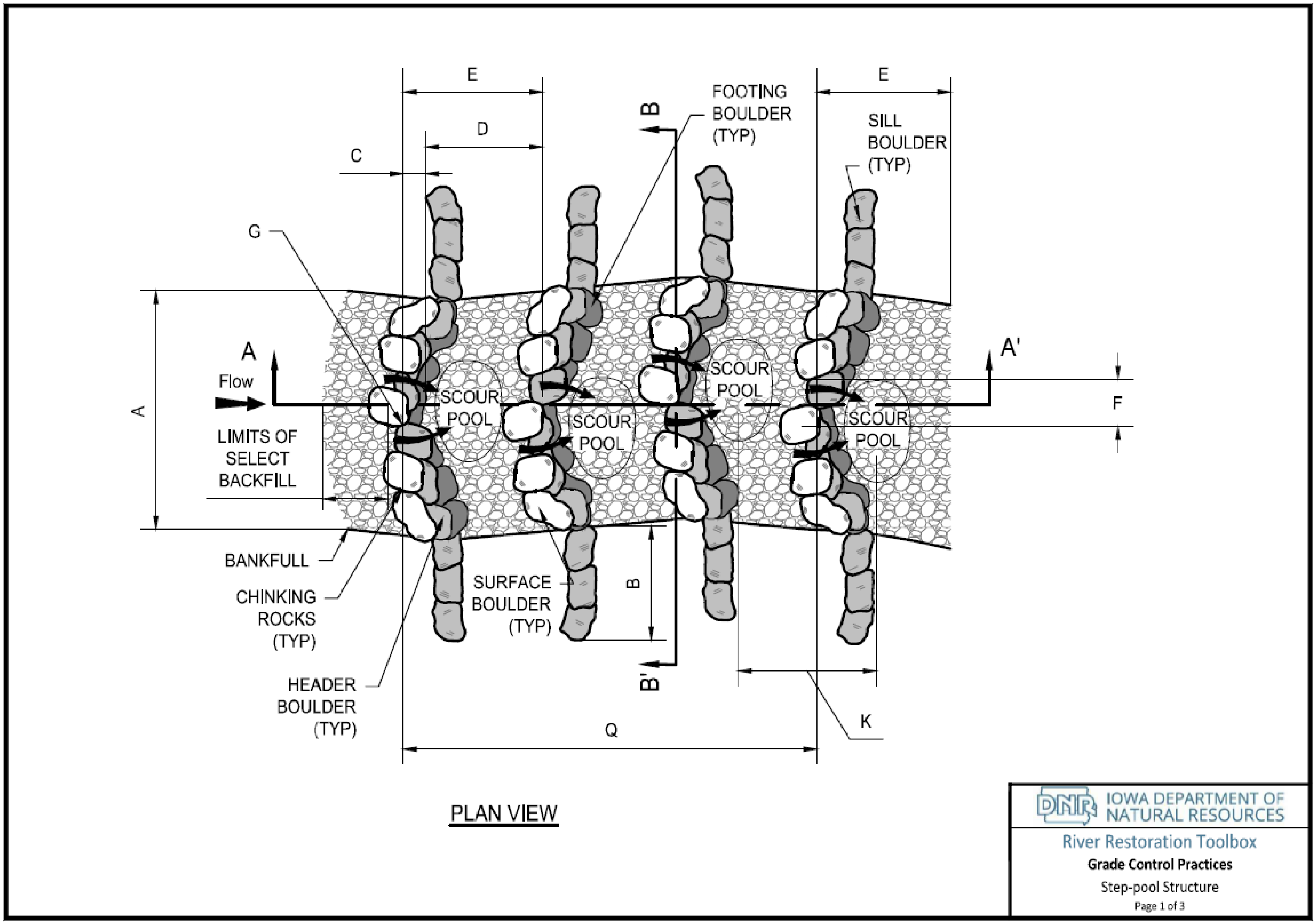
Table 4. Required Design Data for Step-Pool Structures[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
P	D50 of select backfill material	Inches	Minimum size of the intermediate (middle) axis of in-situ stream bed materials excavated for footing placement or off-site material of sufficient gradation, size, and shape to resist becoming dislodged.	Coarse material placed on stream bed and under footing boulders
Q	Step-pool structure length	Feet	--	The entire length of the step-pool structure.
R	Step height	Feet	0.8 ft max.; height difference between the step inverts that does not exceed the physical mobility limitations of subject fish species. Limited to 0.8-foot head loss measured from water surface to water surface at thalweg for Iowa fish passage.	Difference in elevation between each step in the step-pool structure

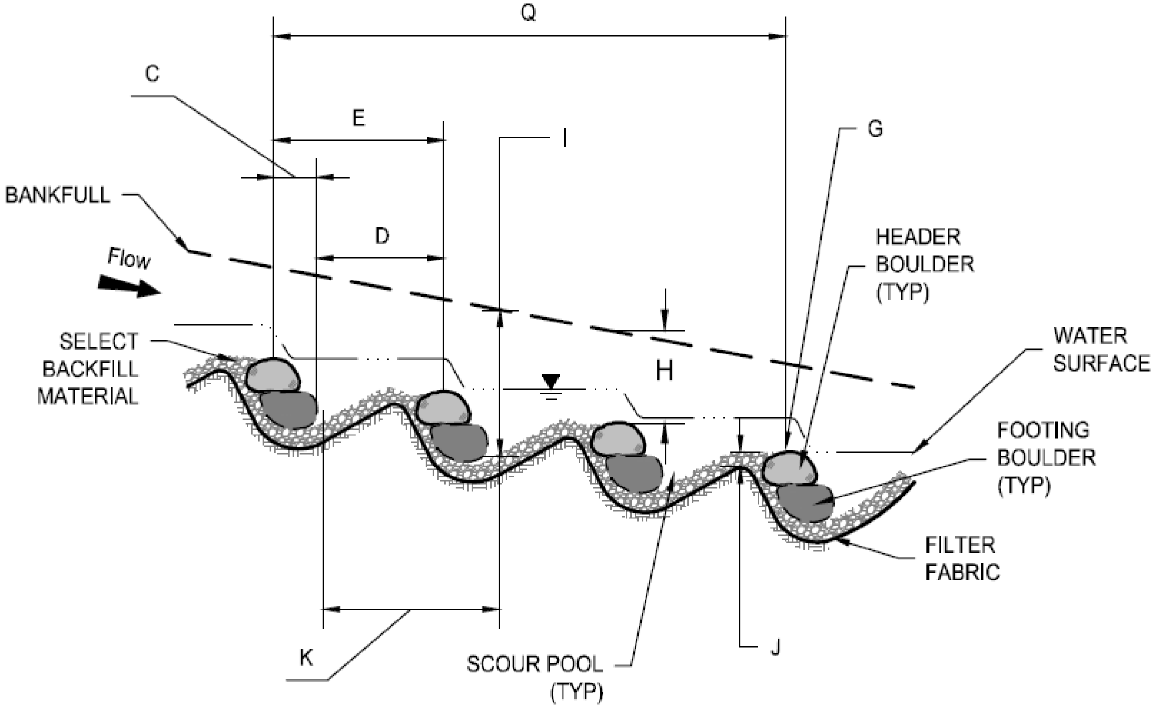
Notes:

1. Data are for step-pool structures constructed of boulders.
2. Some dimension labels are referenced in the detail drawings.
3. Common guidance, values, or ranges are given unless they require computation using site-specific input.
4. NAVD – North American Vertical Datum or other, as appropriate. Elevations relative to local benchmark may also be used.

Drawing 4. Step-Pool Structure



Version 1.0 2/17/2017



PROFILE VIEW A - A'

IOWA DEPARTMENT OF NATURAL RESOURCES

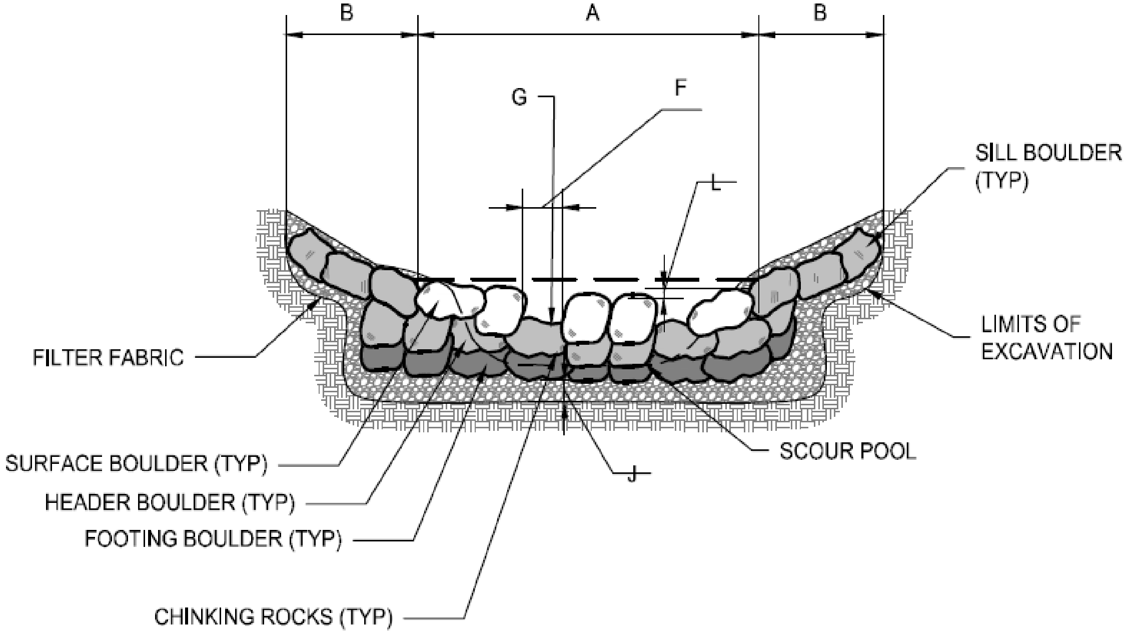
River Restoration Toolbox

Grade Control Practices

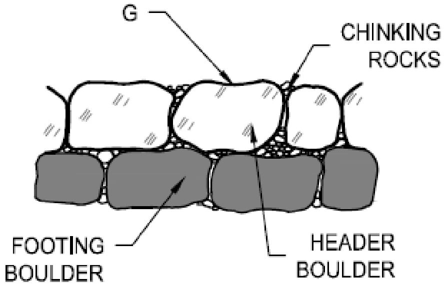
Step-Pool Structure

Page 2 of 3

Version 1.0 2/17/2017



SECTION VIEW B - B'



CHINKING DETAIL

IOWA DEPARTMENT OF NATURAL RESOURCES

River Restoration Toolbox

Grade Control Practices

Step-Pool Structure

Page 3 of 3

Version 1.0 2/17/2017

2.4.4 Specifications

In addition to general information presented in Section 1.0 Introduction, the following information should be developed into specifications to accompany the use of step-pool structures:

- Materials:
    - Boulders (rock) – Headers, footings, and sills (keyways) are typically boulders of durable limestone, dolomite, sandstone, granite, quartzite, etc., and be angular, flat, or cubed and have minimum average dimensions as specified by design. Boulders shall be free of shale, cracks, and other defects. Slag or recycled aggregate will be rejected.
    - Filter fabric – Filter fabric shall be a non-woven geotextile that allows for filtration during stabilization and separation of materials.
    - Select backfill/channel bed lining material – Gravel and cobble with a D50 and specified gradation by design, shall be durable limestone, dolomite, sandstone, granite, quartzite, etc., mined from the project site or an approved location (gravel pit, quarry, etc.). Slag or recycled aggregate will be rejected.
- Equipment – The designer should specify that step-pool structures be constructed using an excavator with a hydraulic thumb to assist with precise placement of boulders and/or logs.
- Sequence – Construct step-pool structures in a downstream succession immediately following channel excavation. Boulder steps are built on top of filter fabric and select backfill/channel bed lining material. Following construction, chinking, and backfill of the steps, the scour pools are shaped.
- Sequence –Step-pool structures are typically built as follows:
    - Excavate stream bed to a depth equal to the total thickness of the heading, footing, and surface boulders, and the select backfill/channel lining material.
    - Place filter fabric.
    - Place channel lining material.
    - Starting with the upstream-most step, place center (or lowest, invert) footing boulder. Construction generally starts at the channel invert and then builds towards each stream bank. There shall be no gaps between footings.
    - Place select backfill behind the footing boulders.
    - Install heading boulders on top of and slightly set back from the footing boulders (such that part of the heading boulder is resting on the select backfill). Heading

    boulders should span the seams of the footing boulders. There should be no gaps between boulders.

    - Place select backfill behind heading boulders ensuring that any voids between the boulders are filled; hand placement or “chinking” may be necessary to ensure voids are filled and there is no sub-surface flow at the structure.
    - Place surface boulders leaving one or two gaps between the boulders to provide one or more flow paths across each step. Each side of the surface boulders should extend into a sill past bankfull.
    - Repeat step construction until all steps are installed.
    - Following step construction, chinking, and backfill of the steps, shape the scour pools.

- Workmanship – The finished surface of the step-pool structure should be naturalistic and in accordance with the lines, grades, cross sections, and elevations of the design. No loose ends of filter fabric should be visible.
- Measurement – A construction precision (tolerance) of 0.1 foot should be specified.

2.4.5 Photographs

Photo 13. Boulder-jam steps. Source: Ridgewater.

Photo 14. Log steps. Source: Stantec.

Photo 15. Boulder steps. Source: Stantec.

Photo 16. Step Pools along Codornices Creek. Source: Stantec.

2.5 ROCK AND LOG RIFFLE

2.5.1 Narrative Description

Rock and log riffles are structures that use natural materials to provide grade control and improve habitat. These constructed riffles use a mix of natural substrates to construct boulder mini-vanes and log vanes and combine them to create a complex riffle with small cascades, drops, and micro-pools. Filter fabric is used in the structure to prevent scour around, between, and/or under the rocks and logs.

Some of the materials used to build the rock and log riffle can be transported and replaced by the stream. Other, larger materials that make up the structure are meant to remain immobile during high flows to stabilize the bed and prevent degradation, which is often a concern in newly constructed channel bottoms. Accurate sediment transport analysis is required to design a riffle that maintains required sediment transport without eroding the bed or adjacent banks.

2.5.2 Technique Information

- **Use**: Intended to provide grade control, regulate sediment transport, and diversify flow regimes using natural materials. The present state of the stream is evaluated and the riffle locations, dimensions, materials, etc. are applied in concert with geomorphic channel excavation, grading, and/or other adjustments to promote a dynamic equilibrium.

- **Other uses:** Can address aquatic habitat objectives by mimicking stable natural riffles. The diverse flow currents such as standing waves, hydraulic jumps, and backwater eddies that are formed in this complex structure work to counteract erosive near-bank shear stress and create the appropriate variety of riffle and pool habitats important to fish and macroinvertebrates in a newly constructed stream.

- **Best applications:**

    - Complex, naturalistic riffles for channels where grade stability is required.

    - Best planform stream position located in cross-over (straight, tangent) sections between meander bends; riffles.

- **Variations:**

    - Combining with aquatic habitat features. See Aquatic Habitat Practice for more information.

    - Combining with stream bank stabilization (e.g. Rock Toe Protection, Root Wad, etc.). See Streambank Toe Protection Practice for more information.

    - Combining with geomorphic channel design principals. See Geomorphic Channel Design practice.

- **Computations:** Computations are necessary and should accompany any design using rock and log riffles. Rock and log riffles require design by a professional.

  Hydrologic and hydraulic computations aid in verifying that the appropriate conditions exist for use of a rock and log riffle. Geometric calculations are required to properly size and situate the structure within the context of its individual location. Hydraulic analysis is required to determine how the riffle will distribute energy at various flow stages and to determine size, thickness, and/or depth of building materials that will resist becoming dislodged or undermined.

- **Key Features:**
  - A floodplain cutoff sill connecting each mini-vane arm at the point where it intercepts the stream bank near the outside of an adjacent meander bend are required to prevent out-of-bank flows from washing around the mini-vanes.
  - Ideally, header and footing boulders should be longer than they are wide and thick ("flat-shaped") and be of a durable composition.
  - All header and footing boulders should be touching (no gaps). If the boulders are irregularly shaped and have gaps, the designer should specify that smaller stones (such as those from the select backfill material) that cannot slip through the gap be hand-placed in the gaps on the upstream side of the cross vane ("chinked").
  - Header and footing boulders should be placed so they are angled slightly downward in the upstream direction to help them resist movement.
  - Log vanes are positioned to angle down toward the stream bed in the upstream direction. The log vanes may cross or not depending upon the total length of the riffle. Additional large "pinch" boulders can be used to secure log vanes that do not interlock. The rock and log riffle can be expanded to include numerous log vane pairs.
  - A non-woven geotextile (filter fabric) should be used upstream of the boulder mini-vanes and log vanes to prevent upstream bed materials and/or select backfill materials from washing through the boulders and logs. No fabric should be visible on the surface of the completed structure.

Select backfill material used to backfill the trenches excavated to install the headers, footings, and logs for the riffle features can be placed along the entire surface of the riffle, in between the boulder mini-vanes and log vanes.

2.5.3 Detail Drawings and Data Table

The following data table and drawings depict information that should be included in construction plans for a rock and log riffle. The data table includes design guidelines and sources, where applicable.

Table 5. Required Design Data for Rock and Log Riffle[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
A	Bankfull width (W_{bkf})	Feet	Small to large streams	The channel width at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
B	Sill length	Feet	Minimum ½ W_{bkf}	Length of floodplain cutoff sills connecting each vane arm at the point where it intercepts the stream bank. Sills are required to prevent out-of-bank flows from washing around the structure.
C1	Log vane angle	Degrees	35-55°; measured upstream from the tangent line where the log vane intercepts the bank. Angle variation is used to adjust log vane length to accommodate the size of logs available for the work	The angle between the log vane and the stream bank
C2	Boulder mini-vane angle, opposite sill	Degrees	35-55°; measured upstream from the tangent line where the mini-vane arm intercepts the bank. Angle variation is used to adjust the shape (arc) of the mini-vane.	The angle between the end of the boulder mini-vane with no sill and the stream bank

Table 5. Required Design Data for Rock and Log Riffle[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
C3	Boulder mini-vane angle, near sill	Degrees	35-55°; measured upstream from the tangent line where the mini-vane arm intercepts the bank. Angle variation is used to adjust the shape (arc) of the mini-vane.	The angle between the end of the boulder mini-vane with sill and the stream bank
D	Inner berm width	Feet	$\leq W_{bkf}$	A channel width between a lower bench or benches, inside the bankfull channel.
E1	Boulder mini-vane invert	Feet (NAVD[4])	Boulder mini-vane inverts are typically set on the longitudinal profile of a stream at the beginning- and end-of-riffle points. Invert elevation should not create a "drop" in water surface that exceeds the physical mobility limitations of subject fish species. Limited to 0.8-foot head loss measured from water surface to water surface at thalweg for Iowa fish passage.	Boulder mini-vane inverts are the low point of the structure, situated in the streambed, and oriented perpendicular to flow

Table 5. Required Design Data for Rock and Log Riffle[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
E2	Log vane invert	Feet (NAVD[4])	Log vane inverts are typically set on the longitudinal profile of a stream within the riffle feature. Invert elevation should not create a "drop" in water surface that exceeds the physical mobility limitations of subject fish species. Limited to 0.8-foot head loss measured from water surface to water surface at thalweg for Iowa fish passage.	Log vane inverts are the low point of the structure, situated in the streambed, and oriented perpendicular to flow
F	Maximum riffle depth	Feet	--	The channel maximum depth above the riffle at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
G	Log vane slope	Percent	2-7%; measured upstream along the surface of the log vane from the vane arm-stream bank intercept down toward the stream bed.	Slope of log vane arm
H	Select backfill width	Feet	≥ boulder width	Width of placement of select backfill (if used) on the upstream side of the boulder mini-vanes and log vanes.
I	Riffle length	Feet	--	The entire length of the riffle bed feature, between the end of the glide feature and the beginning of the run feature.

Table 5. Required Design Data for Rock and Log Riffle[1]

Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
J	Step height	Feet	≤0.8 ft.; height difference between the boulder mini-vane and log vane inverts that does not exceed the physical mobility limitations of subject fish species, limited to 0.8 foot head loss measured from water surface to water surface at thalweg for Iowa fish passage	Difference in elevation between the boulder mini-vane and log vane inverts
K	Boulder offset	Feet	±0.2 ft.; placement of boulders should form the generally parabolic shape of the stream bed	Height difference between adjacent boulders placed to form the step
L	Setback	Feet, inches	± ½ boulder width	Distance header boulder is set back in the upstream direction from the footing boulder.
M	Boulder length	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, header and footing boulders should be longer than they are wide and thick (“flat-shaped”) and be of a durable composition.	One of three measurements to describe size of mini-vane boulder building materials, the length is typically the largest dimension

Table 5. Required Design Data for Rock and Log Riffle[1]

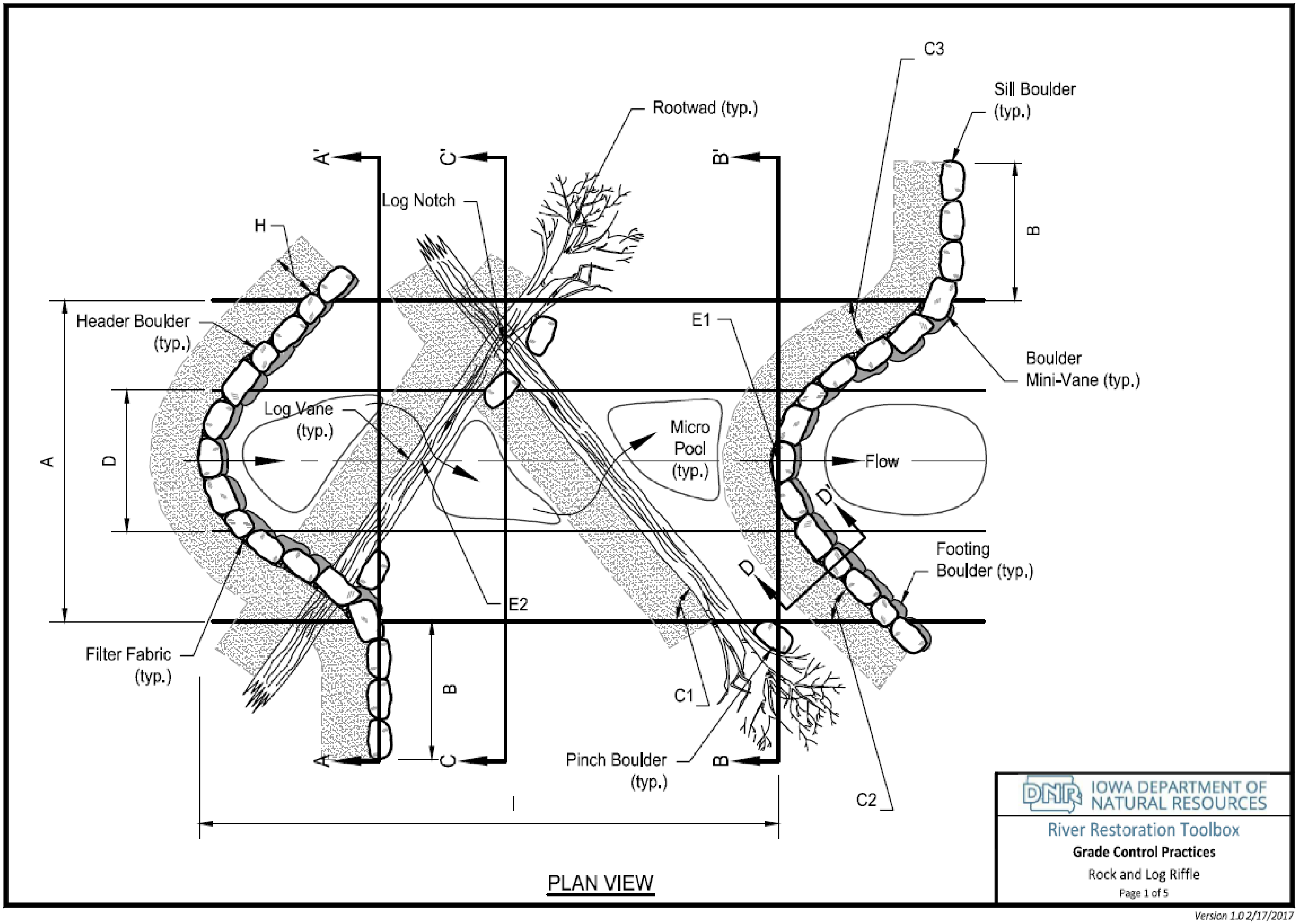
Dimension[2]	Name	Typical Unit	Guidelines[3]	Description
N	Boulder width	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, header and footing boulders should be longer than they are wide and thick ("flat-shaped") and be of a durable composition.	One of three measurements to describe size of mini-vane boulder building materials, the width is typically the middle dimension.
O	Boulder thickness	Feet, inches	Based on empirical data from rivers with bankfull discharge between 20 and 4,000 cfs depicting the relationship of bankfull shear stress to minimum rock size (Rosgen, 2006). Ideally, header and footing boulders should be longer than they are wide and thick ("flat-shaped") and be of a durable composition.	One of three measurements to describe size of mini-vane boulder building materials, the thickness is typically the smallest dimension. It is also the vertical dimension.
P	Log diameter	Feet, inches	±Boulder thickness	Size of logs used in the riffle structure.
Q	Select backfill material D50	Inches	Minimum size of the intermediate (middle) axis of in-situ stream bed materials excavated for footing placement or off-site material of sufficient gradation, size, and shape to resist becoming dislodged.	Coarse material placed around heading and footing boulders and logs after placement.

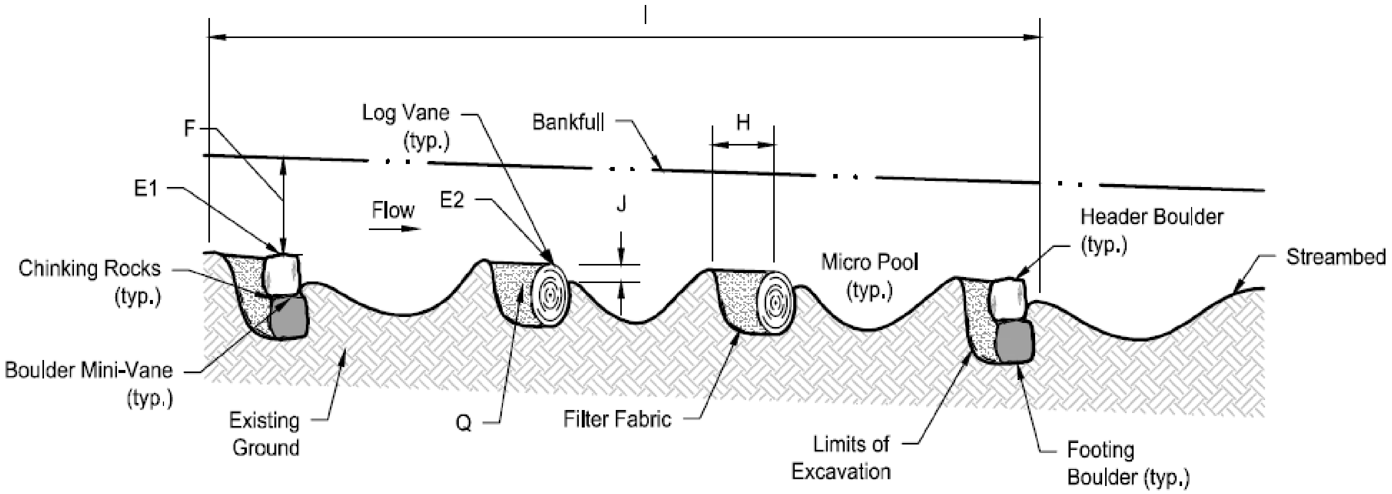
Notes:

1. Data are for rock and log riffles constructed of boulders and logs. Additional and/or different data is required if structure is built with boulder mini-vanes only (no logs).
2. Dimension label references detail drawings.
3. Common values, guidance, or ranges are given unless they require computation using site-specific input.

NAVD – North American Vertical Datum or other, as appropriate. Elevations relative to local benchmark may also be used.

Drawing 5. Rock and Log Riffle





PROFILE VIEW

IOWA DEPARTMENT OF
NATURAL RESOURCES

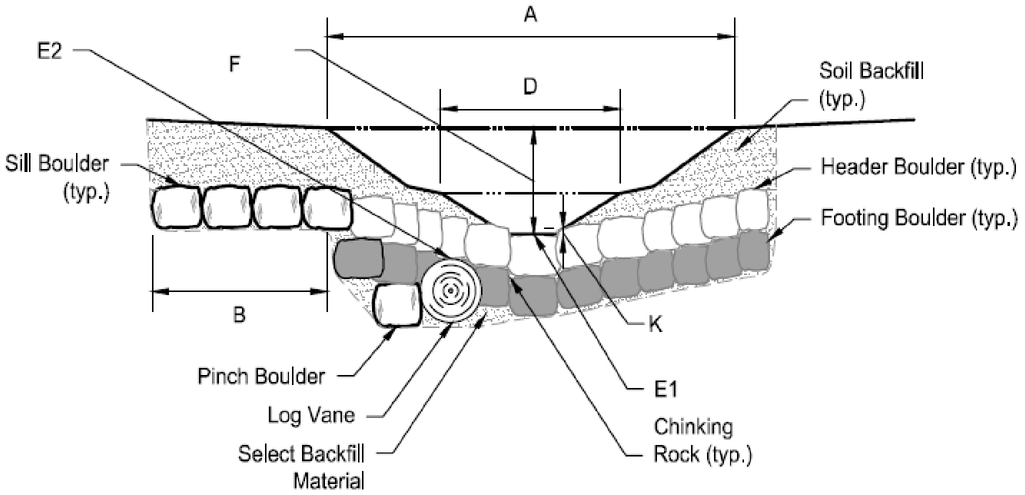
River Restoration Toolbox

Grade Control Practices

Rock and Log Riffle

Page 2 of 5

Version 1.0 2/17/2017



CROSS SECTION A-A'

IOWA DEPARTMENT OF NATURAL RESOURCES

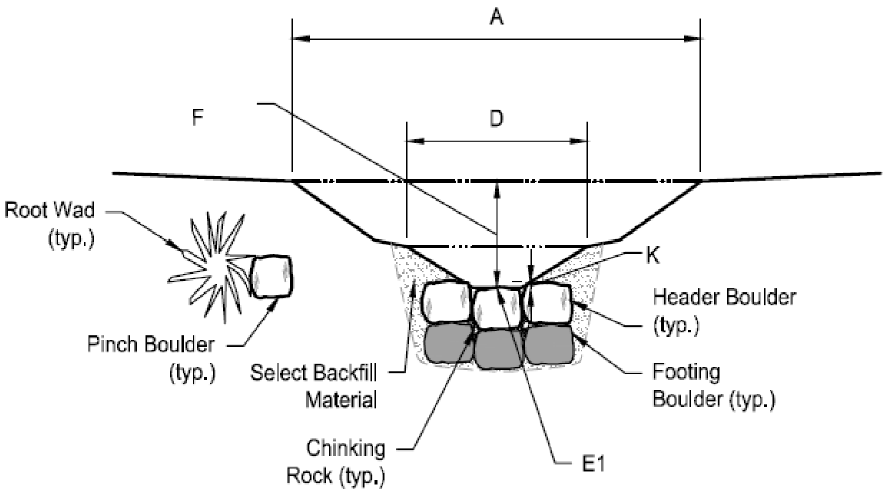
River Restoration Toolbox

Grade Control Practices

Rock and Log Riffle

Page 3 of 5

Version 1.0 2/17/2017



CROSS SECTION B-B'

IOWA DEPARTMENT OF
NATURAL RESOURCES

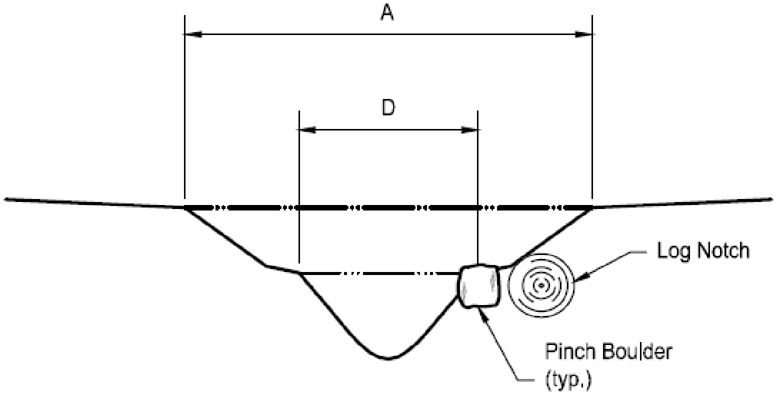
River Restoration Toolbox

Grade Control Practices

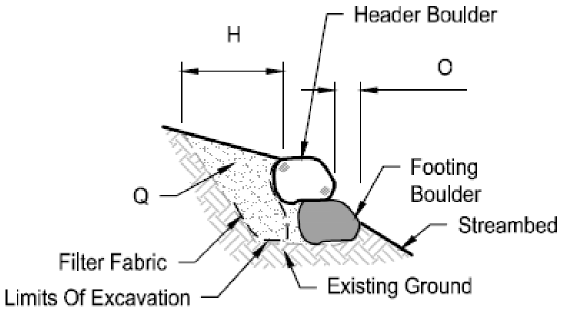
Rock and Log Riffle

Page 4 of 5

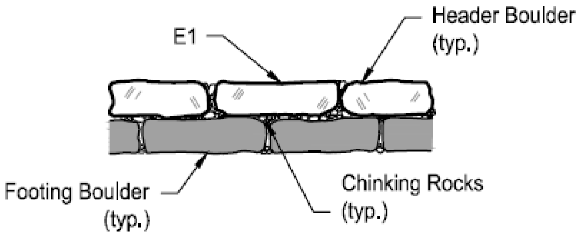
Version 1.0 2/17/2017



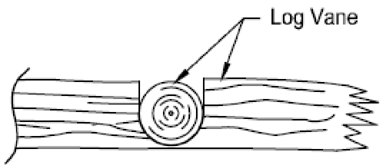
CROSS SECTION C-C'



CROSS SECTION D-D'



CHINKING DETAIL



LOG NOTCH DETAIL

IOWA DEPARTMENT OF
NATURAL RESOURCES

River Restoration Toolbox

Grade Control Practices

Rock and Log Riffle

Page 5 of 5

Version 1.0 2/17/2017

2.5.4 Specifications

In addition to general information presented in Section 1.0 Introduction, the following information should be developed into specifications to accompany the use of rock and log riffles:

- Materials:
  - Boulders (rock) – Headers, footings, and sills (keyways) are typically boulders of durable limestone, dolomite, sandstone, granite, quartzite, etc., and be angular, flat, or cubed and have minimum average dimensions as specified by design. Boulders shall be free of shale, cracks, and other defects. Slag or recycled aggregate will be rejected.
  - Logs – Logs shall be from trees free of rot and/or disease with minimum dimensions, with or without root ball attached, as specified by design. Logs shall be straight with limbs trimmed off, flush.
  - Filter fabric – Filter fabric shall be a non-woven geotextile that allows for filtration during stabilization and separation of materials.
  - Fasteners – Filter fabric attached to log using 2-inch galvanized roofing nails spaced 12 inches on center.
  - Select backfill and or riffle pavement (channel bed lining material) – Gravel and cobble with a D50 and specified gradation by design, shall be durable limestone, dolomite, sandstone, granite, quartzite, etc., mined from the project site or an approved location (gravel pit, quarry, etc.). Slag or recycled aggregate will be rejected.
- Equipment – The designer should specify that rock and log riffles be constructed using an excavator with a hydraulic thumb to assist with precise placement of boulders and/or logs.
- Sequence – Construct multiple rock and log riffles in a downstream succession immediately following channel excavation.
  - Boulder mini-vanes are built starting at the channel invert and then building towards the top of the low flow channel, with each arm extending into the bank.
    - Excavate trench in stream bed to a depth equal to the total thickness of the heading and footing boulders.
    - Place footing boulders. There shall be no gaps between footings.

        - Install filter fabric.
        - Place select backfill behind the footing boulders.
        - Install heading boulders on top of and slightly set back from the footing boulders (such that part of the heading boulder is resting on the select backfill). Heading boulders should span the seams of the footing boulders. There should be no gaps between boulders.
        - Place select backfill behind heading boulders ensuring that any voids between the boulders are filled; hand placement or “chinking” may be necessary to ensure voids are filled and there is no sub-surface flow at the structure.
        - The upstream and downstream most mini-vanes shall have sills extending past bankfull on the side adjacent to the outside bend.
    - Log vanes
        - Excavate trench in stream bed to a depth equal to the total thickness of the log.
        - Place log.
        - Fasten filter fabric to log.
        - Place select backfill behind the log.
        - Place select backfill behind log.
- Workmanship – The finished surface of the rock and log riffles should be naturalistic and in accordance with the lines, grades, cross sections, and elevations of the design. No loose ends of filter fabric should be visible.
- Measurement – A construction precision (tolerance) of 0.1 foot should be specified.

2.5.5 Photographs

Photo 17. Rock and log riffle. Source: Wildland Hydrology.

Photo 18. Rock and log riffle. Source: Wildland Hydrology.

Photo 19. Rock and log riffle. Source: Stantec.

Photo 20. Rock and log riffle. Source: Stantec.

Photo 21. Rock and log riffle. Source: Wildland Hydrology.

Photo 22. Rock and log riffle. Source: Wildland Hydrology.

2.6 ROCK CONSTRUCTED RIFFLE

2.6.1 Narrative Description

Rock constructed riffles are similar to the rock and log riffle structure; however, they do not contain any vane structures. Where possible, native materials should be used to build rock constructed riffles provided they provide adequate resistance to design shear stresses. These riffles are constructed using a mix of natural substrates and contain both riffle pavement and sub pavement material. They can be designed as an alluvial riffle, meaning the riffle material will mobilize through the system and there is enough sediment supply to reform the riffle after storm events or they can be designed as a threshold riffle, meaning the material is sized not to mobilize. Since a lot of streams in Iowa have gravel or sand substrates, often these riffles will need to be designed not to mobilize (threshold). Wood can also be incorporated into these structures.

For a threshold riffle, the larger materials that make up the structure are meant to remain immobile during high flows to stabilize the bed and prevent degradation. Accurate sediment transport analysis is required to design a riffle that maintains required sediment transport without eroding the bed or adjacent banks.

2.6.2 Technique Information

- **Use**: Intended to provide grade control, regulate sediment transport, and diversify flow regimes using natural materials. The present state of the stream is evaluated and the riffle locations, dimensions, materials, etc. are applied in concert with geomorphic channel excavation, grading, and/or other adjustments to promote a dynamic equilibrium.

- **Other uses:** Can address aquatic habitat objectives by mimicking stable natural riffles.

- **Best applications:**

    - Complex, naturalistic riffles for channels where grade stability is required.

    - Best planform stream position located in cross-over (straight, tangent) sections between meander bends; riffles.

    - Although hydraulic calculations can indicate the water's ability to move a given diameter of stone, realize that this type of structure is more vulnerable than other grade control types to impacts from debris and ice floes.

- **Variations:**

    - Can be designed with a sub-pavement and pavement, each requiring a different gradation of rock.

    - Can be designed with riffle material extending above inner berm depth.

  - Combining with temporary erosion control (e.g. Erosion Control Matting, etc.) and re-vegetation techniques. See Vegetative Restoration Practice for more information.

  - Combining with bank shaping and/or multi-stage channels. See Floodplain Restoration Practice for more information.

  - Combining with geomorphic channel design principals. See Geomorphic Channel Design practice.

- **Computations:** Computations are necessary and should accompany any design using rock and log riffles. Rock constructed riffles require design by a professional.

  Hydrologic and hydraulic computations aid in verifying that the appropriate conditions exist for use of a rock constructed riffle. Geometric calculations are required to properly size and situate the structure within the context of its individual location. Hydraulic analysis is required to determine how the riffle will distribute energy at various flow stages and to determine size, thickness, and/or depth of building materials that will resist becoming dislodged or undermined.

- **Key Features:**

  - If large gradation rock is required for the sub-pavement, ensure that voids are filled with the surface stone.

2.6.3 Detail Drawings and Data Table

The following data table and drawings depict information that should be included in construction plans for rock constructed riffles. The data table includes design guidelines and sources, where applicable.

Table 6. Required Design Data for Rock Constructed Riffles

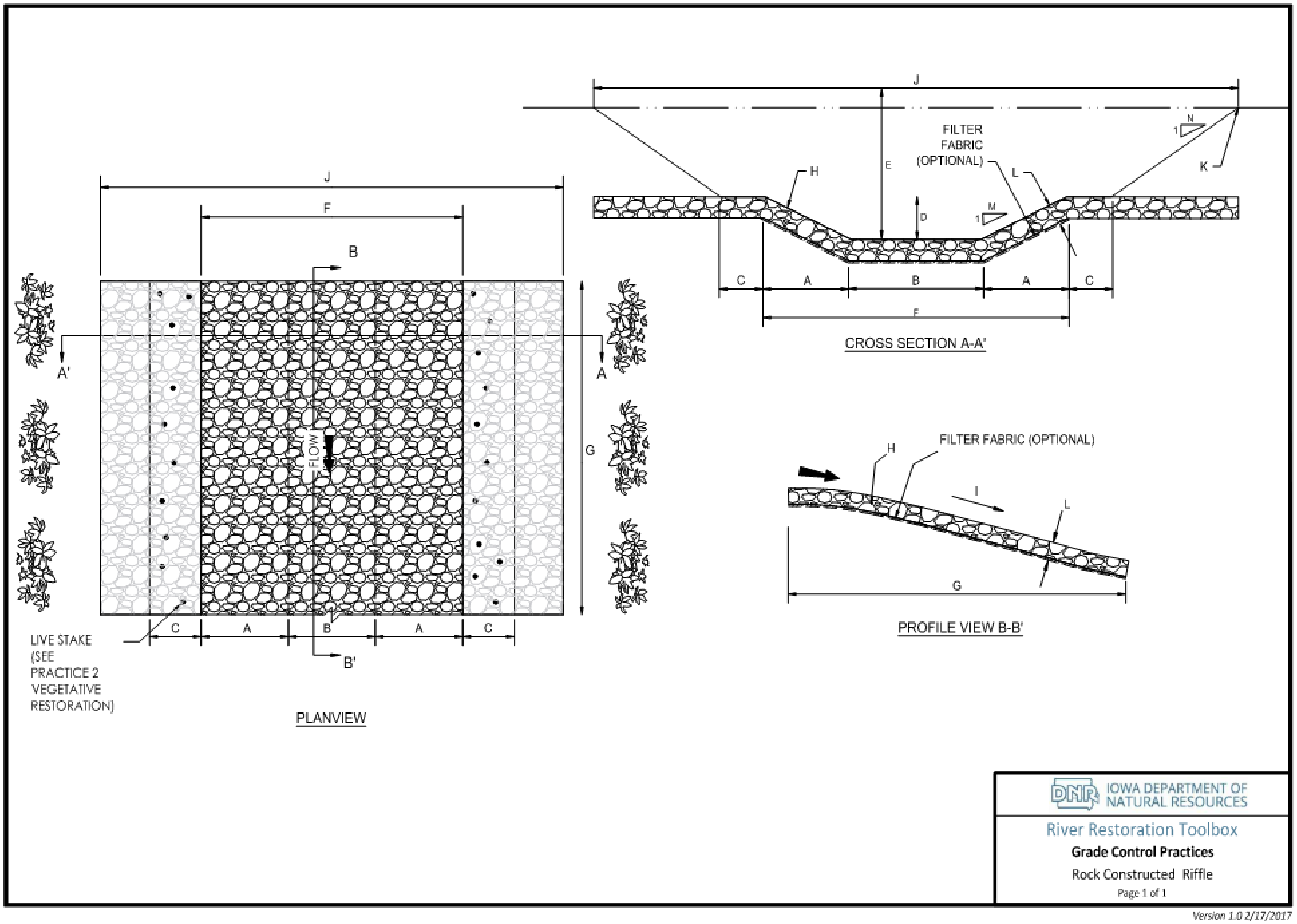
Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
A	Low-Flow Side Slope Width	Feet	--	Horizontal distance from toe of slope to inner berm.
B	Bottom Width	Feet	--	Distance from left toe of slope to right toe of slope constituting the channel bottom.
C	Inner Berm Width	Feet	--	Width from inner berm elevation to toe of slope up to bankfull
D	Inner Berm Depth	Feet	--	Distance from channel bottom to top of inner berm elevation
E	Bankfull Max Depth	Feet	Distinct from mean depth	Depth from thalweg to bankfull elevation
F	Inner Berm Width	Feet	--	Distance from inner berm elevation to opposite bank/inner berm.
G	Riffle Length	Feet	Typically 1-4 bankfull widths, but can fall outside that range.	Length of riffle along the centerline of the channel

H	Riffle Material	Inches, Iowa DOT Standard Types	Size stone based on hydraulic calculations – generally a gradation is provided	Size of stone used to construct riffle
I	Riffle Slope	Feet:Feet, %	Greater than bankfull slope.	Slope along the channel centerline from top to bottom of riffle
J	Bankfull Width[4]	Feet	Generally, < 30 ft; for small to mid-sized streams	The channel width at bankfull stage, where discharge has filled the channel to the top of its banks and water begins to overflow onto a floodplain.
K	Bankfull Elevation	Feet	Typically, NAVD[3]	Elevation at which flow accesses the floodplain
L	Riffle Thickness	Feet	--	Thickness of riffle substrate
M,N	Side Slope	Feet:Feet, %	3:1 or flatter is preferred, no steeper than 2:1	Slopes from toe of slope to inner berm and from inner berm to top of bank

Notes:

1. Dimension label references detail drawings.
2. Common values, guidance, or ranges are given unless they require computation using site-specific input.
3. NAVD – North American Vertical Datum or other, as appropriate. Elevations relative to local benchmark may also be used.
4. Rock can be extended to top of bank as shown, up to inner berm elevation, if applicable or across bottom of riffle as grade control. For all circumstances, rock should extend laterally to top of bank.

Drawing 6. Rock Constructed Riffle



2.6.4 Specifications

In addition to general information presented in Section 1.0 Introduction, the following information should be developed into specifications to accompany the use of rock constructed riffles:

- Materials:
    - Riffle Material – Gravel and cobble with a D50 and specified gradation by design, shall be durable limestone, dolomite, sandstone, granite, quartzite, etc., mined from the project site or an approved location (gravel pit, quarry, etc.). Slag or recycled aggregate will be rejected. May require multiple gradation sizes if a sub-pavement is required.
    - Filter fabric (optional) – Filter fabric shall be a non-woven geotextile that allows for filtration during stabilization and separation of materials.
- Equipment – The designer should specify that rock constructed riffles be constructed using an excavator.
- Sequence – Construct multiple rock constructed riffles in a downstream succession immediately following channel excavation.
    - Excavate trench in stream bed to a depth equal to the total thickness of the riffle material.
    - Install filter fabric, if specified by the design.
    - Place riffle material at the slope and thickness specified in the design. If sub-pavement is required, place it first and then finish with surface stone.
- Workmanship – The finished surface of the rock constructed riffles should be naturalistic and in accordance with the lines, grades, cross sections, and elevations of the design. No loose ends of filter fabric should be visible.
- Measurement – A construction precision (tolerance) of 0.1 foot should be specified.

2.6.5 Photographs

Photo 23. Rock constructed riffle. Source: Iowa DNR

Photo 24. Rock constructed riffle. Source: Iowa DNR

Photo 25. Rock constructed riffle with boulders dispersed throughout. Source: Stantec.

Photo 26. Rock constructed riffle at First Unitarian Church. Source: Iowa DNR.

2.7 GROUTED GRADE CONTROL STRUCTURE

2.7.1 Narrative Description

Grouted Grade Control structures are used in areas subject to significant headcuts where large durable rock is not readily available. This is often the case when working in southwest Iowa, where the geology is such that bedrock readily breaks down over time and durable rock is not available. As the stream degrades and incises, there can be one large headcut (often more than 4 feet of incision has taken place) that works through the system or multiple smaller headcuts, either of which results in a significant change in elevation of the channel bed upstream and downstream of the head cut. With this structure, a sheet pile wall is installed on the upstream end of the riffle and rock is placed upstream and downstream of the riffle and is grouted in place to help minimize the deterioration and mobilization of the rock material. The slope of the weir should be 15:1 or flatter to provide adequate fish passage, whereas other grade control structures need to be 20:1 or flatter to allow for fish passage. Substrate in southwest Iowa is often sandy-silt and grout is necessary to prevent scouring, undercutting, and maintain the weir slope designed for fish passage. Grouted Grade Control structures are often a preferred alternative to fish ladders because fish ladders can catch debris, and the riprap used to construct them is not as strong or as resistant to high flow events (Thomas 2011). Grade control structures, including the Grouted Grade Control structure have been found to have a local positive effect on fish and macroinvertebrates in western Iowa with respect to increased habitat diversity and abundance (Thomas 2011). Note that grouted rock can be easily undermined and subject to deterioration if the material below the structure is eroded. Caution should be exercised when utilizing this structure.

For more information on Grouted Grade Control structures contact John Thomas (john@goldenhillsrcd.org) of Hungry Canyons Alliance. The Hungry Canyons Alliance has been using Grouted Grade Control structures in southwest Iowa since the early 1990s.

2.7.2 Technique Information

- **Use**: Intended to provide grade control, regulate sediment transport, and minimize headcuts using a combination of synthetic and natural materials.
- **Other uses:** Can help to limit channel downcutting and lock in a desired channel bed elevation.
- **Best applications:**
  - Areas highly subject to channel bed degradation, such as southwest Iowa.
  - Best planform stream position located in cross-over (straight, tangent) sections between meander bends; riffles.

- **Variations:**
    - Combining with temporary erosion control (e.g. Erosion Control Matting, etc.) and re-vegetation techniques. See Vegetative Restoration Practice for more information.
    - Combining with bank shaping and/or multi-stage channels. See Floodplain Restoration Practice for more information.
    - Combining with stream bank stabilization (e.g. Rock Toe Protection, Root Wad, etc.). See Streambank Toe Protection Practice for more information.
- **Computations:** Computations are necessary and should accompany any design using Grouted Grade Control structures. These structures require design by a professional.

  The depth of the sheet pile wall should be determined be designing the structure as a free-standing cantilever wall.

  Hydrologic and hydraulic computations aid in verifying that the appropriate conditions exist for use of a Grouted Grade Control structure. Geometric calculations are required to properly size and situate the structure within the context of its individual location. Hydraulic analysis is required to determine how the riffle will distribute energy at various flow stages and to determine size, thickness, and/or depth of building materials that will resist becoming dislodged or undermined.
- **Key Features:**
    - The downstream half of the stilling basin and all of the toe should be loose riprap.
    - Boulders should be placed near the center of the channel with 25% of each rock overlapping the weir centerline.
    - Stilling basin and transition to channel downstream must be located in a straight stream reach.
    - If future degradation is anticipated at the weir outlet, use loose riprap instead of grouted riprap.
    - Weir must be at least as wide at the outlet as the natural channel to reduce water velocities.
    - Weir slope must be ≤ 15:1 to promote fish passage.

- Do not change from grouted to loose riprap on or near the weir slope. Transition from grouted to loose riprap in lower energy areas such as the stilling basin or on the streambanks to prevent movement of loose riprap.
- Make sure to extend sheet piling cut-off wall well up and into the streambank to reduce the risk of flow cutting around the weir.
- Ensure structure is aligned with existing channel to reduce scour.

2.7.3 Detail Drawings and Data Table

The following data table and drawings depict information that should be included in grouted grade control structures. The data table includes design guidelines and sources, where applicable.

Table 7. Required Design Data for Grouted Grade Control Structure

Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
A	Weir Length	Feet	Dependent on Weir Slope	Horizontal length from top of sheet pile to toe of weir slope.
B	Stilling Basin Length	Feet	Stilling basin is not required, but highly recommended.	Length of stilling basin at the bottom of the weir.
C	Outlet Toe Length	Feet	--	Length of loose riprap at the outlet of the stilling basin
D	Bank Stabilization Length	Feet	--	Length of loose riprap bank stabilization downstream of the stilling basin outlet toe
E	Stilling Basin Back Slope	Feet:Feet, %	--	Slope from the end of the weir to the bottom of the stilling basin
F	Bank Stabilization Width (one bank)	Feet	Typically, stabilization placed up to half bankfull height	Width from edge of stilling basin to top of bank stabilization
G	Upper Weir Bottom Width	Feet	--	Bottom width of proposed channel created by the weir at the upstream end of the weir structure.

Table 7. Required Design Data for Grouted Grade Control Structure

Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
H	Channel Width	Feet	--	Bottom width of existing channel
I	Boulder Spacing	Feet	--	Spacing from end of one boulder to the beginning of the next.
J	Boulders	Each	Resistant caprock, quartzite, or manufactured concrete rocks greater than 24 inches on smallest axis	Large rock grouted into weir on alternating sides of the weir center.
K	Lower Weir Bottom Width	Feet	--	Bottom width of proposed channel created by the weir at the downstream end of the weir structure.
L	Stilling Basin Bottom Length	Feet	--	Length of the stilling basin from upstream toe of slope to downstream toe of slope.
M	Stilling Basin Foreslope	Feet:Feet, %	--	Slope from bottom of the stilling basin to tie in to existing grade at the downstream end of the basin.
N	Top of Bank Width	Feet	--	Width from left top of bank to right top of bank.
O	Depth of riprap	Feet	--	Depth of riprap

Table 7. Required Design Data for Grouted Grade Control Structure

Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
O2	Depth of riprap	Feet	--	Depth of riprap, thickness of weir at the upstream end of structure.
O3	Depth of grouted riprap	Feet	--	Depth of riprap at the downstream end of weir.
O4	Depth of riprap	Feet	--	Depth of riprap under the stilling basin bottom
O5	Depth of riprap	Feet	--	Depth of riprap at the outlet toe
P	Sheetpile Length	Feet	--	Length of sheet pile driven into streambed at upstream end of structure.
Q	Weir Slope	Feet:Feet, %	≤ 15:1 to promote fish passage	Slope of weir
R	Weir Height	Feet	Not to exceed 4 feet	Vertical drop over weir.
S	Stilling Basin Depth	Feet	--	Depth of stilling basin
T	Stabilized Channel Depth	Feet	Stabilization typically placed up to half bankfull height.	Vertical distance of stabilized channel from top of riprap to channel bottom.
U	Bank Slope	Feet:Feet, %	--	Slope from top of bank stabilization riprap to edge of weir bottom.

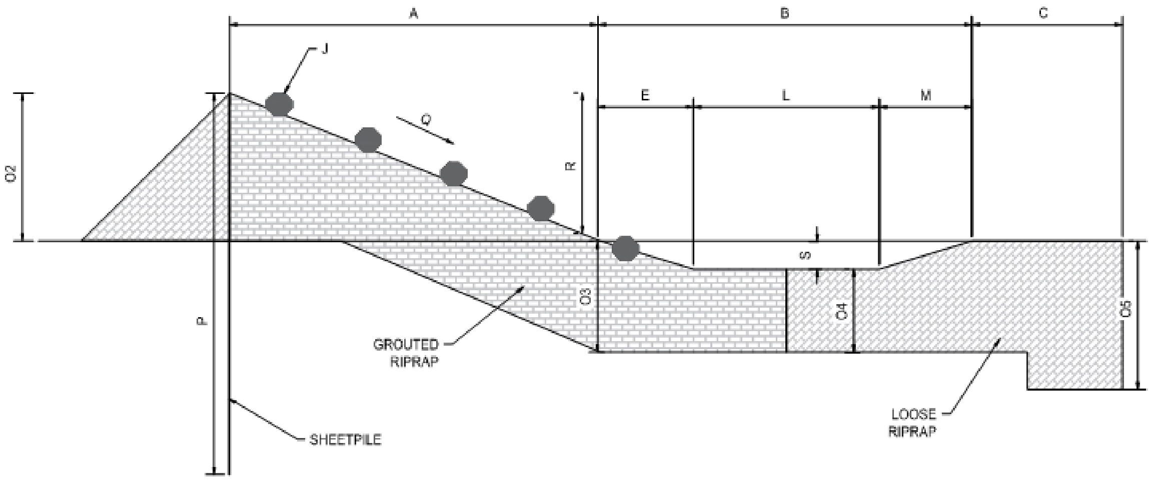
Table 7. Required Design Data for Grouted Grade Control Structure

Dimension[1]	Name	Typical Unit	Guidelines[2]	Description
V	Stilling Basin Bottom Width	Feet	--	Width of stilling basin at toe of structure.

Notes:

1. Dimension label references detail drawings.
2. Common values, guidance, or ranges are given unless they require computation using site-specific input.

Drawing 7. Grouted Grade Control Structure



PROFILE VIEW C–C'

IOWA DEPARTMENT OF NATURAL RESOURCES

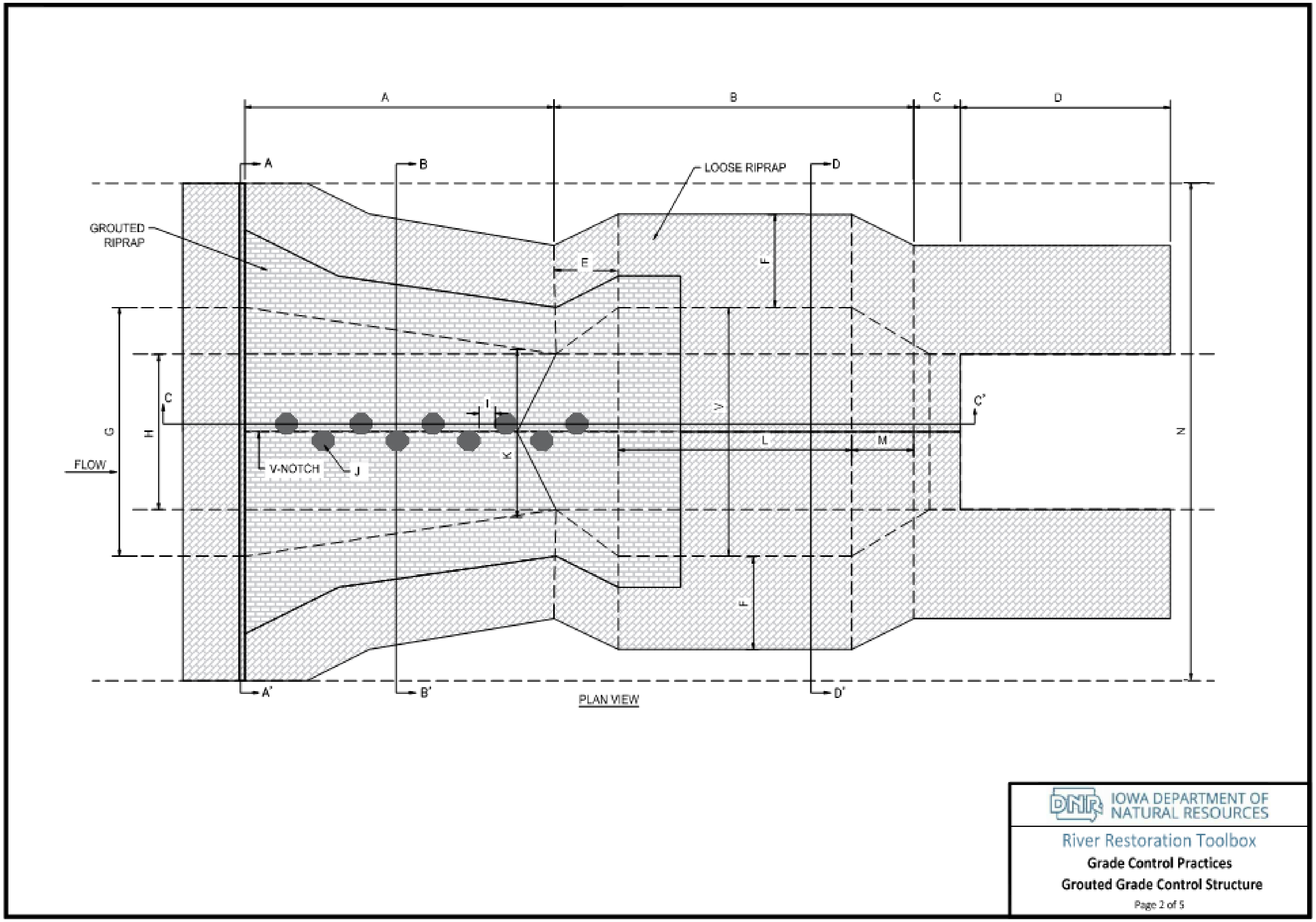
River Restoration Toolbox

Grade Control Practices

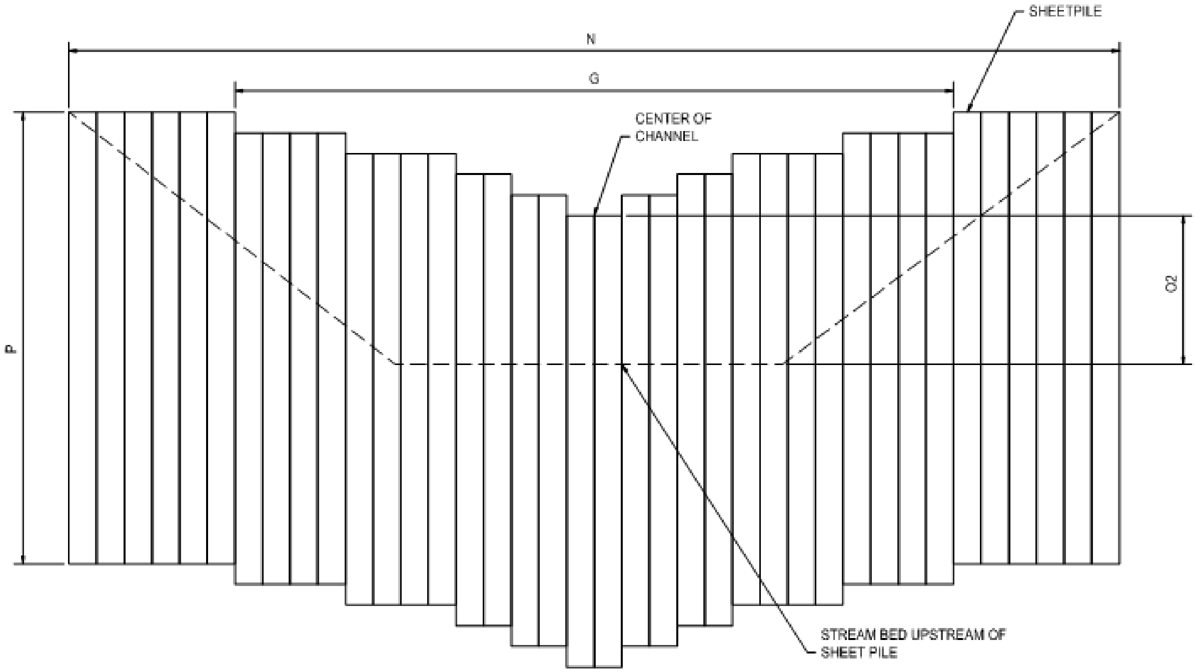
Grouted Grade Control Structure

Page 1 of 5

Version 1.0 2/17/2017



Version 1.0 2/17/2017



CROSS-SECTION A-A'

IOWA DEPARTMENT OF
NATURAL RESOURCES

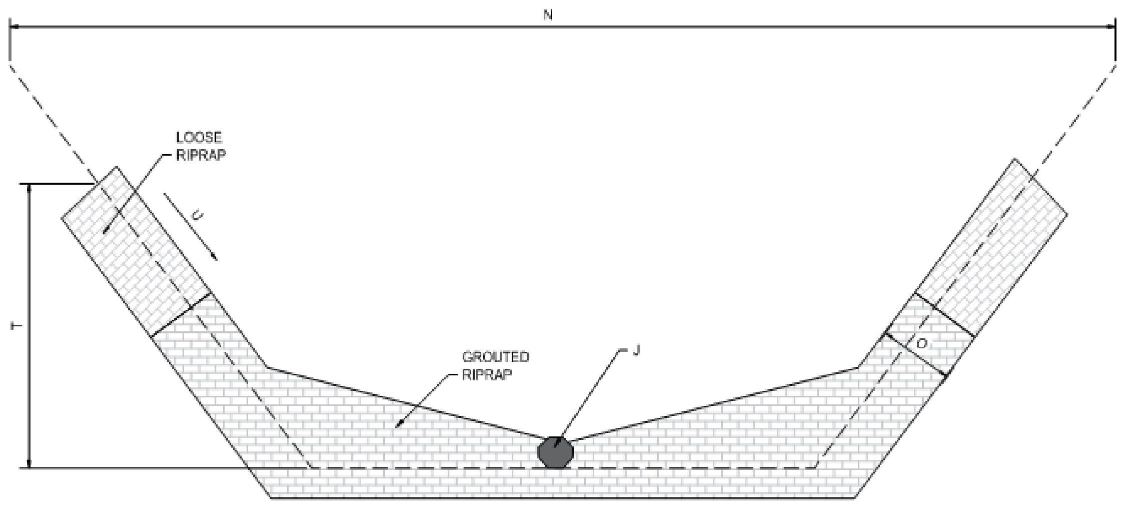
River Restoration Toolbox

Grade Control Practices

Grouted Grade Control Structure

Page 3 of 5

Version 1.0 2/17/2017



CROSS–SECTION B–B'

IOWA DEPARTMENT OF NATURAL RESOURCES

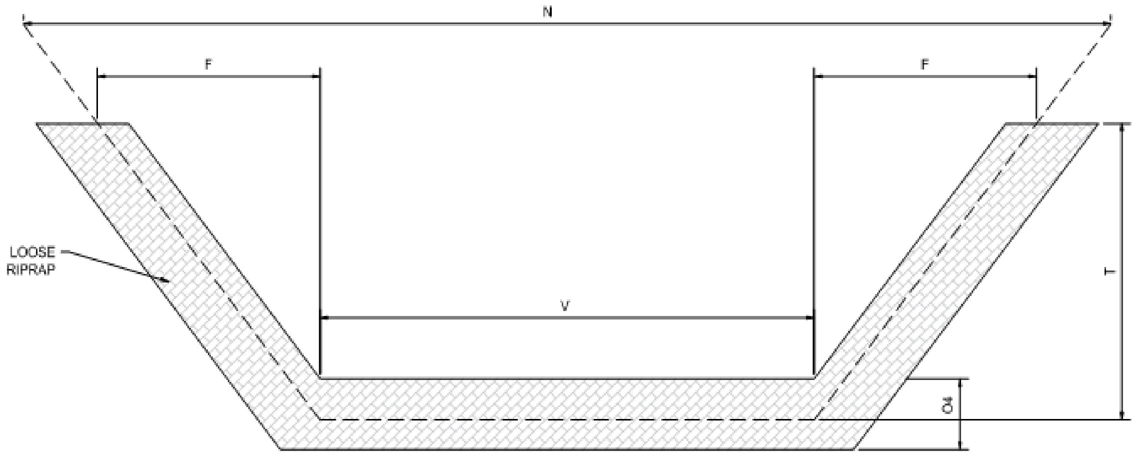
River Restoration Toolbox

Grade Control Practices

Grouted Grade Control Structure

Page 4 of 5

Version 1.0 2/17/2017



CROSS–SECTION D–D'

IOWA DEPARTMENT OF NATURAL RESOURCES

River Restoration Toolbox

Grade Control Practices

Grouted Grade Control Structure

Page 5 of 5

Version 1.0 2/17/2017

2.7.4 Specifications

In addition to general information presented in Section 1.0 Introduction, the following information should be developed into specifications to accompany the use of grouted grade control structures:

- Materials:
  - Boulders – Resistant caprock, quartzite, or manufactured concrete rocks greater than 24 inches in diameter.
  - Stabilization Stone – Smaller rock, typically Class E riprap
  - Grout – rough grout with high slump, not smoothed
  - Sheetpile
  - Filter fabric (optional) – Filter fabric shall be a non-woven geotextile that allows for filtration during stabilization and separation of materials.
- Equipment – The designer should specify that grouted grade control structures be constructed using an excavator with hydraulic thumb. Drop hammers or other vibratory equipment may be used to install sheet pile, but this can be done with the excavator bucket, as well.
- Sequence –
  - Drive sheetpile at the head of the structure to specified elevations.
  - Excavate trench in stream bed to a depth equal to the total thickness of the grouted grade control structure material. Excavate stilling basin.
  - Install filter fabric, if specified by the design.
  - Place riprap along the weir slope at the thickness specified in the design.
  - Install grout along the weir slope, and cut a v-notch down the center of the weir
  - Install boulders alternating back and forth on either side of the v-notch approximate 6-8 feet apart with 25% of each rock overlapping the weir centerline. Fit boulders into the surrounding smaller rock and extending approximately halfway above the adjoining rock. Grout in place.
  - Install loose bank and bed stabilization stone as specified in the design.

- Workmanship – The finished surface of the grouted grade control structure should be naturalistic and in accordance with the lines, grades, cross sections, and elevations of the design. No loose ends of filter fabric should be visible.

- Measurement – A construction precision (tolerance) of 0.1 foot should be specified.

2.7.5 Photographs

Photo 27. Headcut moving upstream in southwest Iowa. Source: Hungry Canyons Alliance.

Photo 28. Grouted Grade Control Structure. Source: Hungry Canyons Alliance.

Photo 29. Grouted Grade Control Structure. Source: Hungry Canyons Alliance.

Photo 30. Sheetpile being driven for Grouted Grade Control Structure. Source: Hungry Canyons Alliance.

Photo 31. Grouted Grade Control Structure. Source: Hungry Canyons Alliance

3.0 REFERENCES

Aadland, 2010. Reconnecting Rivers: Natural Channel Design in Dam Removal and Fish Passage, First Edition. Minnesota Department of Natural Resources.

Chin, et al., 2008. Linking Theory and Practice for Restoration of Step-Pool Streams. Environmental Management. Vol. 43, Issue 4.

Doll, et al., 2003. NC Stream Restoration Institute and North Carolina Sea Grant. Stream Restoration: A Natural Channel Design Handbook. NC State University.

Harman, W. and R. Starr, 2011. Natural Channel Design Review Checklist. US Fish and Wildlife Service, Chesapeake Bay Field Office, Annapolis, MD.

Johnson, et al., 2002. Stream Restoration in the Vicinity of Bridges. Journal of the American Water Resources Association. Vol. 38, No. 1, February 2002.

Newbury, R., 2008. Designing Pool and Riffle Streams: Lectures and Exercises. River Restoration Short Course 2008. Canadian Rivers Institute and Newbury Hydraulics.

Newbury, R. and Gaboury, M., 1993. Stream Analysis and Fish Habitat Design: A Field Manual. Newbury Hydraulics, Ltd. Second Printing. Gibsons, BC.

Raabe, J, 2014. Evaluation of Fish Passage Following Installation of a Rock Arch Rapids at Lock and Dam #1, Cape Fear River, North Carolina (June 9, 2014). International Conference on Engineering and Ecohydrology for Fish Passage.

Rosgen, 2006. The Cross-Vane, W-Weir, and J-Hook Vane Structures: Their Description, Design, and Application for Stream Stabilization and River Restoration. Wildland Hydrology, Pagosa Springs, CO.

Thomas, et al., 2011. Effects of Grade Control Structures on Fish Passage, Biological Assemblages and Hydraulic Environments in Western Iowa Streams: A Multidisciplinary Review.