Stream Simulation

Appendix B—Other Culvert Design Methods for Fish Passage

Several methods exist for designing culverts for fish passage. Different methods produce different levels of passability for various aquatic species. This appendix briefly describes common design methods other than stream simulation. The method descriptions are only intended to put stream simulation in the context of the other methods. They do not include enough detail for design.

B.1 HYDRAULIC DESIGN METHOD

Hydraulic design has been used for decades as the primary (if not the only) design method for fish passage culverts at road crossings. It has been included in design manuals and applied on roads in many countries, and Bates (2003) provides a detailed description of it. Still used as a primary design concept in many locations, hydraulic design also is used for retrofitting impassable culverts to improve their passability.

The goal of hydraulic design is creating water depths and velocities suited to the swimming ability of a target fish at the range of flows when the fish moves in the natural channel. To accomplish this, the design process simultaneously considers the hydraulic effects of culvert size, slope, material, and length. The resulting culvert size is usually narrower than the stream channel **bankfull** width.

Maximum average velocity and turbulence in the culvert cross-section are basic design criteria in the hydraulic method. Increasing hydraulic **roughness**—by adding baffles or by embedding the pipe—increases resistance to flow and is one way to reduce water velocity. Theoretically, increasing turbulence can always reduce the calculated velocity in a steep channel to a level that is passable by specific species. However, if the flow becomes too turbulent, the velocity barrier has simply been converted to a turbulence barrier. Turbulence can be quantified as the energy dissipation per unit volume of water, referred to as the energy dissipation factor (EDF). Bates (2003) suggests limitations of EDF appropriate to the passage of adult salmon. However, we have little data on the subject, and no EDF limits have been suggested for other species or life stages.

Another problem with hydraulic design is the paucity of biological information available for a prudent design. We know little about movement timing and capabilities of many species of fish and other organisms that migrate through the **stream corridor**. Species—and even different life stages within species—move at different times of the year, during different flow conditions. The variability in movement timing and swimming

capabilities means that designing culverts to meet specific depth, velocity, and turbulence requirements for multiple species during all flow conditions is impractical. (Refer to chapter 1, section 1.2.3 for a discussion of problems related to using existing biological data for hydraulic design.)

The hydraulic design method targets distinct species of fish without necessarily accounting for the requirements of nontarget species. Different species use the variety of habitats in a stream channel for movement. As chapter 1 notes, many weak-swimming or crawling species use the slow water at bank edges and along the stream bottom itself. Specific detailed information about the hydraulics in these boundary layers would be necessary to account for those areas in a design. The hydraulic option also does not deal with the ecological and habitat issues at road crossings discussed in chapter 1, sections 1.1.3 and 1.3.1.

B.2 HYBRID DESIGN AND ROUGHENED-CHANNEL DESIGN

Hybrid design and roughened-channel design are styles of hydraulic design that create a nonadjustable streambed inside of a culvert to pass at least some aquatic species. The channel usually resembles the general shape of a natural channel although it may be quite different from the channel in which it is constructed. These design methods are useful when stream simulation is not feasible. Their purpose may be to provide:

- A crossing structure steeper than the natural channel slope (as in an **incised channel**).
- A streambed that will be stable in the absence of bed material supply from upstream (as below a lake).
- A stable streambed where no **reference reach** can be located (as in an unstable channel).

A roughened channel is a well-graded mix of rock and sediment with enough roughness to sustain the required gradient and enough hydraulic diversity to provide passage for some fish. The design method is hydraulic, combining channel dimensions, slope, and bed material to create the water depths, velocities, and low-turbulence conditions that a target species can negotiate. Ideally, a channel is roughened to the point where the potential energy available at the upstream end of a reach is consistently dissipated in

turbulence through the reach and no excess kinetic energy is present within the reach or at the downstream end. The velocity-simulation method (B.3) is similar, except that velocity simulation takes its velocity criteria from the natural channel rather than from published swim-performance values for a target species.

To improve fish passage, roughened channels can be designed to have **banklines**, shallow water margins, and other diversity. Nonetheless, a roughened channel is essentially a hydraulic design. The bed material is not intended to evolve as a natural channel with bed material being scoured and replenished; instead, it is a fixed, semirigid structure. Although individual rocks are expected to adjust position, the larger grain sizes are designed for permanence. Because culverts with roughened channels often are steeper and more confined than the natural upstream channel, **recruitment** of the larger rock in the bed from upstream is not expected. In other words, if large material is scoured, it will not be replaced, and the entire channel will therefore degrade.

If excess infiltration into the roughened channel bed and loss of low surface flow are to be prevented, bed porosity must be controlled. Smaller grains that control the porosity in the roughened channel may gradually be washed out of the bed. If material transported from the natural channel is too small to be trapped in the voids of the roughened channel bed, the bed will become porous.

A hybrid is a roughened channel designed to be similar in shape and **bed structure** (but not bed mobility) to the channel type that would naturally occur at the required culvert slope (see slope ranges for different channel types in table A.2). For example, if a culvert has to maintain a slope of 6 percent in a 3-percent reach, the culvert streambed could be designed as a step-pool channel even if the natural channel is a pool-riffle type. The steps—the structural elements of the bed—would be designed to be stable at all flows, because sediment from upstream is not expected to replenish the larger bed particles if they are eroded away. The culvert streambed will be enriched by smaller sediments moving across the top of the larger material and depositing temporarily. Because a hybrid has hydraulic microenvironments more similar to those of a natural channel, we expect it to pass more species and life-stages than a roughened channel or other hydraulic design.

For the hybrid design, bed structure might be based on a reference reach of the appropriate channel type and slope, if one exists in the area. If not, the streambed could be designed using stable channel design methods such as those described in USDA-NRCS (2001). Examples of hybrid-type designs in open channels are in Castro (2003), who describes artificial step-pool and cascade reaches, and Newbury (1993). (For more examples and design details of various hybrid channels currently used in Europe and elsewhere, see FAO/DVWK 2002.)

B.3 VELOCITY SIMULATION

Browning (1990) described a hydraulic design method that uses the natural channel for determining permissible velocities in the culvert. In this method, velocities in the culvert are allowed to be 25-percent greater than those calculated for the natural channel during a 2-year flood event. Browning also recommends equalizing velocities for a range of flows. There are no specific limitations on culvert slope, width, or length, and depending on how the method is applied, there may or may not be a limitation on the structures or features used within the culvert for controlling the velocity. Similar to the hydraulic method, baffles or permanent rock can be used for controlling velocity, with no consideration of the effects of resulting turbulence on fish passage. Performance of the method will likely vary depending on the capability of the culvert to hold bed material, the occurrence of floods that may scour the bed out, and the supply of bed material load in the stream.

B.4 “NO-SLOPE” DESIGN

The Washington Department of Fish and Wildlife (Bates 2003) developed “no-slope” design as a regulatory option to simplify fish passage design and permitting for private landowners with short crossings under driveways. The no-slope option requires few technical calculations and results in reasonable culvert sizes.

According to the no-slope design method, the bed within the culvert must be at least as wide as the channel bankfull width. Current thinking is that width should be somewhat greater. The culvert is level, and the downstream invert is countersunk below the channel bed by a minimum of 20 percent of the culvert diameter or rise. The upstream invert is countersunk by a maximum of 40 percent of the culvert diameter or rise.

These countersinking requirements limit (a) the channel slope on which you can install this kind of a culvert and/or (b) the length of any culvert that may be designed with this concept. Variations of the method might simply limit the slope and length, allowing the culvert to be sloped. A culvert designed by this method must also be checked for adequate flood capacity.

The published description of this method (Bates 2003) does not suggest installing a bed, nor does it consider bed stability. However, before countersinking a bare culvert into a channel, the designer should consider the potential effects on the channel. Replacing a barrier culvert with a larger embedded culvert can create a headcut. Without an understanding of the effects of such a headcut, the replacement could pose a substantial risk to channel stability (see section 5.3.3).