Massachusetts River and Stream Crossing Standards: Technical Guidelines

August 6, 2004

INTRODUCTION

As long and linear ecosystems, rivers and streams are very important for fish and other wildlife movements, but are also 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 (see Appendix A.).

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. This information was used to develop design standards for culverts and other stream crossing structures.

The following standards were developed by the River and Stream Continuity Steering Committee including representatives from UMass-Amherst, MA Riverways Program, Massachusetts Watershed Initiative, Trout Unlimited, The Nature Conservancy, Mass Highway, and the Massachusetts Department of Environmental Protection. In developing the standards, the steering committee received advice from a Technical Advisory Committee that included representatives of the US Fish and Wildlife Service, USGS BRD, US EPA, US Army Corps of Engineers, MA Division of Fisheries and Wildlife, American Rivers, Connecticut River Watershed Council, Connecticut DEP, and a hydraulic engineering consultant. The standards are intended to serve as recommended standards for permanent crossings (highways, railways, roads, driveways, bike paths, etc) on fish-bearing streams and rivers, and as guidelines for upgrading existing crossings when possible. These standards seek to achieve, to varying degrees, three goals:

1. <u>Fish and other Aquatic Organism Passage</u>: Facilitate movement for most fish and other aquatic organism species, including relatively small, resident fish, aquatic amphibians & reptiles, and large invertebrates (e.g. crayfish, mussels).

2. <u>River/stream continuity</u>: Maintain continuity of the aquatic and benthic elements of river and stream ecosystems, generally through maintenance of appropriate substrates, water depths and flows. Maintenance of river and stream continuity is the most practical

strategy for facilitating movement of small, benthic organisms as well as some large, 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.

This technical guidance adopts a “Stream Simulation” approach for crossing design in order to better protect river and stream ecosystems. 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 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 present no more of an obstacle to movement than the natural channel and that are essentially “invisible” to aquatic organisms.

These guidelines 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 shallow bedrock may make it impractical to embed culverts. In other situations the road layout and surrounding landscape may make it impossible or impractical to achieve the recommended standards for height and openness. 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 guidelines.

1. They are intended for permanent river and stream crossings. They were not intended for temporary crossings such as skid roads and temporary logging roads.
2. They are generally intended for fish-bearing streams. These guidelines 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 species is desired. Further, the standards are not intended for drainage systems designed primarily for the conveyance of storm water or wastewater.
3. These technical guidelines have no regulatory standing. They are intended as technical guidelines that can be used to facilitate the preservation or restoration of river continuity and fish and wildlife movement. These guidelines may not be sufficient to address drainage or flood control issues that must also be considered during the permitting of permanent stream crossings.

STANDARDS FOR NEW CROSSINGS

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.

Fish bearing streams or rivers include rivers and streams that support one or more species of fish, 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 will pass some wildlife species but is unlikely to pass all the wildlife that would be accommodated by the optimum standards.

Standards

- Open bottom arch or bridge span preferred

  Site constraints may make the use of these structures impractical and in some cases well-designed culverts may actually perform better than bridges or open bottom arches. However, in areas where site constraints don't limit the usefulness of these structures, bridges and open-bottom arches are preferred over culverts.

- If a culvert, then it should be embedded $\geq$ 1 foot for box culverts and pipe arches, and at least 25 % for pipe culverts.

  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 box culverts, pipe arches, open-bottom arches, or bridges should be considered instead.

- Natural bottom substrate within culvert (matching upstream and downstream substrates)

  Careful attention must be paid to the composition of the substrate within the culvert. The substrate within the structure should match the composition of the substrate in the natural stream channel at the time of construction and over time as the structure has had the opportunity to pass significant flood events. This substrate should either resist displacement during flood events or the structure should be designed to maintain an appropriate bottom through natural bed load transport.

- Spans channel width (a minimum of 1.2 times the bankfull width)

  A critical feature of stream simulation design is to avoid channel constriction during normal bankfull flows. Spanning an area 1.2 times the bankfull width will help prevent scouring within the structure or at the outlet during less frequent floods.

- Designed to provide water depths and velocities at low flow that are comparable to those found in upstream and downstream natural stream segments

  In order to provide water depths and velocities at low flow it is usually necessary to construct a low flow 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 channel 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.

- Openness ratio $\geq$ 0.25

  Openness ratio is the cross-sectional area of a structure divided by its crossing length when measured in meters. For a box culvert, openness = (height x width)/ length.

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.

Areas of particular statewide or regional significant 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. Optimum standards also should be applied to crossings that would adversely impact Biomap and Living Waters "core habitat" or areas providing linkages between "core habitats."

Important aquatic habitat for rare or endangered species includes, but is not limited to, those areas identified by the Natural Heritage and Endangered Species

Program (via the Living Waters project 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 most 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

- Open bottom arch or bridge span

  Unless there are compelling reasons why a culvert would provide greater environmental benefits, only bridges or open-bottom arches should be used.

- Span the streambed and banks (allowing dry passage for wildlife $\geq$ 80% of the year)

  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.

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

  Openness ratio is the cross-sectional area of a structure divided by its crossing length when measured in meters. For a box culvert, openness = (height x width)/ length.

- Otherwise, maintain a minimum height of 4 ft. and openness ratio of 0.5

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. Culvert replacement or remediation are critical elements for the 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 cause head cutting – the progressive down-cutting of the stream channel – upstream of the crossing. 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 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 longitudinal profiles of sufficient length to understand potential changes in channel characteristics. 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 most cases these replacements will need to be reviewed and permitted by the local conservation commission.

Standards

- Whenever possible replacement culverts should meet the design guidelines for either general standards or optimal standards (see Standards for New Crossings above).
- If it is not possible or practical to meet all of the general or optimal standards, replacement crossings should be designed to at least meet general standards to the extent practical and to avoid or mitigate the following problems.

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

CONCLUSION

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 to address the movement needs of aquatic organisms. A 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.

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 infrastructure that does not fragment or undermine the essential ecological infrastructure of the land and its waterways.

GLOSSARY

→ **Bankfull Width** – Bankfull is 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:

- <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.
- <u>Top of pointbars</u>. 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.
- <u>Bank undercuts</u>. Maximum heights of bank undercuts are useful indicators in steep channels lacking floodplains.
- <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.
- <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.

→ **Culvert –** Round, elliptical or rectangular structures that are fully enclosed (contain a bottom) designed primarily for channeling water beneath a road, railroad or highway.

→ **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 culvert is significantly smaller then stream width the converging flows creates a condition called “flow contraction.” The increased velocities and turbulence associated with flow contraction can block fish and wildlife passage.

→ **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.

→ **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 divided by crossing length when measured in meters. For a box culvert, openness = (height x width)/ length.

→ **Orifice flows –** Flows that fill or nearly fill the entire culvert. These become problematic because there is no space within the culvert for wildlife passage and flows are typically too fast for the passage of fish and other aquatic animals.

→ **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 or erosion of material at the downstream end of culvert. 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 structure that physically blocks fish or wildlife movement as well as structures that would cause a culvert 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.

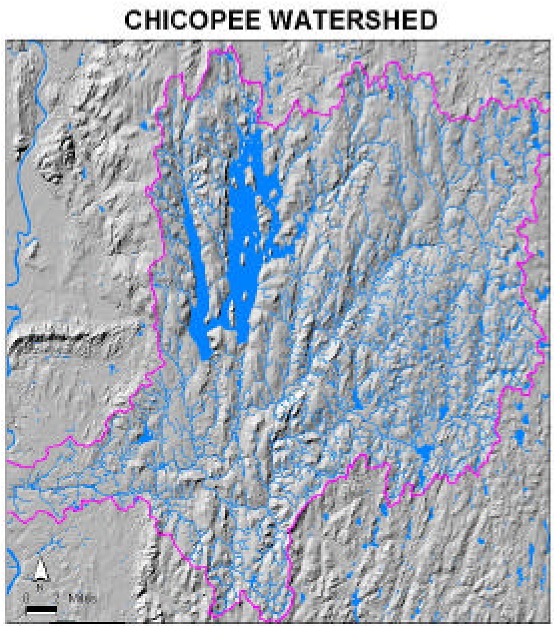
→ **Pipe Arch** – A pipe that has been factory deformed from a circular shape such that the width (or span) is larger that the vertical dimension (or rise), and forms a continuous circumference pipe that is not bottomless.

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

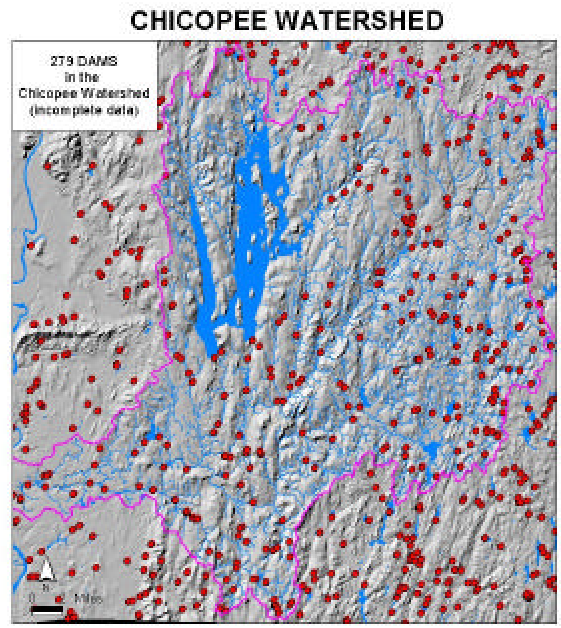
→ **Tailwater scour pool –** A pool created downstream from high flows exiting the culvert. The pool is wider than the stream channel and banks are eroded.

Appendix A.

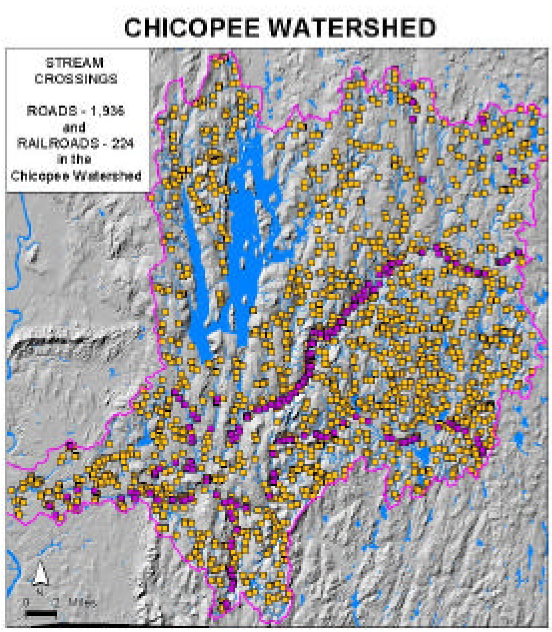
The Geographic Scope of River & Stream Fragmentation in Massachusetts (Courtesy of the Massachusetts Riverways Program)



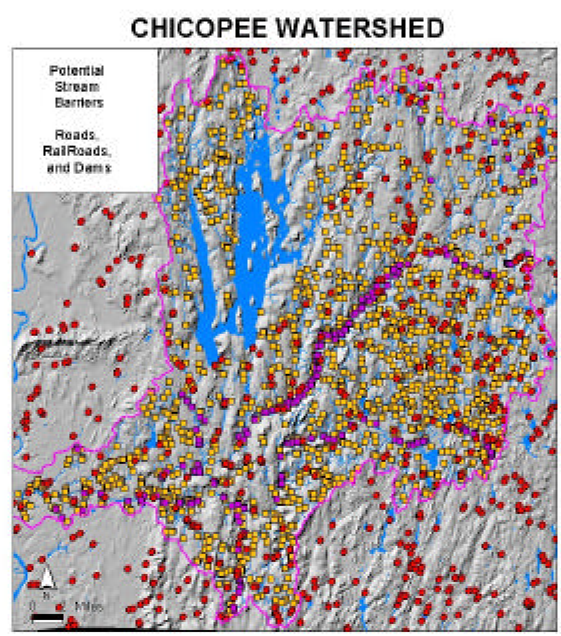
The 721 sq. mi. Chicopee River Watershed is a relatively rural watershed in Central Massachusetts.



A legacy of early American small-scale industrialization, there are at least 279 dams on the tributaries and mainstem of the Chicopee River.



The intersection of the stream network with roads and railroads results in an estimated 2,160 crossings.



The combination of crossings and dams raises serious concerns about the fragmentation of river and stream ecosystems in the Chicopee River watershed.