Massachusetts River and Stream Crossing Standards

Developed by the

River and Stream Continuity Partnership

Including:

University of Massachusetts Amherst
MA Riverways Program
The Nature Conservancy

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INTRODUCTION

Movement of fish and wildlife through river and stream corridors is critical to the survival of individual organisms and the persistence of populations. However, as long and linear ecosystems, rivers and streams are particularly vulnerable to fragmentation. In addition to natural barriers, a number of human activities can, to varying degrees, disrupt the continuity of river and stream ecosystems. The most familiar human-caused barriers are dams. However, there is growing concern about the role of river and stream crossings, and especially culverts, in disrupting river and stream continuity.

Road networks and river systems share several things in common. Both are long, linear features of the landscape. Transporting materials (and organisms) is fundamental to how they both function. Connectivity is key to the continued functioning of both systems. Ultimately, our goal should be to create a transportation network that does not fragment or undermine the essential ecological infrastructure of the land and its waterways.

With funding from the Sweetwater Trust, the Massachusetts Watershed Initiative, and the Massachusetts Riverways Program, the University of Massachusetts–Amherst coordinated an effort to create river and stream crossing standards and a volunteer inventory program for culverts and other crossing structures to more effectively identify and address barriers to fish movement and river and stream continuity. Information was compiled about fish and wildlife passage requirements, culvert design standards, and methodologies for evaluating barriers to fish and wildlife passage.[1] This information was used to develop performance standards for culverts and other stream crossing structures.

[1] In developing the Standards the Partnership benefited greatly from work that has been done and materials developed over the years in Washington State, Oregon, California, and Maine, and by the US Forest Service.

The following standards were developed by the River and Stream Continuity Partnership with input from an Advisory Committee that includes representatives from UMass-Amherst, MA Riverways Program, Massachusetts Watershed Initiative, Trout Unlimited, The Nature Conservancy, the Westfield River Watershed Association, ENSR International, Massachusetts Highway Department (MassHighway), and the Massachusetts Departments of Environmental Protection and Conservation and Recreation. In developing the standards, the Partnership received advice from a Technical Advisory Committee that included representatives of the U.S. Fish and Wildlife Service, USGS BRD, U.S. EPA, U.S. Army Corps of Engineers, MA Division of Fisheries and Wildlife, American Rivers, Connecticut River Watershed Council, Connecticut DEP, a hydraulic engineering consultant, as well as input from people with expertise in Stream Simulation approaches to crossing design[2]. The standards are recommended for new permanent crossings (highways, railways, roads, driveways, bike paths, etc.) and, when possible, for replacing existing permanent crossings.

These standards seek to achieve, to varying degrees, three goals:

1. Fish and other Aquatic Organism Passage: Facilitate movement for fish and other aquatic organisms, including relatively small, resident fish, aquatic amphibians & reptiles, and large invertebrates (e.g. crayfish, mussels).

2. River/Stream Continuity: Maintain continuity of the aquatic and benthic elements of river and stream ecosystems, generally through maintenance of appropriate substrates and hydraulic characteristics (water depths, turbulence, velocities, and flow patterns). Maintenance of river and stream continuity is the most practical strategy for facilitating movement of small, benthic organisms as well as larger, but weak-swimming species such as salamanders and crayfish.

3. Wildlife Passage: Facilitate movement of wildlife species including those primarily associated with river and stream ecosystems and others that may utilize riparian areas as movement corridors. Some species of wildlife such as muskrats and stream salamanders may benefit from river and stream continuity. Other species may require more open structures as well as dry passage along the banks or within the streambed at low flow.

There are a few approaches available for designing river and stream crossings. These Crossing Standards are most consistent with a "Stream Simulation" approach for crossing design. Given the large number of species that make up river and stream communities and the almost complete lack of information about swimming abilities and passage requirements for most organisms, it is impractical to use a species-based approach for designing road crossings. The Stream Simulation approach is the most practical way to maintain viable populations of organisms that make up aquatic communities and maintain the fundamental integrity of river and stream ecosystems. Stream Simulation is an ecosystem-based approach that focuses on maintaining the variety and quality of habitats, the connectivity of river and stream ecosystems, and the essential ecological processes that shape and maintain these ecosystems over time.

Stream Simulation is a design approach that avoids flow constriction during normal conditions and creates a stream channel that maintains the diversity and complexity of the streambed through the

[2] Special thanks go to Ken Kozmo Bates and Kim Johansen for their review and useful comments on previous drafts of the Crossing Standards.

crossing. Crossing structures that avoid channel constriction and maintain appropriate channel conditions (channel dimensions, banks, bed, and bed forms) within the structure should be able to accommodate most of the normal movements of aquatic organisms, and preserve (or restore) many ecosystem processes that maintain habitats and aquatic animal populations. The goal is to create crossings that are essentially “invisible” to aquatic organisms by making them no more of an obstacle to movement than the natural channel.

These standards are for general use to address issues of river and stream continuity, fish passage and wildlife movement. In some cases, site constraints may make strict adherence to the standards impractical or undesirable. For example, in some situations the road layout and surrounding landscape may make it impossible or impractical to achieve the recommended standards for height and openness. These standards may not be appropriate for highly degraded streams where stream instability may be a serious concern. Site-specific information and good professional judgment should always be used to develop crossing designs that are both practical and effective.

Here are some important considerations to keep in mind when using these standards.

1. They are intended for permanent river and stream crossings. They are not intended for temporary crossings such as skid roads and temporary logging roads.
2. They are generally intended for fish-bearing streams. These standards are not recommended for those portions of intermittent streams that are not used by fish. However, these standards may be useful in areas where fish are not present but where protection of salamanders or other local wildlife is desired. Further, the standards are not intended for constructed drainage systems designed primarily for the conveyance of storm water.
3. These standards were developed with the objective of facilitating fish and wildlife movement and the preservation or restoration of river/stream continuity. They may not be sufficient to address drainage or flood control issues that must also be considered during design and permitting of permanent stream crossings.
4. These standards are not prescriptive. They are intended as conceptual performance standards for river and stream crossings. They establish minimum criteria that are generally necessary to facilitate fish and wildlife movement and maintain river/stream continuity. Use of these standards alone will not satisfy the need for proper engineering and design. In particular, appropriate engineering is required to ensure that structures are sized and designed to provide adequate capacity (to pass various flood flows) and stability (bed, bed forms, footings and abutments).
5. The design of any structure must consider the channel type and long profile and must account for likely variability of the stream or river for the life of the structure. A “long profile” is a surveyed longitudinal profile along the thalweg (deepest portion of the channel) of the stream extending well upstream and downstream of the crossing.
6. In urbanizing environments there is greater potential for land use changes to result in stream instability. Wherever there is potential for stream instability it is important to evaluate stream adjustment potential at the crossing location and to factor this into the design of the structure. (This is true of all crossing structures whether or not they are designed to these standards.)

DESIGN STANDARDS FOR NEW CROSSINGS

These standards are for new structures at sites where no previous crossing structure existed. Culvert replacements are addressed in the following section "Standards for Culvert Replacement."

There are two levels of standards (General and Optimum) to balance the cost and logistics of crossing design with the degree of river/stream continuity warranted in areas of different environmental significance.

General Standards:

Goal**:** Fish passage, river/stream continuity, some wildlife passage

Application

Where permanent stream crossings are planned on fish bearing streams or rivers, they should at least meet general standards to pass most fish species, maintain river/stream continuity, and facilitate passage for some wildlife.

> <u>Fish bearing streams or rivers</u> include rivers and streams that support one or more species of fish[3], including those portions of intermittent streams that are used seasonally by fish. These standards are also warranted where fish are not present, but where protection of salamanders or other local wildlife species is desired.

General standards call for open bottom structures or culverts that span the river/stream channel with natural bottom substrates that generally match upstream and downstream substrates. Stream depth and velocities in the crossing structure during low-flow conditions should approximate those in the natural river/stream channel. An openness ratio of 0.25 meters will pass some wildlife species but is unlikely to pass all the wildlife that would be accommodated by the optimum standards.

Standards

1. *<u>Bridges are generally preferred, but well designed culverts and open-bottom arches may be appropriate</u>*

   Site constraints may make the use of bridge spans impractical and in some cases well-designed culverts may actually perform better than bridges (areas with deep soft substrate). However, in areas where site constraints don't limit the usefulness of these structures, bridges are preferred over culverts.

[3] These standards would also be appropriate for a portion of a stream where fish were historically present but were lost as a result of migratory barriers when there is a reasonable expectation that fish could be restored to that stream section.

2. *If a culvert, then it should be embedded:*
   - *≥ 2 feet for box culverts and other culverts with smooth internal walls,*
   - *≥ 1 foot for corrugated pipe arches*
   - *≥ 1 foot and at least 25 percent for corrugated round pipe culverts*

   These minimum embedment depths should be sufficient for many culverts. However, circumstances may dictate a need for deeper substrates that are based on site specific analysis. These include high gradient streams and streams experiencing instability or with potential instability that could result in future adjustments to channel elevation. In these cases long profiles and calculations of potential channel adjustments should be used to determine embedment depth.

   The intent of this standard is to provide for:

   - Sufficient depth of material within the culvert to achieve stability of the culvert bed material comparable to that of the upstream and downstream channel;
   - Sufficient depth of material to permit shaping of material to achieve natural depths of flow at low-flow conditions; and
   - Sufficient embedment to account for long-term vertical channel adjustment anticipated for the adjacent stream bed.

   In some cases site constraints may limit the degree to which a culvert can be embedded. In these cases pipe culverts should not be used and pipe arches, open-bottom arches, or bridges should be considered instead.

   Use scour analyses to determine footing depths for open-bottom arches, open-bottom boxes and bridges.

3. *Spans channel width (a minimum of 1.2 times the bankfull width)*

   It is critical to avoid channel constriction during normal bankfull flows. A width of 1.2 times bankfull width is the minimum width needed to meet these standards. Bankfull width should be determined as the average of at least three typical widths, ideally measured at the proposed structure's location, and then upstream and downstream of the proposed structure (except where stream sections are not representative of conditions where the structure will be located). The stream width should be measured at straight sections of the channel outside the influence of existing structures and unusual channel characteristics. The structure should not be narrower than the bankfull width at the crossing location.

   In constricted channels 1.2 times bankfull may also be adequate for passing large, infrequent storm events and maintaining stability of both the structure and channel. However, this should be verified through standard engineering practices and calculations.

   For streams within floodplains, a clear span of 1.2 times bankfull may not be sufficient to ensure adequate water conveyance for large, infrequent flood events without destabilizing the stream channel. In these cases, wider structures or alternative means of conveying flood waters may be necessary. It is critically important that structure design on these streams be based on sound engineering.

4. *Natural bottom substrate within the structure*

   Careful attention must be paid to the composition of the substrate within the culvert. The substrate within the structure should match the characteristics of the substrate in the natural stream channel (mobility, slope, stability, confinement) at the time of construction and over time as the structure has had the opportunity to pass significant flood events.

   The substrate should resist displacement during flood events and be designed to maintain appropriate channel characteristics through natural bed load transport. Sometimes in order to ensure bed stability (stability is not the same as rigidity) at higher than bankfull flows it may be necessary to use larger substrate within the structure than is generally found in the natural stream channel. In these cases the substrate should approximate the natural stream channel and fall within the range of variability seen in the natural channel upstream and downstream of the crossing.

5. *Designed with appropriate bed forms and streambed characteristics so that water depths and velocities are comparable to those found in the natural channel at a variety of flows*

   In order to provide appropriate water depths and velocities at a variety of flows and especially low flows it is usually necessary to reconstruct the streambed or preserve the natural channel within the structure. Otherwise, the width of the structure needed to accommodate higher flows will create conditions that are too shallow at low flows. When constructing the streambed special attention should be paid to the sizing and arrangement of materials within the structure. If only large material is used, without smaller material filling the voids, there is a risk that flows could go subsurface within the structure.

6. *Openness ratio > 0.25 meters*

   Openness ratio is the cross-sectional area of a structure opening (in square meters) divided by its crossing length when measured in meters. For a box culvert, openness = (height x width)/ length. For crossing structures with multiple cells or barrels, openness ratio is calculated separately for each cell or barrel. At least one cell or barrel should meet the appropriate openness ratio standard. Embedded portions of culverts are not included in the calculation of cross-sectional area for determining openness ratio.[4]

Optimum Standards

***Goal*: Fish passage, river/stream continuity, wildlife passage**

Application

Where permanent stream crossings occur or are planned in areas of particular statewide or regional significance for their contribution to landscape level connectedness or river/stream ecosystems that provide important aquatic habitat for rare or endangered species, optimum standards should be applied in order to maintain river/stream continuity and facilitate passage for fish and wildlife.

[4] An Embedded Area Spreadsheet developed by the U.S. Army Corps of Engineers shows how to calculate the open area for embedded pipe culverts to meet the 0.25 standard for openness ratio. The spreadsheet can be downloaded from the Online Documents section of www.streamcontinuity.org.

Areas of particular statewide or regional significance for their contribution to landscape level connectedness include, but are not limited to, rivers/streams and associated riparian areas that serve as corridors or connecting habitat linking areas of significant habitat (>250 acres) in three or more towns.

Important aquatic habitat for rare or endangered species includes, but is not limited to, those river and stream segments identified by the Natural Heritage and Endangered Species Program (via the Living Waters or Biomap projects or regulatory review) that are considered important for protecting rare or endangered species.

Where permanent stream crossings occur or are planned in areas of high connectivity value – areas of particular statewide or regional significance for their contribution to landscape level connectedness – crossings should be designed to maintain river/stream continuity and facilitate passage for fish and wildlife. The best designs for accomplishing this involve open bottom structures or bridges that not only span the river/stream channel, but also span one or both of the banks allowing dry passage for wildlife that move along the watercourse. Where the crossing involves high traffic volumes or physical barriers to wildlife movement, the crossing structure should be sized to pass most wildlife species (minimum height and openness requirements).

Standards

1. *Use bridge spans*

   Unless there are compelling reasons why a culvert would provide greater environmental benefits only bridges should be used.

2. *Span the streambed and banks*

   The structure span should be at least 1.2 times the bankfull width and provide banks on one or both sides with sufficient headroom to provide dry passage for semi-aquatic and terrestrial wildlife.

   For streams within floodplains 1.2 times bankfull may not be sufficient to ensure adequate water conveyance for large, infrequent flood events without destabilizing the stream channel. In these cases, wider structures or alternative means of conveying flood waters may be necessary. It is critically important that structure design on these streams be based on sound engineering.

   The structure should be designed to allow dry passage (along banks or dry streambed) at least 90% of the year.

3. *Natural bottom substrate within the structure*

   Careful attention must be paid to the composition of the substrate within the culvert. The substrate within the structure should match the characteristics of the substrate in the natural stream channel (mobility, slope, stability, confinement) at the time of construction and over time as the structure has had the opportunity to pass significant flood events.

   The substrate should resist displacement during flood events and be designed to maintain appropriate channel characteristics through natural bed load transport. Sometimes in order to ensure bed stability (stability is not the same as rigidity) at higher than bankfull flows it may be necessary to use larger substrate within the structure than is generally found in the natural stream channel. In these cases the substrate should approximate the natural stream channel and fall within the range of variability seen in the natural channel upstream and downstream of the crossing.

4. *Designed with appropriate bed forms and streambed characteristics so that water depths and velocities are comparable to those found in the natural channel at a variety of flows*

   In order to provide appropriate water depths and velocities at a variety of flows and especially low flows it is usually necessary to reconstruct the streambed or preserve the natural channel within the structure. Otherwise, the width of the structure needed to accommodate higher flows will create conditions that are too shallow at low flows. When constructing the streambed special attention should be paid to the sizing and arrangement of materials within the structure. If only large material is used, without smaller material filling the voids, there is a risk that flows could go subsurface within the structure.

5. *Maintain a minimum height of 6 ft (1.8 meters) and openness ratio of 0.75 meters if conditions are present that significantly inhibit wildlife passage (high traffic volumes, steep embankments, fencing, Jersey barriers or other physical obstructions)*

   Height should be measured from the average invert of the stream bed within the structure to the inside top of the structure.

   Openness ratio is the cross-sectional area of a structure (in square meters) divided by its crossing length when measured in meters. For a box culvert, openness = (height x width)/ length. For crossing structures with multiple cells or barrels, openness ratio is calculated separately for each cell or barrel (do not add together the cross-sectional areas of multiple cells or barrels). At least one cell or barrel should achieve the appropriate openness ratio. The embedded portion of culverts is not included in the calculation of cross-sectional area for determining openness ratio.

6. *If conditions that significantly inhibit wildlife passage are not present, maintain a minimum height of 4 ft. (1.2 meters) and openness ratio of 0.5 meters*

DESIGN STANDARDS FOR CULVERT REPLACEMENT

Given the number of culverts and other crossing structures that have been installed without consideration for ecosystem protection, it is important to assess what impact these crossings are having and what opportunities exist for mitigating those and future impacts. In the short term some barriers can be addresses by culvert retrofits: temporary modifications to improve aquatic organism passage short of replacement. However, culvert replacement and remediation generally offer the best opportunity for restoring continuity and long-term protection of river and stream ecosystems.

Methods have been developed, and are continuing to be refined and adapted, for evaluating culverts and other crossing structures for their impacts on animal passage and other ecosystem processes. Along with these assessments there needs to be a process for prioritizing problem crossings for remediation. The process should take into account habitat quality in the river or stream and surrounding areas, upstream and downstream conditions, as well as the number of other crossings, discontinuities (channelized or piped sections), and barriers affecting the system. It is important to use a watershed-based approach to river and stream restoration in order to maximize positive outcomes and avoid unintended consequences.

Culvert upgrading requires careful planning and is not simply the replacement of a culvert with a larger structure. Even as undersized culverts block the movement of organisms and material, over time, rivers and streams adjust to the hydraulic and hydrological changes caused by these structures. Increasing the size of a crossing structure can destabilize the stream and cause head cutting – the progressive down-cutting of the stream channel – upstream of the crossing. There also may be downstream effects such as increased sedimentation. Crossing replacement can result in the loss or degradation of wetlands that formed above the culvert as a consequence of constricted flow. In more developed watersheds, undersized culverts may play an important role in regulating storm flows and preventing flooding.

Before replacing a culvert or other crossing structure with a larger structure it is essential that the replacement be evaluated for its impacts on:

- downstream flooding,
- upstream and downstream habitat (instream habitat, wetlands),
- potential for erosion and headcutting, and
- stream stability.

In most cases it will be necessary to conduct engineering analyses including long profiles of sufficient length to understand potential changes in channel characteristics. A "long profile" is a surveyed longitudinal profile along the thalweg (deepest portion of the channel) of the stream extending well upstream and downstream of the crossing. The replacement crossing will need to be carefully designed in order to maximize the benefits and minimize the potential for negative consequences resulting from the upgrade. In many instances, some stream restoration will be needed in addition to culvert replacement in order to restore river/stream continuity and facilitate fish and wildlife passage.

Culvert replacements will need to be reviewed and permitted either by either the local conservation commission, the Massachusetts Department of Environmental Protection (§401 Water Quality Certification), the US Army Corp of Engineers, or a combination of the three.

Standards

1. *Whenever possible replacement culverts should meet the design guidelines for either general standards or optimal standards (see Standards for New Crossings above)*
2. *If it is not possible or practical to meet all of the General or Optimal standards, replacement crossings should be designed to:*

    a. *Meet the General Standards for crossing width (1.2 times bankfull width)*

    b. *Meet other General Standards to the extent practical, and*

    c. *Avoid or mitigate the following problems*

        → *Inlet drops*
        → *Outlet drops*
        → *Flow contraction that produces significant turbulence*
        → *Tailwater armoring*
        → *Tailwater scour pools*
        → *Physical barriers to fish passage*

3. *As indicated by long profiles, scour analyses and other methods, design the structure and include appropriate grade controls to ensure that the replacement will not destabilize the river/stream*
4. *To the extent practicable conduct stream restoration as needed to restore river/stream continuity and eliminate barriers to aquatic organism movement*
5. *Avoid High Density Polyethylene Pipes (HDPP) or plastic pipes*

    High Density Polyethylene Pipes, especially smooth bore, or plastic pipes shall not be installed. The inherent hydraulic characteristics (low friction coefficient) of HDPP are not conducive to passing aquatic life.

CONSTRUCTION BEST MANAGEMENT PRACTICES

Construction of road-stream crossings has the potential to generate significant adverse impacts to rivers and streams. Use of appropriate construction methods and best management practices (BMPs) are essential for meeting design standards and avoiding unnecessary impacts to water and habitat quality. Following are a list of BMPs that should be considered.[5]

Road and Crossing Location. Roads should be planned to avoid or minimize the number of road-stream crossings. Where crossings cannot be avoided they should be located in areas that will minimize impacts. Here are some rules of thumb.

- Avoid sensitive areas such as rare species habitat and important habitat features (vertical sandy banks, underwater banks of fine silt or clay, deep pools, fish spawning habitat).
- Avoid unstable or high-hazard locations such as steep slopes, wet or unstable slopes, non-cohesive soils, and bordering vegetated wetlands. Alluvial reaches are poor locations for road-stream crossings.
- Where possible locate crossings on straight channel segments (avoid meanders)
- To the extent possible align crossings perpendicular to the stream channel

Timing of Construction. In general the most favorable time for constructing road-stream crossings is during periods of low flow, generally July 1 to October 1. However, there may be occasions when a particular stream or river supports one or more rare species that would be particularly vulnerable to disturbances during low-flow conditions. Where rare species are a concern, contact the Massachusetts Natural Heritage and Endangered Species Program (NHESP) for information and advice on how to minimize impacts to those species. Such consultations are required for crossings that would affect areas of Priority Habitat identified by NHESP.

Dewatering

- Minimize the extent and duration of the hydrological disruption
- Consider the use of bypass channels to maintain some river and stream continuity during construction
- Use dams to prevent backwatering of construction areas
- Gradually dewater and rewater river and stream segments to avoid abrupt changes in stream flow
- Salvage aquatic organisms (fish, salamanders, crayfish, mussels) stranded during dewatering
- Segregate clean diversion water from sediment-laden runoff or seepage water
- Use anti-seep collars around diversion pipes
- Use upstream sumps to collect groundwater and prevent it from entering the construction site
- Collect construction drainage from groundwater, storms, and leaks and treat to remove sediment
- Use downstream sediment control sump to collect water that seeps out of the construction area

[5] Much of the following information about construction BMPs comes from training materials used as part of the U.S. Forest Service's Aquatic Organism Passage project and that will be included in an upcoming Forest Service publication "Stream Simulation: An Ecological Approach to Road-Stream Crossings."

- Use fish screens around the intake of diversion pipes
- Use appropriate energy dissipaters and erosion control at pipe outlets
- When using diversion pipes make sure adequate pumping capacity is available to handle storm flows

Stormwater Management, Erosion and Sediment Control

- Minimize bare ground
- Minimize impact to riparian vegetation
- Prevent excavated material from running into water bodies and other sensitive areas
- Use appropriate sediment barriers (silt fence, hay bales, mats, Coir logs)
- Dewater prior to excavation
- Manage and treat surface and groundwater encountered during excavation with the following
    - sediment basins
    - fabric, biobag or hay bale corals
    - irrigation sprinklers or drain pipes discharging into vegetated upland areas
    - sand filter
    - geotextile filter bags
- Turbidity of water 100-200 feet downstream of the site should not be visibly greater than turbidity upstream of the project site.

Pollution Control

- Wash equipment prior to bringing to the work area to remove leaked petroleum products and avoid introduction of invasive plants
- To avoid leaks, repair equipment prior to construction
- Be prepared to use petroleum absorbing “diapers” if necessary
- Locate refueling areas and hazardous material containment areas away from streams and other sensitive areas
- Establish appropriate areas for washing concrete mixers; prevent concrete wash water from entering rivers and streams
- Take steps to prevent leakage of stockpiled materials into streams or other sensitive areas (locate away from water bodies and other sensitive areas, provide sediment barriers and traps, cover stockpiles during heavy rains)

Construction of Stream Bed and Banks within Structures

- Check construction surveys to ensure slopes and elevations meet design specifications
- Use appropriately graded material (according to design specifications) that has been properly mixed before placement inside the structure
- Avoid segregation of bed materials
- Compact bed material
- After the stream bed has been constructed wash bed material to ensure that fine materials fill gaps and voids

- Construct an appropriate low-flow channel and thalweg
- Carefully construct bed forms to ensure functionality and stability
- Construct well-graded banks for roughness, passage by small wildlife, and instream bank-edge habitat
- Tie constructed banks into upstream and downstream banks

Soil Stabilization and Re-vegetation

- Surface should be rough to collect seeds and moisture
- Implement seeding and planting plan that addresses both short term stabilization and long term restoration of riparian vegetation
- Water vegetation to ensure adequate survival
- Use seed, mulch, and/or erosion control fabrics on steep slopes and other vulnerable areas
- Avoid jute netting and other erosion control materials that contain mesh near streams or rivers (have been known to trap and kill fish and wildlife)
- Use native plants unless other non-invasive alternatives will yield significantly better results

Monitoring

- Ensure that BMPs are being implemented
- Inspect for erosion
- Evaluate structure stability
- Inspect for evidence of stream instability
- Inspect for presence of debris accumulations or other physical barriers at or within crossing structures
- Ensure streambed continuity is maintained
- Inspect for problems with infiltration in constructed stream beds (subsurface flows)
- Inspect for scouring of the streambed downstream or the aggradation of sediment upstream of the structure

GLOSSARY

→ **Bankfull Width –** Bankfull is a geometric parameter that corresponds with the amount of water that just fills the stream channel and where additional water would result in a rapid widening of the stream or overflow into the floodplain. Indicators of Bankfull width include:

- o Abrupt transition from bank to floodplain. The change from a vertical bank to a horizontal surface is the best identifier of the floodplain and Bankfull stage, especially in low-gradient meandering streams.
- o Top of pointbars. The pointbar consists of channel material deposited on the inside of meander bends. Set the top elevation of pointbars as the lowest possible Bankfull stage.
- o Bank undercuts. Maximum heights of bank undercuts are useful indicators in steep channels lacking floodplains.
- o Changes in bank material. Changes in soil particle size may indicate the operation of different processes. Changes in slope may also be associated with a change in particle size.
- o Change in vegetation. Look for the low limit of perennial vegetation on the bank, or a sharp break in the density or type of vegetation.

→ **Bed Adjustment Potential –** Potential change in the elevation, width, depth, slope or meander pattern of the stream channel as it adjusts to a source of stream instability (changes in discharge, sediment supply, or base elevation). Instability may be caused by changes at a stream crossing site or conditions upstream or downstream of the crossing site or within the watershed (urbanization).

→ **Bedforms –** Natural bedforms include isolated boulders, particle clusters, steps, pools, head of riffles and pool tail crests, large woody debris, transverse bars, longitudinal ribs, and gravel bars. Constructed bedforms may include any of the above as well as rock and log weirs and roughened channels.

→ **Conditions that significantly inhibit wildlife passage –** These include high traffic volumes, steep embankments, fencing, Jersey barriers or other physical obstructions that prevent wildlife passage over the road surface

→ **Culvert –** As used in these Standards, culverts are round, elliptical or rectangular structures that are fully enclosed (contain a bottom) designed primarily for channeling water beneath a road, railroad or highway. Bottomless structures, though sometimes considered culverts by others, are treated separately in these Standards.

→ **Embedded Culvert –** A culvert that is installed in such a way that the bottom of the structure is below the stream bed and there is substrate in the culvert.

→ **Flow contraction –** When a culvert or other crossing structure is significantly smaller then the stream width the converging flow creates a condition called “flow contraction.” The increased velocities and turbulence associated with flow contraction can block fish and wildlife passage and scour bed material out of a crossing structure. Flow contraction also creates inlet drops.

→ **Inlet drop** – Where water level drops suddenly at an inlet, causing changes in water speed and turbulence. In addition to the higher velocities and turbulence, these jumps can be physical barriers to fish and other aquatic animals when they are swimming upstream and are unable to swim out of the culvert.

→ **Long Profile –** A long profile is a surveyed longitudinal profile along the thalweg (deepest portion of the channel) of the stream extending well upstream and downstream of the crossing.

→ **Open Bottom Arch –** Arched crossing structures that span all or part of the stream bed, typically constructed on buried footings and without a bottom.

→ **Openness ratio –** Equals cross-sectional area of the structure opening (in square meters) divided by crossing length when measured in <u>meters</u>. For a box culvert, openness = (height x width)/ length. For crossing structures with multiple cells or barrels, openness ratio is calculated separately for each cell or barrel (do not add together the cross-sectional areas of multiple cells or barrels). At least one cell or barrel should achieve the appropriate openness ratio. The embedded portion of culverts is not included in the calculation of cross-sectional area for determining openness ratio.

→ **Outlet drop** – An outlet drop occurs when water drops off or cascades down from the outlet, usually into a receiving pool. This may be due to the original culvert placement, erosion of material at the area immediately downstream of the culvert, or downstream channel adjustments that may have occurred subsequent to the culvert installation. Outlet drops are barriers to fish and other aquatic animals that can't jump to get up into the culvert.

→ **Physical barriers to fish and wildlife passage** – Any feature that physically blocks fish or wildlife movement through a crossing structure as well as features that would cause a crossing structure to become blocked. Beaver dams, debris jams, fences, sediment filling culvert, weirs, baffles, aprons, and gabions are examples of structures that might be or cause physical barriers. Weirs are short dams or fences in the stream that constrict water flow or fish movements. Baffles are structures within culverts that direct, constrict, or slow down water flow. Gabions are rectangular wire mesh baskets filled with rock that are used as retaining walls and erosion control structures. Steeply sloping channels within a structure resulting in shallow flows and/or high velocity flows can also inhibit movement of fish and other aquatic organisms.

→ **Pipe Arch –** A pipe that departs from a circular shape such that the width (or span) is larger that the vertical dimension (or rise), and forms a continuous circumference pipe that is not bottomless.

→ **River/Stream Continuity** – Maintaining undisrupted the aquatic and benthic elements of river and stream ecosystems, generally through maintenance of appropriate substrates and hydraulic characteristics (water depths, turbulence, velocities, and flow patterns)

→ **Stream Simulation –** A design method in which the diversity and complexity of the natural streambed are created inside a culvert, open-bottom arch, or open-bottom box in such a way that the streambed maintains itself across a wide range of flows. The premise is that if streambed morphology is similar to that in the natural channel the crossing will be invisible to aquatic species.

→ **Tailwater armoring –** Concrete aprons, plastic aprons, riprap or other structures added to culvert outlets to facilitate flow and prevent erosion.

→ **Tailwater scour pool –** A pool created downstream from high flows exiting the culvert. The pool is wider than the stream channel and banks are typically eroded. Some plunge pools may have been specifically designed to dissipate flow energy at the culvert outlet and control downstream erosion.

→ **Thalweg –** A line connecting the lowest points of a stream or river bed.

NOTES AND REFERENCES

Stream Simulation

An important source of information in this document comes from training materials used as part of the U.S. Forest Service's Aquatic Organism Passage (AOP) project. *"Stream Simulation: An Ecological Approach to Road-Stream Crossings"* is a detailed manual currently in preparation by the Forest Service that will likely be available sometime in 2006.

Another important reference for Stream Simulation is *"Design of Road Culverts for Fish Passage"* published by the Washington Department of Fish and Wildlife (2003). This may be downloaded from the following web site: http://wdfw.wa.gov/hab/engineer/cm/

Openness Ratio

There is both published and anecdotal evidence from a variety of sources that some animals (including fish) may be reluctant to enter structures that appear too confining. The occurrence of dead turtles, beavers, muskrat and other riverine animals on roadways above or near road-stream crossings suggests that certain structures may be too small or too confining to accommodate some wildlife.

The inverse of confinement is the concept of openness: the size of a structure opening relative to its length. Openness ratio is defined as the cross-sectional area of the structure opening (in square meters) divided by crossing length measured in meters.

Unfortunately, there is little information available on the openness requirements for fish and wildlife. Reed et al. (1979) concluded that 0.6 is the minimum openness ratio needed for mule and whitetail deer to use a structure. In a study of box culverts in Pennsylvania the average openness ratio for structures used by deer was 0.92 with a range of 0.46 to 1.52 (Brudin 2003). A report from the Netherlands cites data indicating that crossing structures with openness ratios < 0.35 were never used by deer while structures with openness ratios > 1.0 were always used (The Netherlands Ministry of Transport 1995).

Although there are no data or studies available on the openness requirements for species other than deer, we chose to include openness ratio as one of the standards in order to ensure some minimum level of openness. The openness standard of 0.25 in the general standards is well below that required by deer. However, it is hoped that it will be minimally sufficient for fish and small riverine wildlife species. For most roadways, the openness ratio in the optimum standards (0.50) also falls below that generally required by deer. Only when applying the optimum standards under conditions that would inhibit wildlife passage over the road surface (Jersey barriers, fencing, high traffic volumes) does the openness standard (0.75) fall within the range of values for deer. It is hoped that an openness ratio of 0.75 also will be sufficient for other large mammals such as moose and bear.

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