MASSACHUSETTS RIVER AND STREAM CROSSING STANDARDS

Developed by the

RIVER AND STREAM CONTINUITY PARTNERSHIP

Including:

University of Massachusetts Amherst

The Nature Conservancy

Massachusetts Division of Ecological Restoration-Riverways Program

American Rivers

March 1, 2006
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REGULATORY REQUIREMENTS

These standards are not regulations. Local, state and/or federal regulatory authorities will decide the degree to which these standards are adopted, implemented and enforced. For information about regulatory requirements involving these standards please consult the applicable regulations, policies or guidelines and the agencies responsible.

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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 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, Massachusetts Watershed Initiative, Nature Conservancy and Massachusetts Division of Ecological Restoration – 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.

The first version of the Massachusetts River and Stream Crossing Standards was released in August of 2004. The Standards were developed by the River and Stream Continuity Partnership with input from an Advisory Committee that included representatives from UMass-Amherst, MA Division of Ecological Restoration – Riverways Program, Massachusetts Watershed Initiative, Trout Unlimited, The Nature Conservancy, the Westfield River Watershed Association, ENSR International, MA Department of Transportation, MA Department of Environmental Protection and the MA Department of 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 Biological Resources Division (BRD), U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, MA Division of Fisheries and Wildlife, American Rivers, Connecticut River Watershed Council, Connecticut Department of Environmental Protection, a hydraulic engineering consultant, as well as input from people with expertise in Stream Simulation approaches to crossing design[2]. The standards are intended for new permanent crossings (highways, railways, roads, driveways, bike paths, etc.) and, when possible, for replacing existing permanent crossings. After the U.S. Army Corps of Engineers referenced the Standards in the Massachusetts Programmatic General Permit in 2005, a revised version with additional explanatory language was issued on March 1, 2006.

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

With the reissuance in January 2010 of the U.S. Army Corps of Engineers General Permit for Massachusetts, the River and Stream Continuity Partnership decided it was time to evaluate and, as appropriate, to revise the Massachusetts River and Stream Crossing Standards. Feedback on the March 1, 2006 version of the Standards was sought via a web-based survey implemented in 2009. The web survey was not a scientific survey but was essentially a targeted public comment process where input was solicited to gain insight into the issues at hand and suggestions sought on how to improve the Standards. What follows are updated versions of the previous Crossing Standards with modifications based on experience and the input received.

Goals

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, semi-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.

For purposes of these standards full "aquatic organism passage" (AOP) is achieved when a road-stream crossing allows unrestricted movement of all aquatic organisms indigenous to the water body. By aquatic organisms we mean fish and the aquatic life stages of other vertebrates (amphibians), and aquatic invertebrates including small benthic fauna that typically reside within the stream substrate. Unrestricted movement means that all individuals and all life stages are able to move through the structure as freely as they can through the natural stream channel and without delays or obstructions caused by the crossing structure. Full AOP is generally achieved when goals 1 and 2 above are met. Crossing structures that achieve full AOP are expected to maintain more natural river hydrology and transport of sediment and woody debris.

There are a few approaches available for designing river and stream crossings. These Crossing Standards are most consistent with a "Stream Simulation" [3] approach for crossing design. Given the large number of species that make up river and stream communities and the almost complete lack of

[3] U.S. Forest Service, 2008, Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings, WEB: http://www.stream.fs.fed.us/fishxing/aop_pdfs.html

information about swimming abilities and passage requirements for most organisms, it is impractical to use a species-based approach for designing road-stream 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 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.

Some stream and river corridors are also important for maintaining landscape-level connectedness for terrestrial wildlife. In these cases the standards go beyond what is necessary for aquatic organism passage and are intended also to facilitate the movement of a full range of vertebrate wildlife species (mammals, amphibians, reptiles). When wildlife are able to move through road-stream crossings they are less likely to be killed crossing over the road surface.

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 degraded streams or highly urbanized areas 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.

Considerations

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

1. These standards were developed specifically for freshwater, non-tidal rivers and streams and may not be appropriate for coastal waterways.
2. They are intended for permanent river and stream crossings. They are not intended for temporary crossings such as skid roads and temporary logging or construction access roads unless they impact streams that support anadromous fish. The objective of the Crossing Standards is the long term conservation of wildlife, fish and biodiversity resources that can be adversely affected by the barrier effects of road-stream crossings. The impacts of those crossings are a concern when they are manifested at the population level. To the degree that temporary crossings do not result in long-term (sustained) adverse effects on populations of aquatic organisms they should not be the focus of these Standards. For purposes of these Standards a temporary crossing is defined as one that will be in place for three years or less unless the stream supports anadromous fish runs. Temporary

crossing of streams that support anadromous fish should either meet the crossing standards or be otherwise designed not to disrupt the movement of anadromous species using the stream.

3. These standards are not intended for constructed drainage systems designed primarily for irrigation or the conveyance of storm water. Examples include artificial channels, drainage ditches, grassy swales and stone-lined channels when created for the sole purpose of irrigation or storm water management. Natural channels that have been modified to serve an irrigation or storm water management function may still be important for aquatic organism passage and may warrant the use of these standards.

4. The purpose of these standards is to prevent barrier effects of road-stream crossings on populations of fish and wildlife (including invertebrates). It is generally presumed that perennial streams and rivers are always important as habitat and/or movement corridors for aquatic organisms. Many intermittent streams serve as seasonal habitat for fish (especially brook trout) and stream salamanders (two-lined, dusky and spring salamanders). It is not appropriate to dismiss intermittent streams as unimportant for fish and wildlife passage. However, these standards are not intended for channels that lack habitat for fish or wildlife and do not serve as movement corridors needed to access appropriate habitat. That said it can be difficult to determine whether any particular intermittent stream is important for fish and wildlife passage. Unless compelling evidence exists to indicate otherwise, intermittent streams are assumed to have value for fish and wildlife passage.

5. 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. These standards are not intended to address wetland crossings.

6. 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).

7. 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.

8. 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.)

9. For guidance on the technical issues associated with meeting these standards refer to the U.S. Forest Service publication "Stream Simulation: an Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings" available at http://www.streamcontinuity.org/online_docs.htm.

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 "Applying the Standards to Culvert Replacement Projects."

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 new permanent stream crossings are planned on streams or rivers (including intermittent streams) serving as habitat for fish and semi-aquatic wildlife that typically live within stream channels (salamanders, turtles), they should at least meet general standards to pass most fish species, maintain river/stream continuity, and facilitate passage for some wildlife. [4]

Many intermittent streams serve as seasonal habitat for fish (especially brook trout) and stream salamanders (two-lined, dusky and spring salamanders). Although intermittent channels that don't support fish and semi-aquatic wildlife may be used by terrestrial wildlife to move through the landscape, passage for terrestrial wildlife is not the focus of the "General" Standards; they are addressed in the "Optimum" Standards (below). Insects may use intermittent streams above those sections used by fish and semi-aquatic wildlife. However, they typically have adult life stages capable of flight thereby reducing concerns about the impact of road-stream crossing barriers.

General standards call for open bottom structures or culverts that span the river/stream channel with natural bottom substrates that generally match undisturbed 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. A critical element of any stream crossing structure or span design involves identifying the proper "openness". Openness is the cross-sectional area of a structure opening divided by its crossing length when measured in consistent units.[5] An openness of 0.82 ft (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. *Spans (bridges, 3-sided box culverts, open-bottom culverts or arches) that preserve the natural stream channel are strongly preferred.*

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

[5] New England District, U.S. Army Corps of Engineers, Regulatory Division, Openness Ratio Spreadsheet, WEB: http://www.nae.usace.army.mil/reg/Stream/OpennessRatioSpreadsheet.pdf

The preference for spans is to avoid or minimize disruption to the streambed. The structure's design and construction should allow the streambed's natural structure and integrity to remain intact, and work in the stream should be minimized to the greatest extent practicable.

Site constraints may make the use of spans impractical and in some cases well-designed culverts may actually perform better than bridges (e.g. areas with deep soft substrate). However, circumstances where culverts are likely to out-perform spans for aquatic organism passage are very uncommon. Experience has demonstrated that the construction of culverts to meet these standards is not easy. In the vast majority of cases it requires a structure large enough to accommodate equipment for the construction of a stream channel and bed within the culvert. Problems in the design and construction of stable and functional stream channels within culverts are common. In areas where site constraints don't limit the usefulness of these structures, spans that preserve the natural stream channel are strongly preferred over culverts.

2. *If a culvert, then it should be embedded:*
   - *a minimum of 2 feet for all culverts,*
   - *a minimum of 2 feet and at least 25 percent for round pipe culverts*
   - *When embedment material includes elements > 15 inches in diameter, embedment depths should be at least twice the D_{84} (particle width larger than 84 % of particles) of the embedment material*

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. For finer components of the substrate natural movement of bedload could be expected to replace material in the structure that is lost from the culvert during typical high flow events. However, the embedment material must be designed to resist the complete loss of substrate during large, infrequent storms (e.g. 100-year storms),
- Sufficient depth of material to permit shaping of material to achieve natural water depths at low-flow conditions, and
- Sufficient embedment to account for long-term vertical channel adjustment anticipated for the adjacent streambed.

For most crossings embedment material will need to be put in place using equipment; only rarely can bedload transport be relied on to supply a culvert with adequate embedment material.

Use of sills or other similar structural elements designed to hold the substrate in place within a culvert are strongly discouraged for new crossings. Should the substrate material be washed out of a culvert by an infrequent storm the barrier effects of the sills are likely to be worse than that of a bare culvert.

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 (with at least 2 feet of embedment), 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.

For guidance on the technical issues associated with culvert embedment refer to the U.S. Forest Service publication "Stream Simulation: an Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings" available at http://www.streamcontinuity.org/online_docs.htm.

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.[6]

   In naturally 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.

   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. This is especially true for streams with broad floodplains. 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 and, to the extent possible, take into account the potential effects of climate change on future storm characteristics (e.g. storms are likely to be more severe) and how the hydrology of the stream could change due to development within the watershed.

   For guidance on the technical issues associated with sizing crossing structures refer to the U.S. Forest Service publication "Stream Simulation: an Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings" available at http://www.streamcontinuity.org/online_docs.htm.

4. *Natural bottom substrate within the structure*

   Careful attention must be paid to the composition of the substrate within the structure. The movement of benthic aquatic organisms could be obstructed or their necessary life-cycle movements could be substantially disrupted without a natural bottom forming a continuous

[6] Determining bankfull width and appropriate crossing width can be particularly difficult or even impossible in degraded or highly urban streams.

medium through the structure. Substrate characteristics may be a more important determinant of passability than water depth or velocity for animals that tend to crawl (salamanders, crayfish) rather than swim in streams systems.

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. Substrate should be designed to meet desired characteristics after a period of adjustment likely to occur after construction.

The substrate should be designed to resist the complete loss of bed material during large, infrequent storms and to maintain appropriate channel characteristics through natural bed load transport. The goal is to achieve a dynamic equilibrium whereby substrate lost due to bed load transport is balanced by the movement of substrate into the structure from upstream. 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 substrate and when possible should fall within the range of variability seen in the natural channel upstream and downstream of the crossing.

For guidance on the technical issues associated with substrate and culvert embedment refer to the U.S. Forest Service publication “Stream Simulation: an Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings” available at http://www.streamcontinuity.org/online_docs.htm.

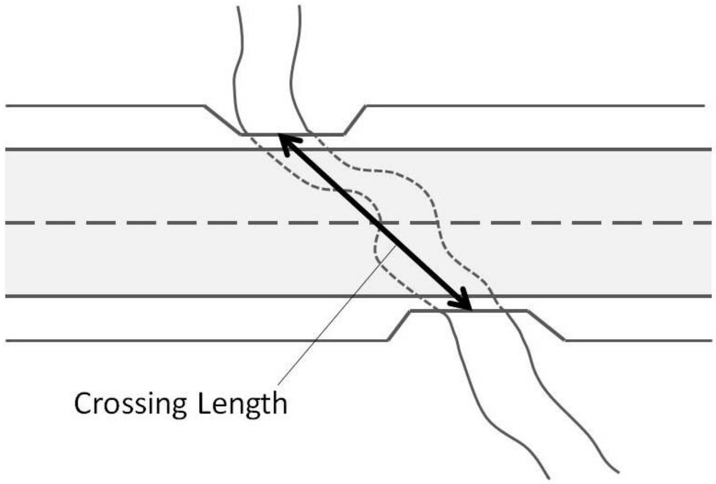
5. *Designed with appropriate bed forms and streambed characteristics so that water depths and velocities are comparable to those found in the natural channel at a variety of flows*

   In order to provide appropriate water depths and velocities at a variety of flows and especially low flows it is necessary to preserve or reconstruct the streambed within the structure. Otherwise, the width of the structure needed to accommodate higher flows will create conditions that are too shallow at low flows. The preference is to preserve the existing channel through the use of open-bottom spans wide enough to preserve the entire streambed. It is important that a continuous thalweg (deepest portion of the channel) be maintained through the structure. 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.

   For guidance on the technical issues associated with the design and construction of stream channels and bed forms refer to the U.S. Forest Service publication “Stream Simulation: an Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings” available at http://www.streamcontinuity.org/online_docs.htm.

6. *Openness> 0.82 feet (0.25 meters)*

   Openness is the cross-sectional area of a structure opening divided by its crossing length when measured in consistent units (e.g. feet). For a box culvert, openness = (height x width)/ length.



For calculating openness length is measured as a straight line connecting the channel midpoint where it enters a structure and where it exits the structure.

For crossing structures with multiple cells or barrels, openness is calculated separately for each cell or barrel. At least one cell or barrel should meet the appropriate openness standard. The embedded portion of a culvert is not included in the calculation of cross-sectional area for determining openness.[7]

Openness > 0.82 feet is recommended to make the structure more likely to pass small, riverine wildlife such as turtles, mink, muskrat and otter that may tend to avoid structures that appear too constricted (see note at the end of this document). This openness standard is too small to accommodate large wildlife such as deer, bear, and moose. Structures that meet this openness standard are much more likely than traditional culverts to pass flood flows and woody debris that would otherwise obstruct water passage. It is likely that most structures that meet all the other general standards will also meet this openness standard. However, for some very long structures it may be impractical or impossible to meet this standard.

7. *Banks should be present on each side of the stream matching the horizontal profile of the existing stream and banks*

   To prevent failure, all constructed banks should have a height to width ratio of no greater than 1:1.5 (vertical:horizontal) unless the stream is naturally incised. They should be tied into the up and downstream banks and configured to be stable during a 100-year storm event. The banks should be designed and constructed so as not to hinder riverine wildlife use of the streambed and banks for passage.

[7] 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 0.82 standard for openness. The spreadsheet can be downloaded from the Online Documents section of www.streamcontinuity.org.

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 optimum standards should be applied in order to maintain river/stream continuity and facilitate passage for fish and wildlife.

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. There are no formal, recognized criteria for classifying streams as warranting optimum standards. The Nature Conservancy and University of Massachusetts Amherst are engaged in a project ("Critical Linkages") to objectively assess landscape-scale connectedness and define areas that serve as critical linkages for wildlife movement and connectivity. This (and potentially other similar projects) will provide assistance in identifying areas where it would be appropriate to use the optimum standards for road-stream crossings.

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 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 all wildlife species (minimum height and openness requirements).

Standards

1. *Use a bridge*

   Unless there are compelling reasons why a culvert would provide greater environmental benefits only bridges should be used. Bridges are preferred over open-bottom culverts because they can be installed with minimal impact to the stream channel and provide more headroom for wildlife.

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.

   It is critical to avoid channel constriction during normal bankfull flows. A width of 1.2 times bankfull width is the <u>minimum</u> 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.[8]

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 and, to the extent possible, take into account the potential effects of climate change on future storm characteristics (e.g. storms are likely to be more severe) and how the hydrology of the stream could change due to development within the watershed.

For guidance on the technical issues associated with sizing crossing structures refer to the U.S. Forest Service publication “Stream Simulation: an Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings” available at http://www.streamcontinuity.org/online_docs.htm.

3. *Natural bottom substrate within the structure*

Careful attention must be paid to the composition of the substrate within the structure. The movement of benthic aquatic organisms could be obstructed or their necessary life-cycle movements could be substantially disrupted without a natural bottom forming a continuous medium through the structure. Substrate characteristics may be a more important determinant of passability than water depth or velocity for animals that tend to crawl (salamanders, crayfish) rather than swim in streams systems.

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. Substrate should be designed to meet desired characteristics after a period of adjustment likely to occur after construction.

The substrate should be designed to resist the complete loss of bed material during large, infrequent storms and to maintain appropriate channel characteristics through natural bed load transport. The goal is to achieve a dynamic equilibrium whereby substrate lost due to bed load transport is balanced by the movement of substrate into the structure from upstream. 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 substrate and when possible should fall within the range of variability seen in the natural channel upstream and downstream of the crossing.

For guidance on the technical issues associated with substrate refer to the U.S. Forest Service publication “Stream Simulation: an Ecological Approach to Providing Passage for Aquatic

[8] Determining bankfull width and appropriate crossing width can be particularly difficult or even impossible in degraded or highly urban streams.

Organisms at Road-Stream Crossings” available at http://www.streamcontinuity.org/online_docs.htm.

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 necessary to preserve or reconstruct the streambed within the structure. Otherwise, the width of the structure needed to accommodate higher flows will create conditions that are too shallow at low flows. The preference is to preserve the existing channel through the use of open-bottom spans wide enough to preserve the entire streambed. It is important that a continuous thalweg (deepest portion of the channel) be maintained through the structure. 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.

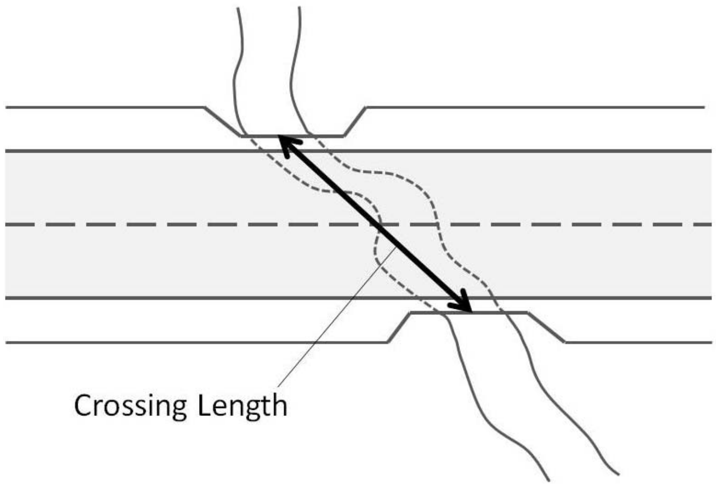
   For guidance on the technical issues associated with the design and construction of stream channels and bed forms refer to the U.S. Forest Service publication “Stream Simulation: an Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings” available at http://www.streamcontinuity.org/online_docs.htm.

5. *Maintain a minimum height of 8 ft (2.4 meters) and openness of 2.46 feet (0.75 meters) if conditions are present that significantly inhibit wildlife passage (high traffic volumes, steep embankments, fencing, Jersey barriers or other physical obstructions*

   If conditions that significantly inhibit wildlife passage are not present, maintain a minimum height of 6 ft. (1.8 meters) and openness of 1.64 feet (0.5 meters)

   Height should be measured from the average invert of the streambed within the structure to the inside top of the structure directly above. The invert is the elevation of the lowest point of the stream channel within the structure.

   Openness is the cross-sectional area of a structure opening divided by its crossing length when measured in consistent units (e.g. feet). For crossing structures with multiple bridge cells openness is calculated separately for each cell (do not add together the cross-sectional areas of multiple cells). At least one cell should achieve the appropriate openness standard.



For calculating openness length is measured as a straight line connecting the channel midpoint where it enters a structure and where it exits the structure.

6. *Banks should be present on each side of the stream matching the horizontal profile of the existing stream and banks with sufficient headroom to provide dry passage for semi-aquatic and terrestrial wildlife*

   To prevent failure, all constructed banks should have a height-to-width ratio no greater than 1.5:1 (horizontal:vertical) unless the stream is naturally incised. Banks within the structure should generally align with the profile and cross section of banks upstream and downstream of the structure and should be stable during a 100-year storm event. The banks should be designed and constructed so as not to hinder wildlife use of the streambed and banks for passage.

Standards Summary

	General Standards	**Optimal Standard**
Structure Type	Open-bottom span preferred	Bridge
Embedment	If a culvert, then it should be embedded: • A minimum of 2 feet for all culverts, • A minimum of 2 feet and at least 25 percent for round pipe culverts • When embedment material includes elements > 15 inches in diameter, embedment depths should be at least twice the D_{84} of the embedment material	NA
Crossing Span	Minimum: 1.2 x bankfull width	Minimum: 1.2 x bankfull width
Substrate	Matches stream substrate	Matches stream substrate
Water Depth & Velocity	Matches water depth & velocity in natural stream over a range of flows	Matches water depth & velocity in natural stream over a range of flows

Openness (& height)	Openness: 0.82 ft. (0.25 m)	Conditions that inhibit wildlife passage over road Openness: 2.46 ft. (0.75 m) Height: 8 ft. (2.4 m) Otherwise Openness: 1.64 ft. (0.5 m) Height: 6 ft. (1.8 m)
Banks	• On both sides of the stream • Match the horizontal profile of the existing stream and banks • Constructed so as not to hinder use by riverine wildlife	• On both sides of the stream • Match the horizontal profile of the existing stream and banks • Constructed so as not to hinder use by wildlife • Sufficient headroom for wildlife

APPLYING THE STANDARDS TO CULVERT REPLACEMENT PROJECTS

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 addressed 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 (in-stream habitat, wetlands),
- potential for erosion and head cutting, 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 upstream and/or downstream of the structure in addition to culvert replacement in order to restore river/stream continuity and facilitate fish and wildlife passage.

Culvert replacements need to be reviewed and permitted by the local conservation commission, the Massachusetts Department of Environmental Protection (§401 Water Quality Certification), and in some cases the U.S. Army Corp of Engineers.

Applying the Standards

1. *Replacement culverts should meet the design guidelines for either general standards or optimal standards (see Standards for New Crossings above) unless:*
    - *Doing so would result in significant stream instability that can't otherwise be mitigated*
    - *Meeting the standards would create a flooding hazard that can't otherwise be mitigated*
    - *Site constraints make it impossible to meet the standards*

2. *If it is not possible to meet all of the applicable standards, replacement crossings should be designed to 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 and wildlife passage*

3. *If it is not possible to meet all of the applicable standards avoid Smooth High Density Polyethylene Pipes (HDPP) or other pipes with a Mannings n equal or less than 0.010.*

4. *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*

5. *To the extent practicable conduct stream restoration upstream and/or downstream of the structure as needed to restore river/stream continuity and eliminate barriers to aquatic organism movement*

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 when installing or replacing road-stream crossings.[9]

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 (where soils were deposited and are shaped by flowing water) 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, replacing or maintaining road-stream crossings is during periods of low flow, generally July 1 through September 30. However, there may be occasions when a 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 re-water 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

[9] 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 and is included in the Forest Service publication "Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings."

- 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
- 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
- After construction remove cofferdams downstream-to-upstream in a manner that minimizes introduction of sediment to the waterway.

Storm Water Management, Erosion and Sediment Control

Use of a downstream sediment retention pond is strongly recommended for all projects that involve work within the streambed.

- 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, mulch or compost filter tubes)
- 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 Streambed 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 streambed 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 in-stream bank-edge habitat
- Tie constructed banks into upstream and downstream banks. Banks within the structure should generally align with the profile and cross section of banks upstream and downstream of the structure, and should be installed so that the juncture between natural bank and constructed bank is stable. The banks should be designed and constructed so as not to hinder wildlife use of the streambed and banks for passage.

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 netting and other erosion control materials that contain coarse mesh capable of trapping and killing fish and wildlife if it gets washed into streams or rivers.
- 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 streambeds (subsurface flows)
- Inspect for scouring of the streambed downstream or the aggradation of sediment upstream of the structure

GLOSSARY

→ **Aquatic Organism Passage –** Full "Aquatic Organism Passage" (AOP) is achieved when a road-stream crossing allows unrestricted movement of all aquatic organisms indigenous to the water body. Aquatic organisms are fish and the aquatic life stages of other vertebrates (amphibians), and aquatic invertebrates including small benthic fauna that typically reside within the stream substrate. Unrestricted movement means that all individuals and all life stages are able to move through the structure as freely as they can through the natural stream channel and without delays or obstructions caused by the crossing structure.

→ **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 <u>Abrupt transition from bank to floodplain</u>. 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 <u>Top of point bars</u>. The point bar consists of channel material deposited on the inside of meander bends. Set the top elevation of point bars as the lowest possible Bankfull stage.
- o <u>Bank undercuts</u>. Maximum heights of bank undercuts are useful indicators in steep channels lacking floodplains.
- o <u>Changes in bank material</u>. 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 <u>Change in vegetation</u>. 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.

→ **Bridge** – As used in this document, a bridge is a bottomless structure erected over a river or stream to provide passage from one bank to the other. In this document bridges are grouped under the term "spans" along with open-bottom arch and open-bottom box culverts.

→ **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.

→ **D_{84}** – Particle width larger than 84 % of particles within a sampled streambed. Width is the diameter of the intermediate axis of a particle; not the longest axis (length) or the shortest axis (thickness).

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

→ **Flow contraction** – When a culvert or other crossing structure is significantly smaller than 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.

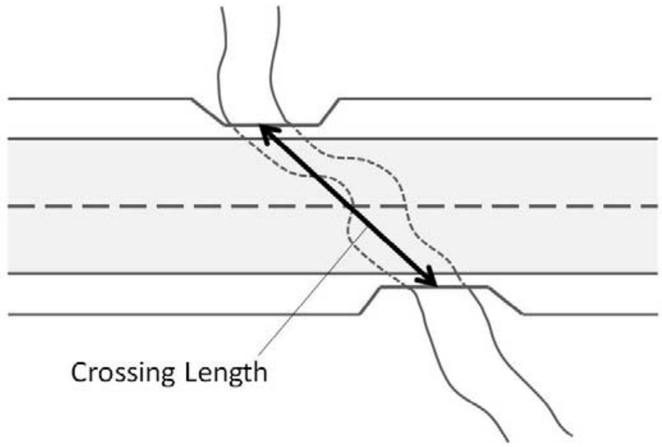
→ **Inlet drop** – Where water level drops suddenly at an inlet, causing changes in water speed and turbulence. In addition to the higher velocities and turbulence, these jumps can be physical barriers to fish and other aquatic animals when they are moving upstream and are unable to swim out of the culvert.

→ **Invert** – The elevation of the lowest point of a crossing structure or if embedded (or an open bottom structure) the lowest point of the stream channel within the structure.

→ **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 streambed, typically constructed on buried footings and without a bottom.

→ **Openness–** Equals cross-sectional area of the structure opening divided by crossing length when measured in consistent units (e.g. feet). For a box culvert, openness = (height x width)/ length. For crossing structures with multiple cells or barrels, openness 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 standard. The embedded portion of a culvert is not included in the calculation of cross-sectional area for determining openness.



For calculating openness length is measured as a straight line connecting the channel midpoint where it enters a structure and where it exits the structure.

→ **Outlet drop –** An outlet drop occurs when water drops off or cascades down from a structure 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 a 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 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)

→ **Span –** A bridge, 3-sided box culvert, open-bottom culvert or arch that spans the stream with abutments landward of the bankfull width

→ **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 (the deepest part of the channel).

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 Providing Passage for Aquatic Organisms at Road-Stream Crossings"* is a detailed manual published by the Forest Service in 2008. The complete citation for this document is:

U.S. Forest Service Stream Simulation Working Group. 2008. Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings. San Dimas: U.S. Forest Service Technology and Development Program.

The document can be downloaded from the Online Documents section of the Streamcontinuity.org web site.

http://www.streamcontinuity.org/online_docs.htm

Openness

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 dark or 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 is defined as the cross-sectional area of the structure opening divided by crossing length measured in consistent units (e.g. feet).

Unfortunately, there is little information available on the openness requirements for fish and wildlife. Reed et al. (1979) concluded that 0.6 meters (2.0 feet) is the minimum openness needed for mule and whitetail deer to use a structure. In a study of box culverts in Pennsylvania the average openness for structures used by deer was 0.92 meters (3.0 feet) with a range of 0.46 (1.52 feet) to 1.52 meters (5.02 feet; Brudin 2003). A report from the Netherlands cites data indicating that crossing structures with openness < 0.35 meters (1.16 feet) were never used by deer while structures with openness > 1.0 meters (3.3 feet) 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 as one of the standards in order to ensure some minimum level of openness. The openness standard of 0.82 feet (0.25 meters) in the general standards is well below that required by deer. The intent is to create an openness standard that is sufficient for fish and small riverine wildlife species. For most roadways, the openness standard in the optimum standards (1.64 feet; 0.50 meters) 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 (2.46 feet; 0.75 meters) fall within the range of values for deer. We expect that an openness standard of 2.46 feet (0.75 meters) also will be sufficient for other large mammals such as moose and bear.

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