

Appendix F—Channel Grade Control Structures

This appendix briefly describes permanent **grade control** structures that are sometimes needed in the upstream and/or downstream **reaches** adjacent to a stream-simulation culvert. Their purpose is to control channel slope and elevation, and they are often used to raise the elevation of a channel that has incised downstream of a culvert. The objective is to avoid steepening the stream-simulation channel inside the culvert, and to allow the design slope to match an available **reference reach** (section 5.5). In some cases, grade-stabilization structures designed to adjust gradually in response to high flows are also used upstream of stream-simulation culverts to moderate the rate of erosion of a large wedge of sediment accumulated above an undersized culvert. Some grade control structures also can be shaped to improve **bankfull** flow alignment with the culvert inlet.

How well these structures provide passage for all aquatic organisms depends on how well they mimic structures found in the natural channel. The more rigid a control structure, and the more uniform in cross section and hydraulic characteristics, the less certain the provision of passage for aquatic organisms. The key to providing as unrestricted a passage as possible is to design the structure for maximum variety of passage opportunities (water depth, velocity, substrate). Determining with certainty how well specific aquatic organisms can pass grade-control structures may necessitate biological monitoring.

The information in this appendix is general and not adequate for design purposes. For details on design considerations, applications, and limitations, consult other references, such as the U.S. Department of Agriculture, Natural Resource Conservation Service (2001); Rosgen (2006); and Salde-Caromile et al. (2004).

The three most common types of artificial grade control structures are boulder weirs, roughened channels, and rigid weirs.

Boulder Weirs

Boulder and log weirs can be designed to imitate natural steps (figure F.1). These weirs are appropriate grade controls in step-pool channels, and channels with forcing features such as large rock and **woody debris**. In other channels, the degree to which the weirs permit passage of aquatic organisms will vary.

Stream Simulation



Figure F.1—Natural boulder step on a tributary to the Entiat River, Willamette National Forest, Washington.

Low weirs have been built for many years for backwatering perched culverts and low dams, and for controlling grade. Though many of those structures have deteriorated and disappeared over time, they can be durable and effective if well designed and constructed. Their success largely depends on the size and quality of material, the care and skill of the equipment operator, the supervision of construction, and the equipment used to place the rocks.

To create a long-lasting boulder weir, use durable rock shaped so that individual rocks can be keyed together. As somewhat angular boulders are much more stable than round ones, individually select specific rocks to fit together. A common guideline is to use rock twice the size of the largest mobile particles in the channel. The U. S. Department of Agriculture, Natural Resources Conservation Service 2001 suggests that D_{50} of weir rock be equal to what is calculated as stable riprap, and that D_{max} be twice that size. Keep in mind that scour depth is also a factor. For a 1-foot drop, place rocks on footer rocks embedded from 2.5 feet to 3.5 feet in gravel and sand beds, respectively. Boulders also can be sized conservatively using a stability analysis procedure published by Fischenich and Seal (2000) for individual boulders rolling or sliding on the streambed. Rosgen (2006) and Thomas et al. (2000) provide empirical methods for sizing rocks used for weirs and steps.

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Drop structures concentrate energy as water plunges over the crest, and turbulence and bed scour dissipate the energy. Bed scour can undermine the structure, and bank erosion can cut around the ends. Outflanking is one of the most common modes of failure. Designing the structures with a V-shape in both plan view and cross-section view helps prevent these types of failure.

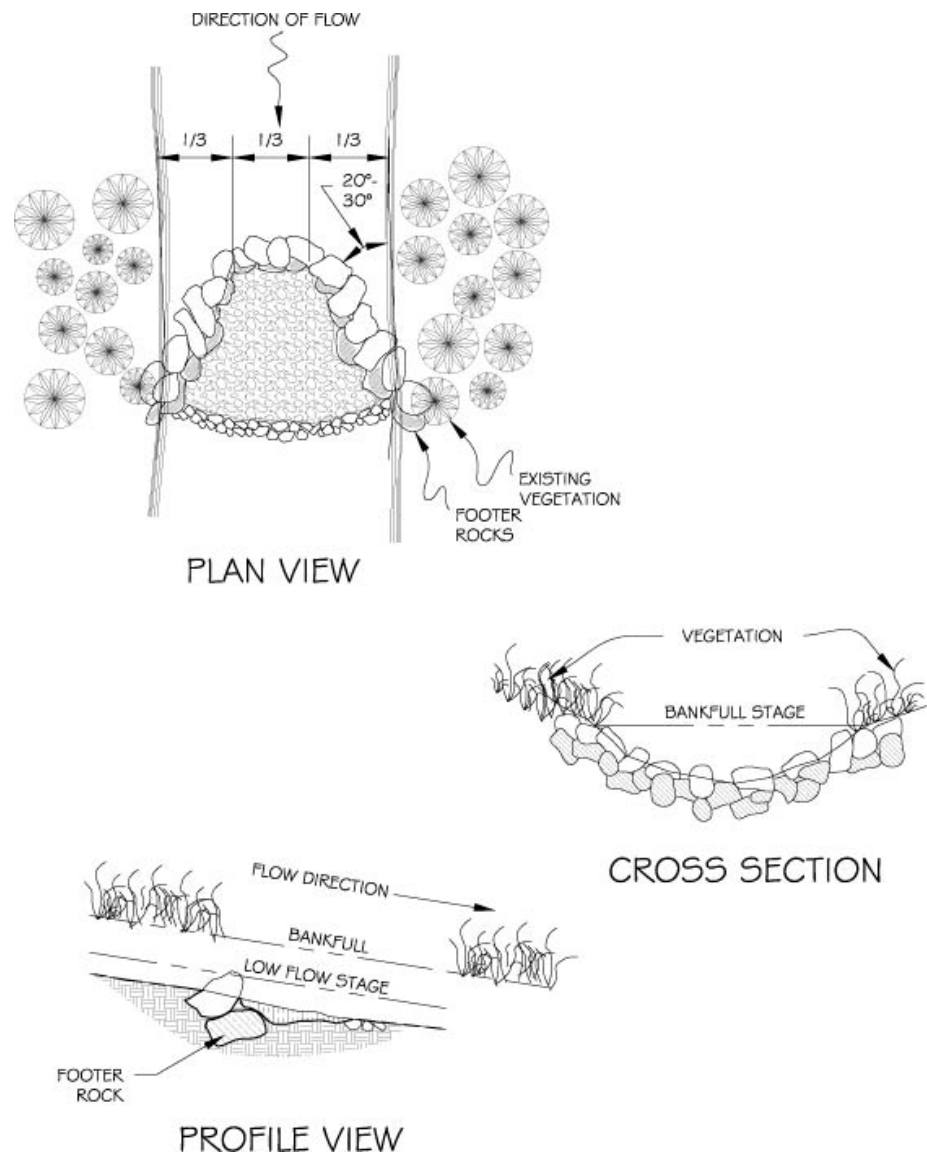


Figure F.2—Typical plan, cross section, and profile views of a rock weir, taken from a stream-simulation contract in Alaska.

Stream Simulation

This V-shaped configuration in both plan and elevation views concentrates the spill towards the center of the channel as flow is directed perpendicular to each leg of the structure. This hydraulic condition tends to concentrate scour away from streambanks and can help maintain a natural and more complex channel cross section. The scour hole will be longer and the structures may therefore have to be placed further apart than if they are straight and horizontal. This concept applies to any style of drop structure. Variations on this shape can help guide flow around channel bends.

In plan view, the weir is shaped like an arch or a convex-upstream V, so that adjacent rocks support each other. Carefully place individual rocks with equipment that allows the rock to be rotated for precise alignment and fitting. Place footer rocks below the elevation of the final grade, to support a second row of rocks. Then place the top row of rocks against the footer boulders and slightly upstream of them, so that they are supported with multiple points of contact. Footer rocks should be placed so that they prevent the formation of a scour pool the top rock could roll into. However, they should not be so far in front or so high as to act as a splash pad that could prevent fish passage. When the arch is complete, each boulder bears against its downstream neighbor and—ideally—against the two footer rocks below it. The force of the streamflow and bedload will then transfer through the weir to the footer rocks and banks. Fitting the rocks together in this way often requires moving rocks several times.

In cross section, the weir crest should slope down toward the apex, approximating the intended cross section of the channel. To avoid outflanking, key boulders at the ends of the weir well back into the banks to at least bankfull elevation and backfill them securely. Place well-graded seal material with some fines on the upstream side of the control, to limit permeability and leakage. Bed material that accumulates on the upstream face of the weir provides much of the structural integrity and sealing of boulder weirs. Without continued **recruitment** of sediment for maintaining the weirs, they will become more porous, eventually leaking and becoming vulnerable to failure.

Boulder weirs carry the risk of domino failure. If one weir in a series fails, the risk of other failures increases, because the added head differential increases the plunging flow, scour, and hydrostatic forces on the next weir upstream. See Salde-Caromile (2004) for a fuller description of rock weirs and other drop structures, and Rosgen (2006) for a discussion of boulder weir styles and failure modes.

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Roughened channels Oversteepened channel segments have traditionally been designed as roughened channels, in which high bed-**roughness** limits water velocity to allow the passage of a target fish, and bed material is sized to be immobile at the design flow (see also appendix B). More recently, artificial pool-riffle, step-pool, and cascade reaches have been constructed for maintaining grades steeper than the reference reach or the project stream, but in a more naturalistic manner (figure F.3). We refer to these as “hybrid” designs because, while they are basically hydraulic designs, they also incorporate elements of natural channel design. See appendix B for a discussion of hybrid design.

Where a hybrid or roughened channel segment plays the role of grade control downstream of a stream-simulation culvert, design both control and culvert conservatively. If the control incises at all, the stream-simulation channel will also be at risk of incision. To minimize the risk, countersink the culvert deeper than normal.



*Figure F.3—Rock riffle used to **backwater** the outlet of a box culvert on Dickson Brook, Bay of Fundy, New Brunswick, Canada. Photo courtesy of Dr. Robert Newbury, Newbury Hydraulics, Okanagan Centre, British Columbia, Canada.*

Stream Simulation

Rigid Weirs

Rigid weirs are fixed, nondeformable structures used for precisely controlling the channel profile. They can be built out of logs, sheet piling, or concrete. One benefit of rigid weirs is that they can often be built at a steeper grade than other structures, thus minimizing the footprint of a project. Slopes steeper than about 5 percent require additional structure (floors and walls) to protect bed and banks.

Log sills (log weirs) span the entire channel and create a series of small drops, raising the downstream-water surface to the elevation of a culvert. Log sills are a low-cost, durable means of fish passable grade control for streams with moderate gradients and channel toe widths of less than about 30 feet. Although they are typically used downstream of a culvert, they may also be used upstream. Log sills include a variety of designs, including single logs, multiple stacked logs, straight weirs, angled weirs, and V-weirs. Any level sill should have a low-flow notch cut into it.

Simple, straight, double-log sills are the most secure. These require the least overall channel length and are the least costly of the styles. Other styles, such as sills that dip toward the middle of the channel or angle downstream, tend to create more channel and hydraulic complexity. Because of the recommended maximum slope for rigid weirs (5 percent), steepening a channel with a natural slope already greater than about 3 percent is difficult. In small channels, planks can be used instead of logs.

Precast concrete or steel sheet-pile weirs are other options for rigid controls. Their advantages are that they can be manufactured precisely, resulting in a good seal, with a varied cross section similar to the natural channel, and a crest shape specifically designed for fish passage. You can custom-design their installation to fit the needs of the site; for example, a single precast concrete unit could include a weir, a stilling basin, wing walls, and a head wall. Steel-pile weirs can be solid sheet-piles or H-piles with wood or precast concrete lagging between them. Concrete highway median barriers and “ecology blocks” are not recommended for use in grade-control structures; they commonly fail when used as weirs unless they are anchored for stability, modified to provide a sharp crest and a deep plunge pool, and sealed permanently to prevent leakage.

Straight, level, rigid weirs can have negative impacts on channels. They tend to create channels that are trapezoidal and very uniform in cross section. Even though full channel-spanning level structures may look like natural embedded wood structures, they lack the variety of passageways found in most complex natural structures. Poorly designed structures commonly fail by scouring either under or around the end of the structure. Rigid structures are more likely than adjustable rock structures to become barriers to fish passage when downstream scour occurs.