

Recommendations for Aquatic Organism Passage at Maryland Road-Stream Crossings



Chesapeake Bay Program
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The text and figures throughout this document are unique, however, the concept of this document and its general layout follow the 2nd edition of the *Massachusetts Stream Crossings Handbook*, published in 2012 by the Massachusetts Division of Ecological Restoration and biodrawiversity LLC (www.biodrawiversity.com). Writing and design for this document was completed by Jeff Gring of Coastal Resource, Inc. Unless otherwise noted, all photos in this document were taken by the author. Additional figures and diagrams were created by Jenny Saville and Samantha Moxey of Coastal Resources, Inc. and cannot be reproduced without permission. On the cover page, the bottomless culvert photo was provided by the USFWS (unknown photographer) and the brook trout photo was taken by Ryan Hagerty (USFWS).

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BACKGROUND AND PURPOSE

Members and associates of the Chesapeake Bay Program's Fish Passage Workgroup, from state and federal agencies and non-profit organizations, began meeting during the spring of 2018 with the intent to increase the number of fish-friendly culverts in Maryland. Many agencies and organizations throughout the United States, and particularly in the northeast, have increased their efforts to remove instream barriers to ensure that fish can migrate upstream and downstream in rivers and streams to access habitat important during various life stages. This group first inventoried what Maryland and other states were doing to ensure that road-stream crossings allow for fish passage. They next invited a speaker to inform the group about how Massachusetts is approaching aquatic connectivity at road-stream crossings. The "Massachusetts Stream Crossings Handbook" and related stream crossing standards have served as the basis for stream crossing recommendations and guidelines used by several other states throughout the eastern United States. Subsequently, the group met with individuals from agencies in Maryland that review permits for road-stream crossings (i.e., bridges and culverts) to discuss their review and permitting process. Following this meeting, the group determined that there was a need for communication tools, including a document that provides recommendations for aquatic organism passage at road-stream crossings in Maryland.

This document is meant to inform local conservation groups, city and county engineers, highway departments, resource agencies, and the general public on the importance of stream continuity to the health of Maryland streams. This document also provides recommendations for crossing structures to improve or maintain aquatic organism passage along non-tidal waterways. This document is not a technical handbook or design

manual and cannot be used as a standalone reference to successfully replace or install a culvert. The crossing recommendations presented are intended to be used in conjunction with sound engineering and design practices in accordance with all state and federal regulations. Additional project and site considerations should occur early in the planning and design process, including owner agency design objectives, considerations, and constraints. Potential objectives and constraints include permit requirements, working within the roadway right-of-way, an analysis of design alternatives, capital and life-cycle costs, risk-based decision making (e.g., public safety, environmental, etc.), use of sound science and engineering approaches, and constructability.

The main goal of this document is to present Maryland stream crossing recommendations to promote stream continuity, aquatic organism passage, and in some cases, terrestrial wildlife passage. Local conservation groups, city and county engineers, highway departments, resource agencies, and the general public can use this document to help promote stream continuity throughout Maryland.

These recommendations were developed based on a literature review of over 90 sources and coordination and review by a stakeholder group consisting of members of the Chesapeake Bay Program's Fish Passage Work Group and members from other state agencies, federal agencies, and conservation groups. The **Additional Resources** section at the end of this document provides resources to aid in the implementation of the recommendations provided in this document. Finally, the **Definitions** section at the end of this document defines the italicized terms used throughout the document.

INTRODUCTION

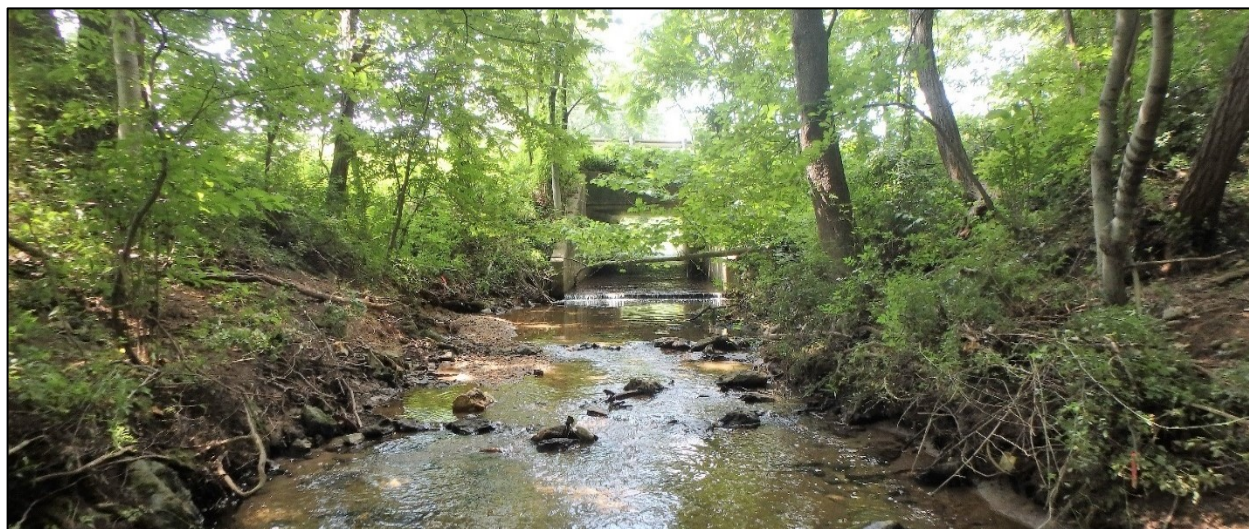
Maryland contains over 10,000 miles of freshwater streams and rivers, with the majority draining to the Chesapeake Bay. Maryland's waterways are exceptional for their beauty, ecological importance, and recreational value. The diverse stream and habitat types found throughout the state support a unique and broad range of aquatic fauna, such as fish, salamanders, turtles and freshwater mussels. Similar to much of the United States, land use changes have historically impacted aquatic habitats in Maryland, from indirect effects on water quality associated with watershed development to aquatic migration barriers associated with roadways.

Fragmentation of aquatic habitats by dams, culverts, and other infrastructure is a primary threat to aquatic species throughout the United States. The need to improve aquatic connectivity in the Chesapeake Bay watershed has been the focus of government agencies and other environmental groups for decades. From 1989 to 2013, the Chesapeake Bay Program's Fish Passage Workgroup has implemented dam removal and fish passage projects that have opened over 2,500 miles of stream for river herring, American shad, hickory shad, American eel, and/or brook trout within the Chesapeake Bay watershed. The Fish

Passage Workgroup has committed to opening an additional 1,000 miles of stream and subsequently 132 miles every two years for these target species by 2025.

When not properly designed, crossings can impede movement of migratory fish species, fragment populations of resident aquatic organisms, and degrade water quality and aquatic habitat quality through the alterations of flow and sediment transport. However, *stream continuity*, or the uninterrupted connection of a river network, is not always the primary consideration when designing road-stream crossings. Other project objectives, such as providing safe transport for the public, providing flood conveyance, and adhering to financial constraints may be prioritized over aquatic organism passage.

The removal of aquatic barriers located along free-flowing waterways can have numerous ecological benefits, including increasing biodiversity, improving floodplain and riparian function, and re-establishing migratory routes and habitat access for aquatic organisms. In addition, properly designed crossings and design approaches can benefit aquatic organisms and reduce road maintenance costs caused by high water and subsequent erosion.



IMPORTANCE OF STREAM CONTINUITY FOR AQUATIC COMMUNITIES

Access to spawning areas: Stream continuity is important for reproduction of migratory and resident fish species, alike. Both resident and *diadromous* fish species migrate to access spawning areas. Spawning runs range from short distances for resident species to hundreds of miles for some diadromous species. Stream continuity is crucial for *anadromous* and *semi-anadromous* fish species, which include striped bass, hickory shad, American shad, blueback herring and alewife (collectively known as river herring), white perch, and yellow perch in the state of Maryland.

Access to coldwater habitats: Many aquatic species in Maryland, such as brook trout, rely on coldwater habitats as *thermal refugia* during warm summer months. These coldwater habitats include groundwater-fed, headwater streams that maintain cooler temperatures during the summer, as well as deeper pool habitats found along cool and coldwater streams. These thermal refugia are crucial for the survival and maintenance of coldwater aquatic communities – organisms that are excluded from coldwater habitats during summer months due to movement barriers are more susceptible to heat stress and mortality.

Access to forage: Varied stream habitats have different prey communities and feeding opportunities depending on the location and time of year. For example, large predators, such as striped bass, will often travel to exploit schools of baitfish during certain seasons or time of day. Macroinvertebrate communities also vary along the stream network, presenting different feeding opportunities depending on location. When road crossings restrict movement, the fragmentation of streams can impede access to feeding areas and impact fish communities.



School of alewife during spawning run in Deer Creek, Maryland (Photo credit: Ryan Hagerty, USFWS)



Brook trout, the only trout species native to Maryland, have been deemed a “species of greatest conservation need” by MDNR. Brook trout are sensitive to poor water quality conditions and require access to coldwater habitats for survival. (Photo credit: Ryan Hagerty, USFWS)



Macroinvertebrate communities vary along stream networks, providing different feeding opportunities for fish

Natural dispersal: In addition to fish, other aquatic, semi-aquatic, and even terrestrial species rely on stream corridors for natural dispersal and re-colonization after disturbances (e.g., droughts, water quality contamination). Aquatic and semi-aquatic salamanders, frogs, and turtles utilize streams and streambanks for daily and seasonal movement. A barrier at a road-stream crossing may force these species to navigate over land and across roadways, exposing them to predators and roadway mortality. Unlike reptiles and amphibians, which move freely on their own, freshwater mussel dispersal requires host fish species for dispersal. Mussels reproduce by releasing larvae, or glochidia, into the water. The glochidia attach to the fins or gills of host fish species and later release from the fish to colonize new stream reaches. Therefore, if a stream crossing blocks fish movement, then it also blocks upstream dispersal of freshwater mussels.

Maintaining habitat: Culverts can create channel instability that degrades habitat, making conditions uninhabitable by native plants and animals. Undersized culverts can lead to upstream and downstream bank erosion, resulting in wider stream channels and increased fine sediment deposition that affect the quality of stream and riparian habitats.

Genetic diversity: Populations require movement of individuals and habitat connectivity to maintain genetic diversity. Habitat fragmentation can result in unfavorable gene flow due to isolation and inbreeding within smaller groups of individuals. Road-stream blockages can isolate populations, which can lead to whole populations being eliminated, reduced, or genetically damaged. Maintaining genetic diversity is critical because it allows populations to adapt to changing environments.



Adult northern two-lined salamanders are often found along stream margins, using streams and stream banks to travel. (Photo credit: Kevin Stohlgren, Coastal Resources, Inc.)



Wood turtles utilize both aquatic and terrestrial habitats. During mating season, stream blockages can be hazardous to wood turtles by forcing them to navigate across roadways. (Photo credit: Kevin Stohlgren, Coastal Resources, Inc.)



Freshwater mussels require host fish species for distribution of their larvae throughout stream networks. Host species for this Eastern elliptio include American eel, yellow perch, brook trout, and mottled sculpin.

COMMON CULVERT PROBLEMS

Some causes of barriers to fish and other aquatic organisms can be traced back to the incorrect sizing or installation of the structure. Site characteristics, such as downstream channel degradation, steep channel slopes, sediment load, and overall channel stability can also influence whether a culvert becomes a barrier to aquatic organisms. Identifying and understanding characteristics of poor stream crossings is critical for evaluating whether a certain crossing should be fixed or replaced and informs recommendations for proper stream crossing design.

Undersized culverts can constrict channel flow relative to the natural upstream and downstream flow conditions, especially during flood events. This can lead to sediment deposition, ponding, flooding, clogging, and erosion. If undersized crossings are left unchecked, they can result in failed structures and damage to roadways or other infrastructure. Undersized culverts create high velocity through the structure during high flow events. This high velocity can result in downstream scouring and sometimes *perching*. Resulting scour pools downstream of undersized culverts can pose an ongoing maintenance issue that needs to be corrected with rip rap or other scour protection to protect the structure. The scouring can create a drop in water level below the outlet of the culvert that results in a barrier to fish passage. Perched culvert conditions can also result from *long-term bed degradation* downstream of the culvert, or steeper channel and structure slopes.

Structure installation, or placement, determines the horizontal and vertical angle of the crossing structure, relative to the stream channel. Shallow crossings can result from structures that have been installed too high, resulting in water depths that are insufficient for aquatic organism passage. Shallow crossing can also result from steep channel and structure slopes or sediment deposition in or upstream of the culvert.

Open-bottomed structures and culverts embedded below the streambed can allow for substrate and flows comparable to the surrounding stream. Careful consideration should be given to the vertical and horizontal alignment of the crossing structure, relative to upstream and downstream conditions.



Perched Culvert



Shallow Crossing

CONSEQUENCES OF POORLY DESIGNED STREAM CROSSINGS



Vertical Barrier

Perched crossings can create an impassable vertical barrier when an organism cannot overcome the difference in water surface elevation from within the structure to downstream during typical flow conditions. Water depth below the outlet can also dictate whether the vertical barrier is passable for certain species by providing a jumping pool.



Low Flow

Shallow crossings can be a problem for fish and other organisms when water depths are insufficient for navigation through the crossing structure. Aquatic organisms need sufficient water depths to navigate a structure under typical flow conditions.



Unnatural Bed Substrate

Smooth and uniform surfaces of concrete and metal culverts provide no hiding and resting areas for aquatic organisms and are not ideal for organisms that travel along the streambed. Natural substrate, including rocks and finer sediments, should match substrate characteristics of the surrounding stream.



High Flow Velocity

When channel flows are constricted at a crossing, water velocity can be substantially higher within the structure and out the outlet, compared to the surrounding stream. During flood events, water velocities within undersized crossing structures can prevent successful passage by fish and other aquatic organisms.



Clogging

Undersized crossings and crossings consisting of multiple cells can be prone to clogging by woody debris, leaves, trash, and other materials carried downstream. Debris jams at the upstream end of crossings can inhibit organism passage and can often lead to costly maintenance to avoid flooding or structure failure.



Scour and Bank Erosion

Undersized or improperly aligned crossings can result in bed scour and bank erosion due to high water velocities. Excessive scour can create a large scour pool and perched outlet. Scour can also cause undermining of a culvert's wing walls and outlet apron resulting in structural failure.

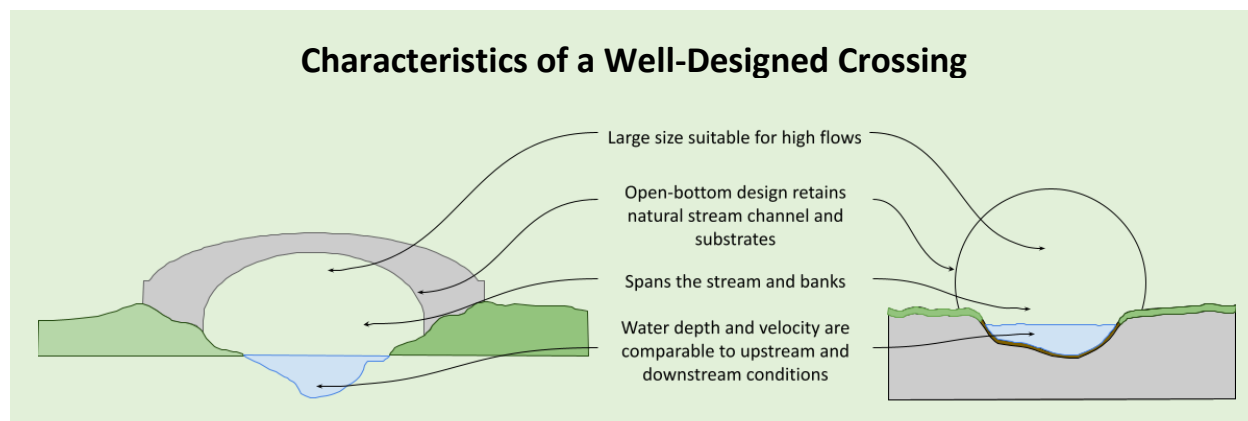
STREAM CROSSING RECOMMENDATIONS

Below is a set of recommendations based on the *geomorphic simulation* design approach for road-stream crossings. Using a geomorphic simulation approach allows for natural system processes including flood resilience and aquatic organism passage. The recommendations below can assist designers in selecting stream crossing structures and placement that retain stream continuity and protect stream health, as well as reduce maintenance costs associated with erosion and structural damage. This design approach allows conditions within crossing structures to be comparable to upstream and downstream conditions, with an emphasis on continuity of flow and substrate through the crossing and avoiding constriction of the channel and streambanks. Our goal is to present recommendations for road-stream crossings in Maryland that can be considered during the design process.

These recommendations were developed for permanent road-stream crossings located along non-tidal streams. They are intended for new and replacement crossing structures, not repairs to existing structures. Recommendations should be used to the maximum extent practicable given existing site and project constraints and are intended to provide conceptual guidance for passage of aquatic organisms and terrestrial organisms under typical flow conditions. These recommendations are not all-encompassing and

are meant to be used as minimum requirements for maintaining stream continuity. Although descriptions of hydrologic site analysis are not included here, due diligent site design to meet minimum cross-sectional area requirements should be used. To complete a geomorphic assessment of the stream, existing conditions (e.g., bankfull width, gradient, water velocity, depth, and substrate) upstream and downstream of the crossing should be measured. A section of the stream that is unimpacted by the crossing can be selected to represent characteristics that can be simulated within the crossing.

Each section below includes an **Objective** as well as two sets of recommendations: **General** or **Preferred**. The goal of the general recommendations is to provide overall stream continuity and passage for aquatic organisms and semi-aquatic and smaller terrestrial organisms. The preferred recommendations should be considered for crossings where the stream corridor functions as a significant landscape-level corridor and for crossings where terrestrial wildlife passage is of particular concern. Preferred recommendations include some numerical descriptions intended solely as guidelines to clarify recommendations. The definitions section should be referenced for further understanding of terminology used in the below recommendations.



MARYLAND STREAM CROSSING RECOMMENDATIONS

Note: see **Design Considerations** on pages 9, 10, and 11.

1. Crossing Type

Objective: A single structure that allows the stream to pass through a single opening.

General: Spanning structures are recommended (bridges, bottomless arches, 3-sided box culverts, and other open-bottom culverts). One round, elliptical and box culvert can be used where its dimensions can meet the other recommendations (2-6) in this document. Use of multiple culverts should be avoided. If the use of multiple culverts is required, ensure that all flow passes through one culvert during most flow conditions and other culverts are used only in high flow conditions.

Preferred: Use a bridge.

2. Crossing Dimensions

Objective: A structure that spans the channel and *banks* to allow aquatic organism passage and dry passage for most terrestrial species over a short distance.

General: The structure should be wide enough to encompass a natural stable channel and banks, to allow not only aquatic but also semi-aquatic and terrestrial passage. To reduce length of passage for aquatic organisms, crossing length should be minimized, with the use of headwalls if necessary.

Preferred: A structure that is wide enough to span a natural stable channel and banks (a minimum structure width of 1.2 times the channel width) plus additional headroom to provide semi-aquatic and terrestrial wildlife passage. To achieve headroom for terrestrial species, the structure should have an *openness ratio* above the streambed, of 0.82 - 1.64 feet (0.25 - 0.5 meters). Minimize crossing length with the use of headwalls if necessary.

3. Embedment

Objective: Natural stream bottom through a crossing and stable footers for bottomless structures.

General: Per Maryland state regulations, culvert bottoms should be *embedded* below the streambed a minimum of 1 foot. Footers of bottomless structures should be placed at a depth and width to avoid destabilization through scour.

Preferred: If a bridge is not feasible due to project constraints, culvert bottoms and footers for bottomless structures should extend below the *vertical adjustment potential*.

4. Location, Alignment, and Placement

Objective: A structure that avoids unwanted aggradation and degradation inside or outside of the crossing due to unnatural slope or incorrect alignment.

General: Culverts should be aligned with the natural stream channel and skew should be minimized.

Preferred: Culverts should be aligned with the natural stream channel and skew should be minimized, not exceeding 30 degrees. The gradient should not exceed 3% for buried/sunken culverts. If the gradient exceeds 3%, a bottomless culvert or bridge should be used. When possible, crossing structures should be located at a pool feature.

5. Water Velocity and Depth

Objective: Maintain water velocity and depth, similar to conditions in the rest of the stream.

General and Preferred: Water velocity and depth within the crossing structure should match those observed at locations upstream or downstream, not impacted by the crossing. Low flow conditions should not result in reduced fish passage within the culvert, compared to upstream and downstream conditions.

6. Substrate

Objective: Natural substrate through the road-stream crossing to provide habitat for aquatic and terrestrial species, similar to conditions upstream and downstream of the crossing.

General and Preferred: Substrate should be placed within the structure, including both fine and coarse substrate, and should match the natural substrate composition found upstream or downstream in an area not impacted by the crossing. Bank and other key bed structural elements and characteristics should be resilient to high-flow events. If recommendations 1-5 of this document are used, natural aggradation and degradation of substrate should not result in excessive scour within the crossing. Channel manipulation upstream and downstream of the structure (e.g., stream restoration, stabilization, etc.) maybe be needed to fill scour holes and reduce aggradation caused by previous road-stream crossing structures. Scour protection should not result in reduced aquatic organism passage.

DESIGN CONSIDERATIONS

The primary purpose of the recommendations presented in this document is to prevent barrier effects of road-stream crossings on fish and other aquatic organisms. With that in mind, these recommendations were developed to promote designing crossings that are nearly “invisible” to aquatic organisms by maintaining stream continuity. These recommendations may not be sufficient for all project needs, including addressing drainage or flooding issues. Project and site constraints must also be considered during the design and permitting of new and replacement stream crossings. For example, effects of downstream flooding resulting from increasing the size of a culvert needs to be considered.

These stream crossing recommendations are not prescriptive, and the use of these recommendations does not replace the need for sound engineering and design practices completed by qualified professionals. The design approach for a road-stream crossing should be dictated by project objectives and site/project constraints. Common design approaches for providing aquatic organism passage, such as *geomorphic simulation*, *hydraulic simulation*, and *hydraulic design*, all require an understanding of project needs, stream geomorphology, and hydrology. The recommendations presented here are most consistent with the geomorphic simulation, or “Stream Simulation”, design approach. Crossings designed with this approach have a continuous bed that approximates the natural streambed up to bankfull flows. The “Stream Simulation” approach avoids constriction of the channel and banks and creates a stream channel with a diverse streambed throughout the crossing, reflective of conditions along the adjacent stream. For additional details, please refer to the U.S. Forest Service publication “Stream Simulation: An Ecological Approach to Providing Passage for

Aquatic Organisms at Road-Stream Crossings”, included under **Additional Resources**.

Structure Width: A structure width of 1.2 times the channel width is intended to be the minimum recommended width for maintaining channel and bank stability during frequent storm events (e.g., about 1.5-year storms); however, this should be verified based on site characteristics. The minimum structure width may be inadequate for maintaining bank and other key bed elements within the crossing structure during higher flows associated with infrequent storm events. Wider structures or the use of multiple culverts to convey flood waters may be necessary to avoid excessive flow constriction and washout of bed materials during high flow events. Channel width should be determined from a minimum of three measurements. For new crossings, channel width should be measured at the proposed crossing location, as well as upstream and downstream of the proposed location. For replacement crossings, channel width should be determined along straight sections of the stream, outside the influence of the existing crossing or other structures. Determining channel width and the appropriate structure size can be particularly difficult in degraded or urban streams. The minimum structure width of 1.2 times the channel width is typically recommended under the assumption that *bankfull width* is used as the channel width (e.g., “Massachusetts Stream Crossings Handbook”). A calculated bankfull width using regional curve data can be used to verify field calculations (See **Additional Resources**). Alternative channel width measurements can also be used to determine structure width, such as *active channel width*; however, different multipliers, such as 1.5 times the active channel width are typically used (e.g., National Marine Fisheries Service “Guidelines for Salmonid Passage at Stream Crossings”) to meet the objectives of this recommendation.

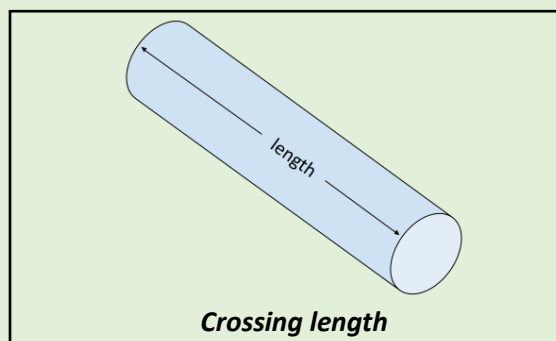
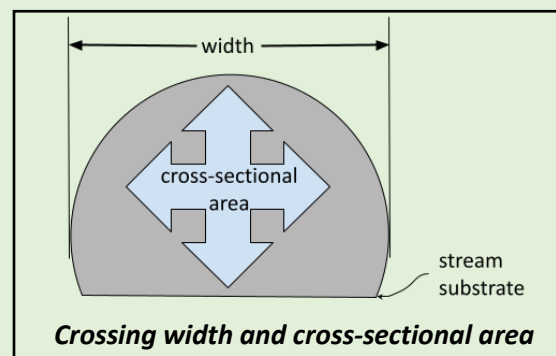
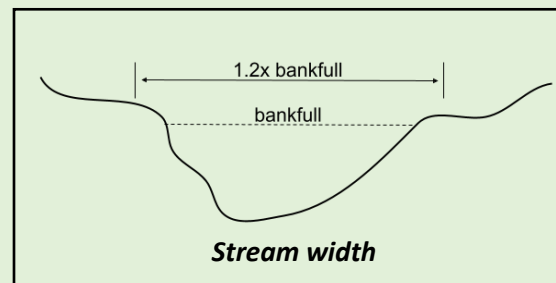
Openness: There is limited information on how fish and wildlife utilize culverts in response to different openness ratios; however, confinement is generally thought to lead to avoidance. Studies on structure usage and avoidance by large mammals have found that minimum openness ratios for passage range from about 1.5 feet to over 3 feet. The goal of the minimum openness ratio recommendation of 0.82 feet is to maintain an openness ratio that is sufficient for fish and small riverine wildlife species. Structures that meet this openness ratio are also more likely than traditional culverts to pass flow and debris that could otherwise obstruct water passage. The intent of the maximum openness ratio of 1.64 feet is to provide additional connectivity along the stream corridor for terrestrial species. This ratio, with a structure clearance of at least 6 feet, has been used by other states to provide some passage for larger mammals.

Embedment and Substrate: The minimum embedment recommendations may not be sufficient for all culverts. Ideally, culvert bottoms and footers should be placed below the elevation of the vertical adjustment potential and should account for long-term bed degradation. Stream conditions may dictate the need for greater embedment, such as in higher gradient streams or less-stable systems. Scour protection measures can also be considered, depending on the magnitude of predicted vertical adjustment potential and long-term bed degradation; however, protection measures should not result in reduced aquatic organism passage. Substrate within the structure should be similar to the characteristics of the substrate in the natural stream channel upstream and downstream of the crossing. Design considerations should be made to ensure that substrate within the structure meets the desired characteristics after a period of adjustment following construction. Substrate characteristics should be designed for resiliency, to resist the complete loss of bed material during large storms events and to maintain appropriate

channel and bed characteristics through natural bed load transport. In order to ensure bed stability at higher flows, it may be necessary to use larger substrate within the structure than is found upstream or downstream, depending on site characteristics.

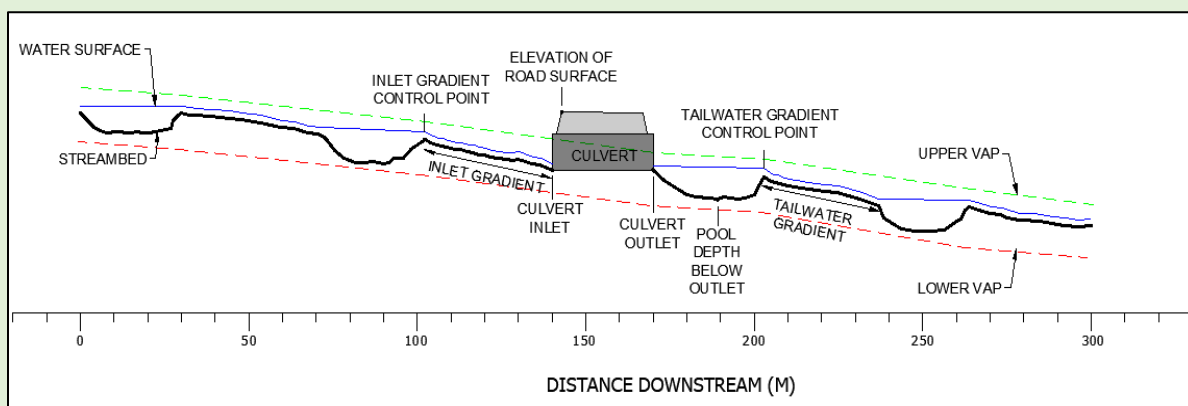
Predicted channel evolution upstream and downstream of the crossing should also be considered, as well as the potential for upstream bed degradation resulting from the use of an embedded structure.

Common Stream Crossing Measurements



Location, Alignment, and Placement: Structure design should consider the channel type and *longitudinal profile* of the stream. The longitudinal profile should provide enough information to determine the vertical alignment of the stream through the crossing (e.g., concave, convex, uniform slope, etc.) and the survey should ideally extend 20-30 times the bankfull width on both the upstream and downstream ends of the crossing. Structure location and alignment should include considerations outside of the footprint of the structure in order to account for the stream's existing geomorphology and predicted channel evolution upstream and downstream of the channel. In some situations, channel manipulation upstream and downstream of the crossing (e.g., stream restoration, stabilization, etc.) may be required to maintain stability of the structure and channel. On some occasions, a crossing may need to maintain a slope different than the natural stream channel. For example, an existing structure may be acting as a grade control due to an incised downstream channel. This needs to be considered early in the planning and design process for replacement structures to determine the best design alternatives for maintaining aquatic organism passage.

Regulations: The stream crossing recommendations presented in this document are not regulations. These recommendations are intended to be used in conjunction with local, state, and/or federal regulations, including those found in Code of Maryland (COMAR) Sec. 26.17.04.06. Bridges and Culverts, Maryland State Programmatic General Permit (SPGP), and Regional Conditions to the 2020 Nationwide Permits (NWP) for the State of Maryland. Under COMAR Sec. 26.17.04.06, culverts "shall have at least one cell placed at least 1 foot below the invert of the stream" and "protective measures may not prevent the passage of fish." Under the SPGP-5, activities within Waters of the U.S. "must not block or impeded the movements of anadromous or resident fish species." The SPGP and NWP guidelines also require depressing culvert bottoms and considering the use of bridges or bottomless crossing structures. See **Additional Resources** for resources on state and federal regulations.



Example of a longitudinal profile, showing basic measurements often used by engineers in stream-crossing design. An example of vertical adjustment potential (VAP) is also depicted, showing the range of potential vertical streambed adjustment.

ADDITIONAL CONSIDERATIONS

Although not specifically addressed by recommendations in this document, future changes to the watershed, such as planned development, and changes in storm frequency and intensity associated with climate change should be considered when determining structure size and alignment, to the extent feasible. Engineers typically use historic data to predict the magnitude, seasonality, and duration of low flows critical to aquatic organism passage, and to characterize storm event patterns in order to design resilient crossings based on the probability of similar storm events occurring in the future. Past practice has assumed that the magnitudes and temporal patterns of future flows will match those that occurred in the past. However, observations show that these patterns are changing, and models predict that they will continue to change within the design life of structures. Instead of relying solely on historical data, climate models and assessments should be considered during the design process to account for predicted changes in hydroclimate, including alterations in seasonal precipitation, the duration of dry periods, and the timing and distribution of precipitation events. See **Additional Resources** for climate change resources.

Crossing structures designed and installed in other states that followed similar recommendations presented in this document have been found to safely pass large volumes of water, sediment, and debris stirred up by high flows, while maintaining safe travel for the public. This is important with respect to climate change, because predicted changes in storm frequency and intensity will likely result in more frequent large-flow events. Because common causes of movement barriers for aquatic organisms can often be traced back to undersized structures (e.g., perched outlets, scour pools, and debris jams), goals for aquatic organism passage and infrastructure resiliency can often align by maintaining or restoring stream continuity.

Undersized crossings are more vulnerable to overtopping and can be more susceptible to failure during high flow events. Future planning that considers this overlap between ecological and transportation goals by promoting flood resiliency and stream continuity can benefit the communities utilizing both the road and the stream. Additional details on the financial benefits of maintaining aquatic continuity through flood-resilient crossings are provided in the following section.



Flooded roadway along MD 450 due to undersized and clogged culverts (Photo credit: Capital Gazette)



Undersized culverts can become a barrier to aquatic organism movement long before they become an issue for public safety and infrastructure. (Photo credit: Seth Moessinger, Trout Unlimited)

FINANCIAL BENEFITS OF MAINTAINING STREAM CONTINUITY

Financial considerations in the planning and design process should account for long-term benefits and not solely the short-term costs of replacing or installing a structure. This includes considering the economic, societal, and natural resources costs of a potential crossing failure, including effects on adjacent infrastructure and private property. In addition, delay costs and risks to public health and safety from the disruption of commerce and travel due to a failed structure and collapsed roadway should be considered, despite the difficulty in quantifying such costs.

During storm events, crossing structures may fail when flows exceed the hydraulic capacity of the structure and/or sediment and debris clog the structure, which can result in severe and costly impacts to human safety, property, and infrastructure. The likelihood of a culvert failing during a flood event can be reduced through appropriate sizing and configuration, especially when those culverts are replaced with a bridge or appropriately designed culvert. Emergency structure replacement costs following an unexpected structure failure are generally higher than planned replacement costs.

Utilizing a design approach that provides better ecological connectivity and flood resiliency over traditional hydraulic design practices focused on flood capacity can appear less economical due to higher upfront installation costs. For example, data from culvert replacements in the northwestern United States indicates that increasing the width of a crossing structure by 50 percent can result in an increase in installation costs by 20 to 33 percent. These replacement costs also depend on stream size, as the cost of removing barriers at culverts typically increases with stream size.

When maintenance, replacement, and longevity are considered in overall cost, however, the average annual cost of a stream crossing that

spans the banks and is capable of passing higher flows can be lower over its lifetime than an undersized crossing structure. Stream simulation designs that span the bankfull channel can have little or no annual maintenance costs and are resilient to flooding, whereas hydraulic designs that constrict the stream channel can require frequent maintenance for debris removal and can pose a greater risk of failure during large floods. Further, bottomless or properly embedded structures that span the channel can be protected from bedload abrasion by the constructed stream channel bed and margins. Galvanized steel culverts installed using stream simulation design methods can have an expected service life of 50 to 75 years, compared to 25 to 50 years for a traditional galvanized steel culvert installed with hydraulic design methods. Following large storm events, adjustments to streambed construction can sometimes be necessary for structures designed using stream simulation methods; therefore, maintenance costs are not always negligible and case studies in Maryland are needed to assess the performance structures designed using “Stream Simulation” methods.

Additional information on financial benefits and economic analyses of improved road-stream crossings can be found in the **References** section.



*Collapsed roadway in Ellicott City, MD due to flooding
(Photo credit: Katherine Frey, The Washington Post)*

CASE STUDY: WOLFDEN RUN CULVERT REPLACEMENT

Wolfden Run is a tributary to the Potomac River, located in Garrett County, Maryland. The surrounding land was acquired by the Maryland Department of Natural Resources (DNR) and has been incorporated into the Maryland State Park system. The road-stream crossing at Wolfden Run was prioritized by Trout Unlimited because the stream is inhabited by brook trout. Due to the presence of multiple culverts and poor condition of the crossing, fish passage was severely limited. In addition, the existing road did not meet standards required for emergency vehicles to access the now state-owned property. Maryland DNR, Trout Unlimited, and USFWS partnered to replace the road-stream crossing with a goal of providing fish passage and stream continuity. Maryland DNR completed the survey and design work for the project with guidance from USFWS.

Trout Unlimited served as the project manager and received funding from the USFWS's National Fish Passage Program and National Fish Habitat Partnership through the Eastern Brook Trout Joint Venture.

The project removed the barrier for migrating fish, reconnecting brook trout to 2.8 miles of headwater habitat and provided a stable span bridge sufficient for conveying emergency vehicles into the park. The bridge will improve recreational opportunities within Wolfden Run State Park, allowing visitors to have better access for fishing, bird watching, hiking, and other outdoor recreational activities.



Original multiple pipe culvert (Photo credit: Seth Moessinger, Trout Unlimited)



Replacement span bridge (Photo credit: Seth Moessinger, Trout Unlimited)



Replacement span bridge and educational plaque (Photo credit: Seth Moessinger, Trout Unlimited)

Location: Kitzmiller, MD

Project Partners: Maryland DNR, Trout Unlimited, USFWS, Eastern Brook Trout Joint Venture, National Fish and Wildlife Foundation

Project Cost: \$156,000

CASE STUDY: BOBBS CREEK AQUATIC ORGANISM PASSAGE PROJECT

Bobbs Creek is a high quality coldwater tributary to Tionesta Creek, located in the Allegheny National Forest (ANF) in Forest County, Pennsylvania. Trout streams within the ANF are considered a priority for brook trout conservations due to existing brook trout populations and its proximity to the western extent of the current range for eastern brook trout.

Within the ANF, US Forest Service (USFS) Road 116 parallels Bobbs Creek for over a mile and a half, crossing two unnamed tributaries. These two crossings (hereafter crossings 116/1 and 116/2) were acting as fish barriers, becoming choked with debris and creating conditions that were impassable for brook trout during much of the year. In addition, these crossings also had a high potential for failure, safety concerns, and the potential to deliver large sediment loads to Bobbs Creek. Both crossings were comprised of multiple pipe culverts – crossing 116/1 was comprised of

two 48 in. x 26 ft. corrugated metal pipes and crossing 116/2 was comprised of three 48 in. x 34 ft. corrugated metal pipes.

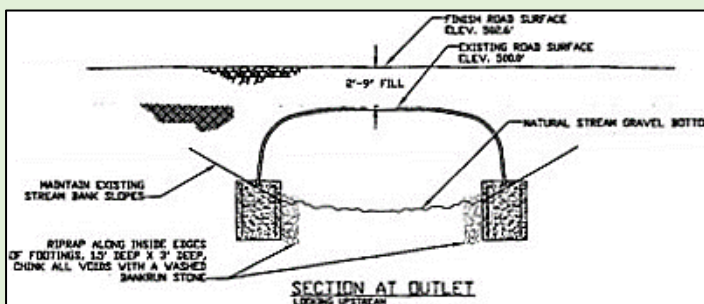
In the summer of 2011, both crossings were replaced with bottomless galvanized steel box culverts, set on concrete footers and filled with natural gravel substrate. The new structures span the bankfull width of the streams, restoring aquatic organism passage to 3.8 miles of habitat. Additional project goals included re-establishing natural stream processes and habitat conditions; improving recreational fisheries; reducing flooding potential of USFS road 116; and reducing sediment delivery downstream to Bobbs Creek. With an expected lifespan of at least 50 years for the replacement culverts, this project is expected to have long-term benefits to the watershed, as well as providing improved flood resilience for USFS Road 116 at these crossings.



Original triple pipe culvert at USFS Road 116/2 (Photo credit: Brent Pence, USFS)



Replacement bottomless culvert at USFS Road 116/2 (Photo credit: unknown, USFS)



Replacement bottomless culvert at USFS Road 116/2

Location: Forest County, PA

Project Partners: USFWS, Eastern Brook Trout Joint Venture, and Allegheny National Forest (USFS)

Project Cost: \$93,000 per crossing

CASE STUDY: FISH KILL CREEK CULVERT REPLACEMENT

Working with the USFWS, the Town of Newfield (New York) replaced a failing culvert along Douglas Road, located at the Fish Kill Creek crossing. Because of an overlap between conservation priorities and the need to repair the failing culvert, technical and funding support was available to the Town of Newfield. During the planning process, the Town of Newfield considered replacing the structure with a bridge; however, that option would have required Tompkins County to take ownership and maintenance of the structure which would have resulted in project delays. Due to safety concerns with the existing culvert rusting and joints becoming separated, a bottomless culvert option was selected to avoid delays and funding issues.

In 2016, the original 10 ft. diameter steel pipe that was conveying Fish Kill Creek underneath of

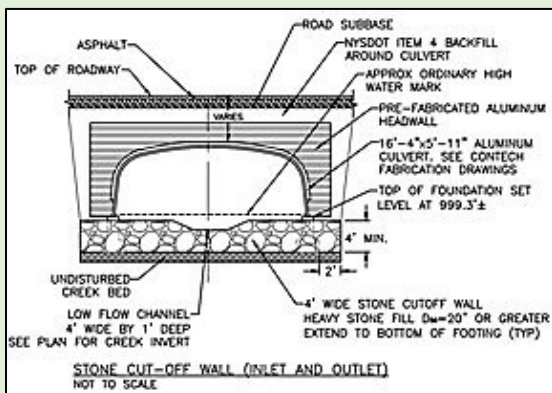
Douglas Road was replaced by a bottomless aluminum box culvert, designed by Contech Engineering Solutions. During installation, the old culvert was removed and concrete foundations were formed and poured. The streambed below the culvert was armored with coarse stone and then backfilled after the culvert was set in place. The replacement culvert was 16 ft. and 4 in. wide, with a rise of 5 ft. and 11 in and a total length of 49 ft. and 9 in. The minimum culvert width requirement for New York (1.25 times the width of the stream channel bed) could not be attained due to site constraints; however, the larger structure width improved existing conditions by more closely reflecting the upstream ordinary high water width. In addition, the open bottom allowed for natural substrate to fill in, improving aquatic organism passage.



Original steel pipe culvert at Douglas Road



Replacement bottomless culvert at Douglas Road



Replacement bottomless culvert at Douglas Road

Location: Newfield, NY

Project Partners: USFWS, Town of Newfield

Project Cost: \$129,620

CASE STUDY: RUTLAND ROAD FISH PASSAGE PROJECT

The North River flows into the tidal South River and eventually out to the Chesapeake Bay. Historically, the North and South Rivers supported spawning runs for a variety of migratory fish species, including yellow perch. The lower extent of the North River parallels MD Route 450, or Defense Highway. The North River flows under Rutland Road, near its intersection with MD Route 450.

The pre-existing structure located at the Rutland Road crossing was a triple-cell culvert consisting of 48 in. corrugated metal pipes. This triple-cell culvert was failing structurally, contributing to flooding of Rutland Road and MD Route 450, and was acting as a blockage to migrating fish. In 2018, the Anne Arundel County Bureau of Watershed Protection and Restoration (BWPR) replaced the failing culverts with a pre-stressed concrete slab bridge that spans the channel.

The structure replacement also involved stabilizing the North River streambed approximately 350 feet between Rutland Road and a large, open-water wetland complex upstream. This project presented non-traditional design constraints, as the open-water wetland complex upstream had to be maintained. To overcome this constraint, weir wall structures were utilized upstream of the bridge and rock ramps were utilized downstream of the bridge to maintain the open-water habitat and aquatic organism passage.

The project successfully removed the physical barrier to migrating fish that was created by the old triple-cell culvert, providing access to approximately six miles of upstream habitat for yellow perch and other species. Preliminary reports also indicate that the project may have helped with roadway flooding issues, as MD Route 450 remained open during most heavy rain events following the completion of the project.



Original triple pipe culvert at Rutland Road



Replacement slab bridge at Rutland Road



Weir wall structures installed upstream of roadway

Location: Davidsonville, MD

Project Partners: Anne Arundel County BWPR; County Engineers Association of Maryland

Project Cost: \$1,850,000

PRIORITIZING EFFORTS FOR TARGET SPECIES

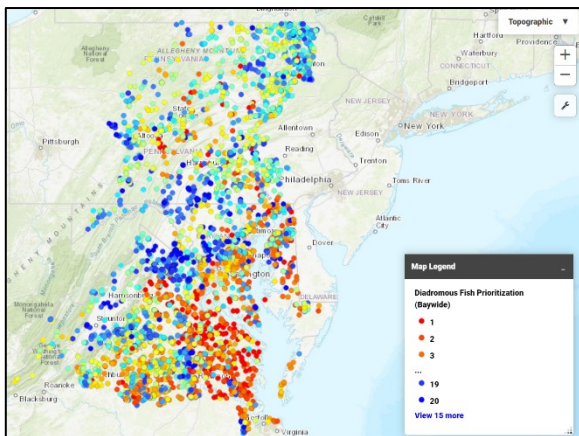
Although stream continuity benefits aquatic communities as whole, the Chesapeake Bay Program's Fish Passage Workgroup has worked to develop criteria for prioritizing fish passage projects in the Chesapeake Bay region. Specific target fish species for conservation efforts in Maryland include diadromous species (American eel, alewife, blueback herring, American shad, and hickory shad), brook trout, and rare, threatened, and endangered species. Through collaborative efforts, the Fish Passage Workgroup and The Nature Conservancy (TNC) developed the Chesapeake Fish Passage Prioritization Tool (<https://maps.freshwaternetwork.org/chesapeake/>), which uses GIS data to rank potential barrier removal projects throughout the Chesapeake Bay watershed. This online tool houses GIS data and metrics on hundreds of documented fish blockages in the region and rankings can be customized to meet different needs. Potential fish passage projects with the following characteristics were deemed high priorities for removal by the Fish Passage Workgroup: barrier to migratory fish; benefits to multiple species; largest habitat gains; high quality habitat; barrier to brook trout.



American eel (Photo credit: Kevin Stohlgren, Coastal Resources, Inc.)

The North Atlantic Aquatic Connectivity Collaborative (NAACC) also has valuable resources for documenting and assessing the severity of blockages at road-stream crossing as well as prioritizing conservation efforts. The NAACC houses an online database (https://naacc.org/naacc_search_crossing.cfm) where road-stream crossing assessment data are stored. The distribution of available road-stream crossing assessment data in Maryland is based on U.S. Fish and Wildlife Service's priority species including anadromous fish, brook trout, federally listed species, and at-risk species. The NAACC website also houses additional information about road-stream crossings such as prioritizations and protocols for assessing road-stream crossings.

Other states have developed prioritization models to rate aquatic connectedness and inform stream-crossing design practices. For example, the University of Massachusetts developed Critical Linkages to assess connectivity and restoration potential for barrier removal projects. The University of Massachusetts also developed the Conservation Assessment and Prioritization System (CAPS) to assess the ecological integrity for various ecological communities, including streams. Resource information for Critical Linkages, CAPS, the Chesapeake Fish Passage Prioritization Tool, and the NAACC database can be found in the **Additional Resources** section.



Chesapeake Fish Passage Prioritization Tool (Obtained from <https://maps.freshwaternetwork.org/chesapeake/>)

DEFINITIONS

Active channel width: The width between the ordinary high water lines of the channel measured perpendicular to streamflow. The active channel width is typically narrower than the bankfull width. Ordinary high water lines are typically determined by changes in bank vegetation; changes in sediment size and/or color; water lines on the bank, trees, or leaves; or the point where debris accumulation begins.

Anadromous: Fish born in freshwater that spend most of their lives in saltwater and return to freshwater to reproduce, or spawn.

Bankfull width: The width of the water surface elevation at bankfull discharge, measured perpendicular to streamflow.

Diadromous: Fish that spend part of their life cycle in freshwater and part of their life cycle in saltwater.

Embedded: Also referred to as sunken, countersunk, or depressed, with respect to culverts. Embedded culverts are placed with their bottom below the streambed elevation to allow for natural substrate along the bottom.

Geomorphic simulation: Design approach that attempts to maintain or recreate natural stream reach geomorphic elements through the crossing, including slope, channel width, substrate, and bedform.

Hydraulic design: Design approach that utilizes natural or artificial flow control structures to create hydraulic conditions (e.g., water depth and velocity) that meet the swimming abilities of target fish species during specific periods of fish movement or migration.

Hydraulic simulation: Design approach that attempts to closely match streamflow characteristics in the crossing structure to that of the natural stream. Common techniques include embedding culvert structures, avoiding most channel constriction, and using natural and coarse sediment in the structure. This approach assumes that providing hydraulic diversity that is similar to that found in the natural stream will allow for aquatic organism passage.

Long-term bed degradation: The vertical change in the channel profile other than that caused by local or contraction scour.

Longitudinal profile: A longitudinal profile is a surveyed profile along the deepest portion of the stream channel. This plot of elevation over distance along the channel is used to characterize the stream slope and depths of various channel features.

Openness ratio: Defined as the cross-sectional area of a structure's opening divided by the crossing length, when measured in consistent units (e.g., feet, meters, etc.). The embedded portion of a culvert is not included in the cross-sectional area for determining openness.

Perching: The tendency to develop a scour hole at the outfall of a culvert due to erosion of the stream channel.

Semi-anadromous: Fish that occupy intermediate life history characteristics between resident and anadromous fish. They feed in brackish waters at the mouths of rivers and estuaries and reproduce in freshwater without fully migrating to saltwater habitats.

Stream continuity: The uninterrupted connection of a river network where the natural physical characteristics of the stream have not been significantly altered and few or no barriers exist that would hinder or block movement up and downstream through the system by aquatic organisms.

Thermal refugia: A place that serves as shelter from adverse temperatures.

Vertical adjustment potential: The range of elevations over which the streambed might vary over the life of a structure. A longitudinal profile is necessary to determine the vertical adjustment potential of the streambed.

ADDITIONAL RESOURCES

State and Federal Regulations and Permits

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Maryland Stream Crossing Recommendations

An inventory of standards, recommendations, and guidelines used by other states and organizations across the United States can be found at the following link on the Chesapeake Bay Program's website: [Placeholder for link](#)

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