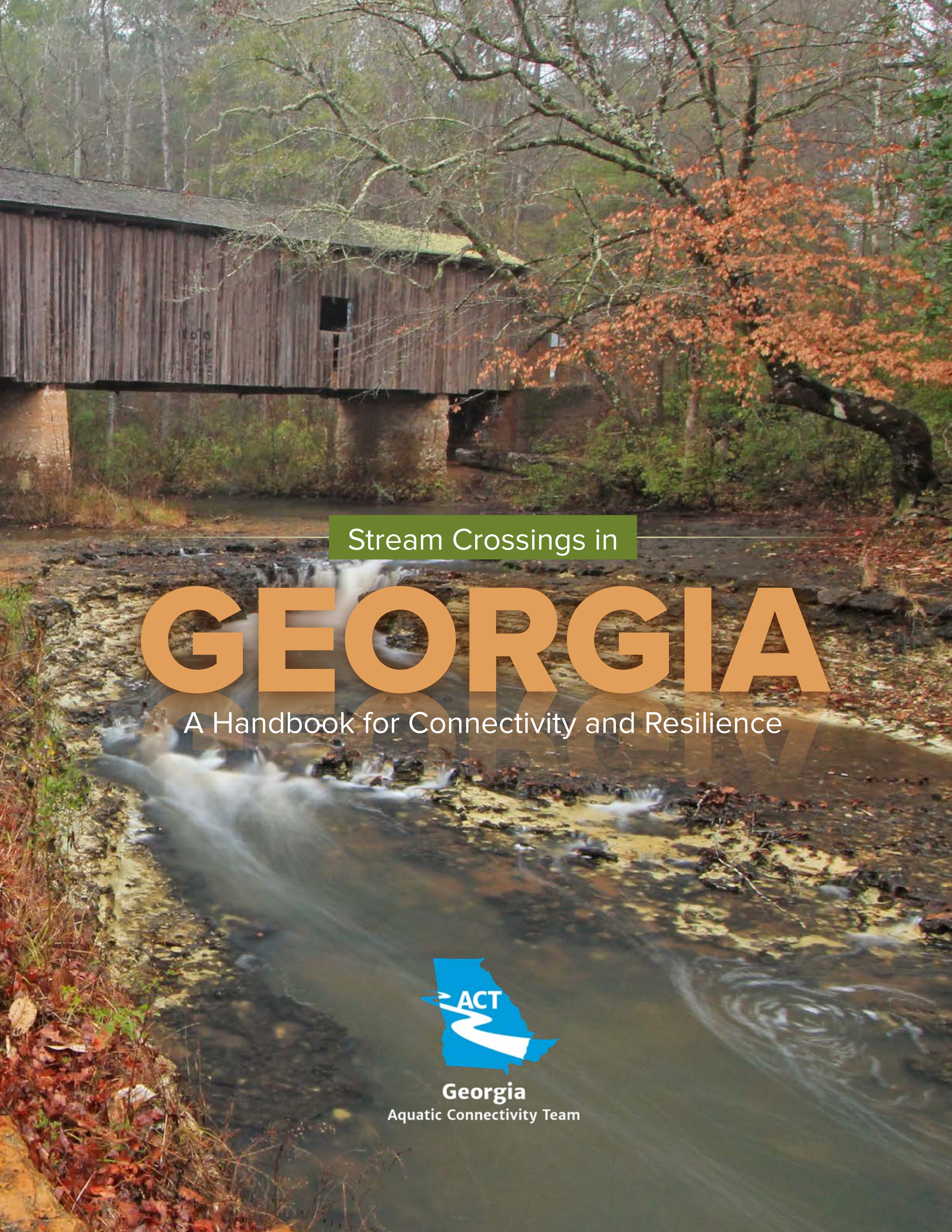

Stream Crossings in

GEORGIA

A Handbook for Connectivity and Resilience

Georgia
Aquatic Connectivity Team

CONTENTS

Cover and backcover:
Stream crossings have long been a necessary part of the transportation system in Georgia. The Coheelee Creek Covered Bridge was built in 1891 in Early County.
Credit: Alan Cressler

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Stream Crossings in GEORGIA

A Handbook for Connectivity and Resilience

This handbook builds upon the original 2012 version by Eric Prowell and Will Duncan (U.S. Fish and Wildlife Service, Georgia Ecological Services) and Brett Albanese (Georgia Department of Natural Resources, Wildlife Resources Division). We are grateful for the U.S. Fish and Wildlife Service, Georgia Department of Natural Resources, Georgia Department of Transportation, U.S. Army Corps of Engineers, National Resource Conservation Service, University of Georgia, U.S. Environmental Protection Agency Region 4 and private businesses for their contributions in writing and revising this new edition. All photographs in this handbook are from Georgia and are those of the authors unless otherwise specified. Copies of this publication can be downloaded from the Georgia Aquatic Connectivity Team website (ga-act.org) or by contacting:

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Newly installed bottomless arch culvert on Perry Creek in Fayette County.
Credit: Sara Gottlieb/TNC

This handbook is intended to encourage the proper design and implementation of all new stream crossings in Georgia to maintain stream connectivity, improve stream health, provide for public safety, improve water quality and make communities more resilient.

Section 1

Introduction and Background

The southeastern United States is home to an extraordinary diversity of aquatic-dependent wildlife. Yet where roads and streams intersect, poorly designed culverts, bridges and other structures often fragment aquatic habitats – contributing to the Southeast also having one of the highest fish imperilment rates in the world (Elkins et al, 2016; 2019). Poorly designed or degraded stream crossings also alter hydrology, impact water quality and often fail during extreme weather events. Large numbers of aging, undersized and poorly maintained stream crossings in a watershed can result in widespread failures, closing roads and stranding communities during extreme rainfall and flood events. South Carolina faced this in October 2015 when dozens of roads failed during a 1,000-year storm event (Gassman et al, 2017). These culvert washouts are dangerous, disruptive and extremely costly.

Georgia's more than 70,000 miles of rivers and streams flow from the Appalachian Mountains to the Atlantic and Gulf coasts, and intersect with more than 85,000 roads. Through different physiographic regions, these streams create unique and diverse habitats that support many types of species. About three-quarters of fish species and more than 90 percent of all mussel and crayfish species native to the United States reside in a 500-mile radius of Chattanooga, Tenn. (Elkins et al, 2019) – a diversity of life that is nationally and globally significant.

Georgia's rivers and streams are also exceptional for their beauty and recreational value. Protecting them is a matter of pride for Georgians, as is evident by the many stream cleanup events, restoration projects and water trail designations across the state. Despite this public awareness, however, few people consider how stream crossings can degrade stream habitat and threaten public safety.

Aquatic connectivity at stream crossings is best maintained by providing flow conditions through the structure that mimic, as much as possible, the conditions in the natural stream. Such a structure will have comparable water depths and velocities as those in the channel upstream and downstream. This will allow animals to migrate along the stream corridor and high flows and sediment to pass through. Historically, road designers did not consider stream continuity. Even crossings that were not barriers when built may now block wildlife and sediment because of erosion, deterioration of the structure or changes in the shape of the channel upstream or downstream.

Natural resource agencies and the U.S. Army Corps of Engineers have developed regulations designed to keep these large and diverse stream networks connected where roads are constructed over a stream (referred to throughout this handbook as stream crossings). Nevertheless, surveys show that stream crossings continue to fragment habitat and rarely meet the regulatory requirements under nationwide permits (Duncan, et al, 2018). This handbook encourages proper design and installation of new stream crossings in Georgia along with, where possible, replacing or retrofitting improper crossings, all with the goal of preventing the decline of species, improving stream health and public safety, and making communities more resilient to floods.

Fortunately, we have learned how to design stream crossings that allow aquatic and terrestrial wildlife unrestricted access to a watershed, and these designs often cost less over their lifetimes than traditional ones. Design guidelines for fish and wildlife passage are now part of the federal permitting process in Georgia. Local governments, property owners and conservation groups can use the information in this handbook to help protect and restore stream continuity throughout Georgia.

Initially published in 2012 (Prowell, Duncan and Albanese, 2012), this revised, expanded and updated handbook is intended for general audiences including consultants, county engineers, backhoe operators, students, regulators and anyone else interested in the cost-effective design of stream crossings to promote public safety, watershed health, flood resilience and wildlife passage. We outline the importance of maintaining aquatic connectivity at stream crossings, highlight examples where aquatic and terrestrial wildlife can pass easily (and where they cannot), review regulations in general terms, and provide examples to illustrate regulatory intent.

Several new sections highlight an expanded focus on indirect impacts, barrier assessment protocols, resources for getting started and recent case studies. ■

Shoals spider lilies at Hightower Shoals in the Flint River in Talbot and Upson counties, just one of the unique aquatic habitats that depend on healthy, free-flowing rivers and streams in Georgia. Credit: Alan Cressler

An example of poor design: a multiple parallel pipes culvert on Proctor Creek in Atlanta.
Credit: Kelly Rudell/City of Atlanta DWM

Section 2

Signs and Consequences of Poor Design and Indirect Impacts

Signs of Poor Design

Most problematic stream crossings fall into at least one of three broad categories: multiple structures, undersized structures and crossings that are poorly aligned relative to the stream profile and/or gradient. Each of these crossing types is likely to hamper the passage of fish and other aquatic organisms, water quality, infrastructure and public safety.

Multiple Structures

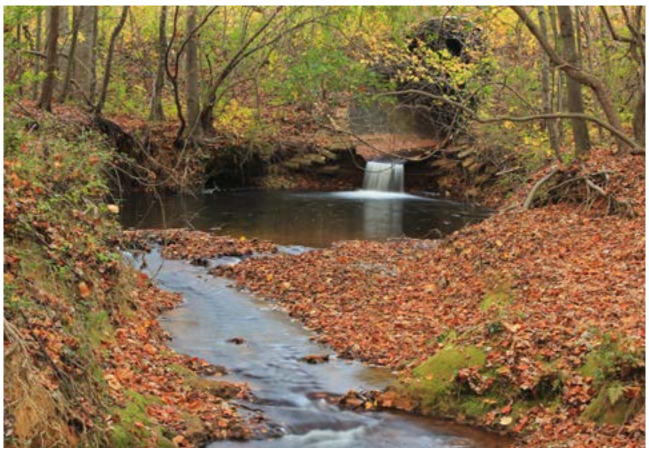
Examples include crossings built using multiple parallel pipe culverts or box culverts with multiple barrels. Multiple entry crossings are prone to clogging and may inhibit the movement of aquatic and terrestrial wildlife. They can also widen the stream, altering channel morphology if too many are placed in the system at stream grade.

Undersized Structures

Undersized structures were not built with proper consideration of the stream's width or its range of flows. These structures restrict natural stream flow, particularly during floods. This can scour and erode streambanks and streambeds, increase water velocity, alter sediment transport, clog and create ponds. They are also more prone to failure than properly sized structures. Structures should be large enough to pass fish, aquatic and terrestrial wildlife and 100-year storm flows per stream simulation guidance (see section 8).

Poor Alignment

Stream crossings that are not properly aligned to the natural stream profile and/or gradient can increase erosion within or downstream of the crossing, perch, scour and erode streambanks, and create shallow water depth in the crossing during periods of normal flow. These alterations can have profound impacts on stream morphology, impact aquatic and terrestrial wildlife passage and eventually lead to failure. Crossings should match the natural channel alignment and gradient to ensure aquatic organism passage and long-term stability and functionality.



Poorly aligned culvert on Basin Creek in Upson County. Credit: Alan Cressler

Consequences of Poor Design

Recognizing poorly designed stream crossings is an important step in managing and evaluating hazards to people and wildlife. Below are some common consequences of poorly designed stream crossings:

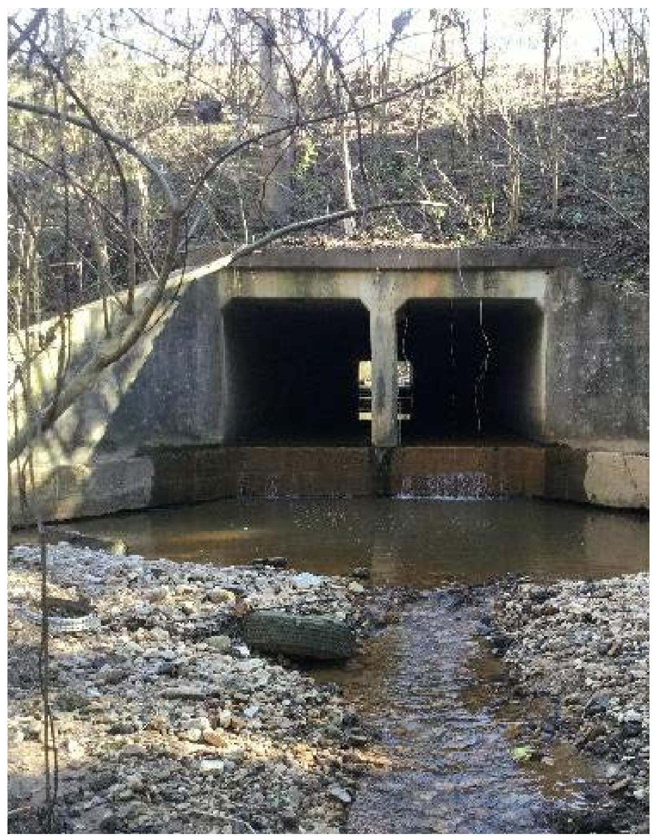
High Water Velocity

Water velocity is increased when the channel is constricted and higher stream flows cannot diffuse onto the floodplain, or the gradient is steeper in the crossing structure than the channel profile upstream or downstream of the crossing. This increased water velocity can inhibit aquatic and terrestrial wildlife passage, increase the likelihood of scour and erosion, and weaken the structural integrity of crossings. These problems are most likely to occur during high flows and floods, but the signs of scour and erosion may also be evident during low and normal flows.

Drainage-ditch flash flood on Noses Creek in Cobb County. Credit: Alan Cressler

Perched Crossings

Perched crossings occur when the structure's bottom is above the level of the streambed at the downstream end. Improper structure design and/or installation, even when initially at the proper stream elevation, can increase water velocities causing downstream streambed erosion that results in a perched crossing. Perched crossings can form a waterfall or cascade that may prevent or reduce aquatic organism passage and may undermine the crossing structure.



Perched box culverts. Credit: Kelly Rudell/City of Atlanta DWM

Upstream Backwater Formation

Undersized crossings can impede water flow through the crossing during high flow events, causing backwater areas to form upstream. As a result, fine sediments suspended in the high flows will settle immediately upstream, degrading upstream habitat and depriving downstream areas of natural sediment transport.

Shallow Water

Fish and other aquatic organisms need sufficient water depth to move through a stream crossing. Although shallow water may only be a seasonal issue, many aquatic species disperse during low flow periods to seek refuge in deeper water or complete life history stages. Water depths within a crossing structure should match that in the surrounding stream throughout the year to ensure migration is not impeded.

Shallow water and unnatural stream-bed materials below a culvert on Yellow Creek below Murray County. Credit: Sara Gottlieb/TNC

Unnatural Bed Materials and Lack of Substrate

Metal and concrete are not appropriate substrate materials for aquatic species that live in or travel along the streambed. The substrate on the bottom of the crossing should match the natural substrate of the surrounding stream. Natural substrates provide cover from predators and resting habitat during dispersal and can also reduce water velocities inside the structure.

Recurring Clogging

Some crossings, especially those that are undersized and/or contain multiple entries/structures, can become clogged by woody debris, leaves and other material. Clogging prevents aquatic and terrestrial wildlife passage and can cause flooding, which may result in problems for roadways and hazardous conditions for motorists, as well as scour that compromises the integrity of the crossing.

Box culverts clogged with woody debris and tires. Credit: Kelly Rudell/City of Atlanta DWM

Indirect Impacts

In addition to negatively affecting terrestrial and aquatic wildlife and their habitats, problematic stream crossings can degrade water quality, cause safety issues, contribute to property damage and impose excessive maintenance costs on private landowners, municipalities, and state and federal agencies responsible for managing infrastructure. These indirect impacts include:

Impacts to Water Quality and Impairment of the Designated Use

Poorly designed stream crossings can alter the physical, chemical and biological integrity of the stream by altering stream temperatures, lowering dissolved oxygen and creating a barrier to fish passage. These alterations may affect the stream's ability to meet state water quality standards, including water quality criteria that supports designated use of aquatic life. Loss of flow or changes to physical habitat, including excess fine sediment below the crossing can impact aquatic macroinvertebrates and fishes (Wood and Armitage, 1997), which are used as water quality indicators under the state's Clean Water Act (CWA) programs.[1] Any of these impacts may cause the stream to not meet water quality criteria, and may result in impairing the designated use under the CWA (US EPA, 2015; Connolly & Pearson, 2007; Wood & Armitage, 1997; Lemay, 2010; Cui et al, 2008).

Increased Risk of Flooding and Reduction or Loss of Road Access

Undersized crossings or those prone to clogging can increase the risk and magnitude of flooding and structural failure. Flooded roads or failed crossings can subsequently impact property, the road network, public safety and emergency service response times, as well as access to private or public lands. South Carolina experienced dozens of road washouts during an historic flooding event in October 2015 (National Oceanographic and Atmospheric Administration National Weather Service, 2016; Gassman, 2017), and climate change predictions indicate an increase in the intensity and frequency of flooding events in the southeastern U.S. (Scott, 2019).

Washed out stream crossing on a tributary to Snake Creek in Carroll County. Credit: Alan Cressler

Additionally, flooding caused by undersized crossings can also increase or prolong the public's exposure to contaminated water (e.g., water containing fecal coliform), which could have public safety implications.

Increased Maintenance Time and Cost

Although properly sized and designed culverts may add 20-to-40% more cost to initial construction than undersized culverts, they offer significant financial savings over time (Broviak, 2006; O'Shaughnessy et al, 2016; RBouvier Consulting, LLC, 2016). Routine maintenance is required to keep undersized culverts clear and functioning. Properly sized culverts require less maintenance, have an increased service life and are less likely to need expensive emergency repairs or replacement after extreme weather events.

Increased Likelihood of Regulatory Burden

Poorly designed crossings may increase flooding, scour channels, erode streambanks and displace unnatural materials (e.g., riprap washing into the stream), negatively affecting roads and downstream water quality. To comply with applicable local, state and/or federal laws, those responsible for the crossing may be required to implement stream channel, streambank or road maintenance/restoration activities to properly mitigate impacts and ensure compliance.

Degradation of Recreational Sport Fisheries

Crossings that degrade fish passage or aquatic habitat can negatively affect recreational fisheries at the crossing location and throughout the stream network. Many popular sport fish species are highly mobile and migrate upstream and downstream to reproduce or to seek refuge from stressors (e.g., high temperatures). When their habitat is degraded and passage is prevented or inhibited, these species may decline, which can decrease angling success. ■

Suwannee bass (*Micropterus notius*) in the Alapaha River. Credit: Brentz McGhin

1 Georgia Environmental Protection Agency Clean Water Act monitoring program: epd.georgia.gov/watershed-protection-branch/monitoring

Cost Benefits of Properly Sized Stream Crossings

Cost continues to be a primary reason for state and local municipalities and transportation agencies to not install or upgrade to properly designed stream crossings, even when there is a clear understanding of the benefits (MassDOT, 2020; AASHTO, 2017). However, new economic studies are changing that assumption. The American Association of State Highway and Transportation Officials (AASHTO) found that lifetime costs of properly designed stream crossings were lower than traditionally designed culverts when accounting for maintenance, risk of catastrophic failure, recreation and health benefits. The net lifetime benefit for aquatic organism passage (AOP) designed culverts ranged from $540,618 for a three-sided box culvert to more than $1.2 million for each crossing when compared to traditional culverts not designed for AOP (AASHTO, 2017).

State studies on the costs of long-term maintenance have come to the same conclusion. According to Massachusetts' DOT, "[a]n undersized culvert in [the town of] Becket failed multiple times over a six-year period, costing the town more than $140,000 in repairs. The improved crossing, designed to convey the stream's future water flows and to provide habitat connectivity with adequate fish passage, cost $593,000 to construct. The new structure will likely save the town over $1,000,000 in repairs over its lifetime" (MassDOT, 2020).

States are also reassessing financial impact due to increased extreme weather events. In Vermont, 960 traditional culverts blew out during one tropical storm, with total damages to roads and highways of more than $700 million (Vermont Agency of Natural Resources, 2012; Kinzel, 2011). In a comprehensive study after hurricanes Sandy and Irene, the second-highest recommendation for New England states was to upgrade stream crossing infrastructure before future storms, calling this "one of the best, most cost-effective and least intrusive ways to reduce damage from river floods" (Vogel et al, 2016). In a separate economic analysis, Maine found that if investments were made in upgrading culverts, "a significant economic return can be expected for the state" (Colgan et al, 2013).

Stream crossing constructed by the WPA in the 1930s at the historic Decatur Water Works over Burnt Fork Creek in DeKalb County. Credit: Sara Gottlieb/TNC

Culvert assessment protocol training in 2017. Credit: Sara Gottlieb/TNC

Section 3

Barrier Assessment Methodology

With over 85,000 stream crossings across the state of Georgia, it is important to determine which of these crossings represent a barrier to aquatic organism passage (AOP) while being at risk of failure, and to prioritize which of these barriers would provide the most overall benefit if replaced. Following methodology developed by the North Atlantic Aquatic Connectivity Collaborative (NAACC), in 2017 the Southeast Aquatic Resources Partnership (SARP) developed a standardized method for assessing the impacts of stream crossings on aquatic connectivity across the Southeast. The Southeast Stream Crossing Survey Protocol measures parameters at each crossing and produces a combined score to determine how much the crossing deviates from an ideal crossing. SARP holds several workshops each year to train people in using this protocol to collect data for entry in SARP's online database. The database is used to prioritize stream crossing replacement projects using SARP's Southeast Aquatic Barrier Prioritization Tool (connectivity.sarpdata.com).

When following the protocol, measurements are taken at each crossing and compared to an upstream reference reach outside of the influence of the crossing. Key parameters include the presence of inlet and outlet scour pools, the constriction of flow through the crossing, and flow alignment. Within each structure, the height, width, length and the drop from the outlet to the water surface are measured. Inside of each structure, the presence and severity of any physical barrier such as debris or sediment are noted, and the depth, velocity and substrate type and coverage are compared to observations from the reference reach.

Following data collection, parameters are weighted and combined using a standard algorithm to produce a final score for each structure. The crossing itself then receives a final score from the most passable (highest-scoring) structure, assuming that wildlife will choose the most passable pipe to enter.

Because people and communities depend on roads that cross streams for transportation and safety, the protocol includes parameters related to the structure's condition as well as factors such as the road fill height and structure material. These parameters can provide a sense of the urgency to replace a potentially failing crossing and inform estimates of the associated cost.

Anyone with the proper training and a few pieces of equipment can assess a stream crossing. Contact Kat Hoenke (kat@southeastaquatics.net) at SARP for information on taking part in a training workshop, and visit the Georgia Aquatic Connectivity Team website (ga-act.org/identification-and-prioritization-of-barriers-in-georgia) to download the current Stream Crossing Survey Data Form Instruction Guide.

In addition to stream crossings on inland roads, a protocol is being developed to assess tidally influenced crossings (e.g. Steckler et al., 2017). This protocol expands on the inland protocol developed by NAACC and adopted by SARP, incorporating information such as tidal stage, tide gates and more. At the time of publication of this handbook, SARP is working to adapt this protocol for use in the Southeast. ■

Field technician measures the height of a metal pipe culvert. Credit: Duncan Elkins/UGA

Failed metal pipe culverts removed from Mill Creek during construction of a new stream crossing in Chattahoochee National Forest, Paulding County. Credit: Sara Gottlieb/TNC

Section 4

Resources for Getting Started

After barrier assessment or other visual inspection identifies crossings for potential replacement, the following steps may help initiate the process:

1. Determine the entity responsible for maintaining the structure, which is dependent on road type – private, local/municipal, county or state (search roadmaps on the GDOT website, dot.ga.gov/DS/Maps, or download the Tiger/Line GIS data set from the U.S. Census Bureau at census.gov/geographies/mapping-files/time-series/geo/tiger-geodatabase-file.html).

2. Search the GDOT project database to determine if already-planned construction could incorporate the stream crossing (dot.ga.gov/BS/Projects/ProjectSearch).

3. Consult DNR's Georgia Biodiversity Portal to determine if rare aquatic species potentially reside in the vicinity of the crossing, information that can help provide resources for aquatic habitat restoration (georgiabiodiversity.org).

4. If rare aquatic species are determined to be present, and high-quality habitat exists upstream, the U.S. Fish and Wildlife Service (USFWS) Fish Passage Program or Partners for Fish and Wildlife Program may be able to provide financial and technical resources for replacement (fws.gov/fisheries/fish-passage.html and fws.gov/southeast/our-services/partners-program).

5. Georgia does not currently have a statewide grant program for culvert replacement assistance, but one could be modeled after the Massachusetts program

(mass.gov/how-to/culvert-replacement-municipal-assistance-grant-program). Georgia could identify a source of funding, likely linked to community resilience, such as Federal Emergency Management Agency (FEMA) Building Resilient Infrastructure and Communities (BRIC) and water quality improvement measures such as 319 grants for nonpoint source implementation, or levy a fee on new construction to raise funds independent of other grant programs. At the county level, in 2017 Fayette County passed a Special-Purpose Local Option Sales Tax to generate significant funds to address stormwater-related infrastructure needs, including culvert replacements (fayettecountyga.gov/splost-2017/index.php).

Retrofits and Replacements

Many stream crossings were designed and installed before there was broad understanding of their potential environmental impacts. Aged crossings, even those that are still effective, may need upgrades or replacement after weathering decades of floods and erosion. Climate change further increases the risks related to aging and undersized structures (National Research Council, 2008). Periodically upgrading bridges, culverts, tide gates and roads ensures that transportation networks can support the communities they connect, while also providing opportunities to enhance designs.

When deciding whether to retrofit or replace a crossing, planners should consider project costs and environmental impacts. Culvert replacement is preferable over retrofitting whenever feasible because it allows planners to implement updated design principles while maximizing a bridge or culvert's lifespan. Replacement designs should adhere to the standards for new crossings (see the "Permitting and Regulations" section for details). In some cases, a retrofit may be more appropriate, leaving the current culvert in place and making sustainable modifications. ■

Concrete bottomless arch culvert being installed in Kedron Creek in Fayette County, funded by a SPLOST in 2017.
Credit: Fayette County Road Dept.

Construction of an aluminum open-bottom arch culvert in Rock Creek at Peeples Road Spur in Murray County.
Credit: Sara Gottlieb/TNC

Section 5

Regulations, Permitting and Mitigation

Stream crossing projects (i.e., culvert/bridge installations, removals, retrofits and replacements) in Georgia may require permits and compliance with these regulations:

- Clean Water Act of 1977 (CWA) – Section 404
- National Environmental Policy Act of 1969
- Endangered Species Act of 1973
- Fish and Wildlife Coordination Act of 1934
- Magnuson-Stevens Fishery Conservation and Management Act, or Sustainable Fisheries Act of 1996 (for coastal culverts and bridges)
- Georgia Erosion and Sedimentation Control Act
- National Pollutant Discharge Elimination System (NPDES) Municipal Stormwater Program
- National Historic Preservation Act – Section 106 (for historic bridges)
- Coastal Zone Management Act of 1972
- Codes and standards specific to a municipality

Federal Agency Coordination

Clean Water Act - Section 404

Stream crossing projects may require approval and permitting by the U.S. Army Corps of Engineers (Corps) under Section 404 of the Clean Water Act[2]. The Corps has various permitting mechanisms to approve stream crossings, including the Nationwide Permit (NWP) Program, Regional General Permits (RGP) and Individual

[2] epa.gov/cwa-404/permit-program-under-cwa-section-404

Permits (IP). In the Corps' Savannah District, if a project results in the permanent loss of less than 0.05-acre of stream impact per crossing, the impacts may be authorized under the NWP program. A project that exceeds 0.01 acre of stream impact requires a pre-construction notification (PCN). There are other conditions in the NWP program that require submittal of a PCN regardless of the area of impact associated with the project. For more information on the Corps' permitting process, please visit the Savannah District's website[3]. Potential applicants should contact the Savannah District to discuss the permitting requirements for any proposed stream crossing projects prior to construction.

Compensatory mitigation[4] is generally required for adverse effects to >0.01 acre of stream in Georgia. In compliance with the 2008 Mitigation Rule, compensatory mitigation may occur through the purchase of mitigation credits from an approved mitigation bank, payment to an approved in-lieu fee program, or through permittee responsible mitigation projects. The Savannah District published the 2018 Standard Operating Procedures for Compensatory Mitigation, which provides mitigation guidelines for various types of impacts. More information regarding compensatory mitigation can be found at the Savannah District's website referenced above.

National Environmental Policy Act

The National Environmental Policy Act, or NEPA, requires that federal decisions on permitting and funding consider the environmental consequences of those actions. Using the NEPA process, federal agencies evaluate the environmental and related social and economic effects of their proposed actions (e.g., making decisions on permit applications). For example, the Corps conducts the NEPA analysis before issuing a CWA Section 404 permit needed for the construction of stream crossings that discharge dredged or fill material into Waters of the U.S. Agencies also provide opportunities for public review and comment on those evaluations. For more information on how the Corps and other federal agencies use the NEPA review process, please visit the Council on Environmental Quality's Agency NEPA Implementing Procedures website.[5]

Endangered Species Act

Georgia is home to many rare and imperiled species that depend on well-designed stream crossings as movement corridors connecting habitat patches across the landscape (see next section). The Endangered Species Act (ESA) regulates a range of activities that can affect endangered or threatened plants and animals. All stream crossing project managers and permitting agencies are responsible for avoiding or minimizing negative impacts to federally listed animal species and their habitats. Further, Section 7(a)(1) of the ESA directs federal agencies to aid and promote the conservation of listed species, and Section 7(a)(2) requires the agencies, through consultation with the U.S. Fish and Wildlife Service or National Marine Fisheries Service, to ensure their activities are not likely to jeopardize the continued existence of listed plant or animal species, or destroy or adversely modify their designated critical habitat.

As part of the ESA review, project managers use the Information for Planning and Consultation (IPaC) tool,[6] where project boundaries can be delineated to get a list of species that should be evaluated for potential effects.

Magnuson-Stevens Fishery Conservation and Management Act, or Sustainable Fisheries Act of 1996

Coastal waters in Georgia include essential fish habitat (EFH) designated under this statute. Stream crossings on

[3] sas.usace.army.mil/Missions/Regulatory/Regulatory-Program/
[4] sas.usace.army.mil/Missions/Regulatory/Mitigation/

[5] ceq.doe.gov/laws-regulations/agency_implementing_procedures.html
[6] ecos.fws.gov/ipac

Seining for fish at a stream crossing in Big Dry Creek in Floyd County. Credit: Alex Lamle/USFWS the coast should ensure that culvert design, installation and maintenance support the functional integrity of essential fish habitat. Georgia Department of Natural Resources and National Marine Fisheries Service (or National Oceanographic and Atmospheric Administration – Fisheries) reviews activities authorized or funded by Federal agencies and coordinates to ensure that this habitat is not degraded.

State Agency Coordination

Georgia Erosion and Sedimentation Control Act

Under Georgia's Erosion and Sedimentation Control Act[7] (O.C.G.A. § 12-7-6), land disturbances within riparian buffers directly related to or necessary for the construction of a roadway drainage structure (e.g., bridge or culvert) do not require an approved buffer variance provided that effective erosion control measures are incorporated in the project plans and specifications and are implemented. For more information on adequate erosion control measures, see the Manual for Erosion and Sediment Control In Georgia.[8]

National Pollutant Discharge Elimination System (NPDES) Municipal Stormwater Program

Georgia is authorized by the U.S. Environmental Protection Agency (EPA) to administer the federal National Pollutant Discharge Elimination System (NPDES) program for wastewater discharges, including stormwater discharges associated with municipal separate storm sewer systems (MS4s). The state issues permits for small, medium and large MS4s. Communities covered under these permits are required to follow design principles in the Georgia Stormwater Management Manual[9] and its Coastal Stormwater Supplement. These resources offer valuable technical guidance for culvert and bridge design, including site planning and design tools. A NPDES construction general permit may be required for projects disturbing one or more acres; additionally, a land disturbing activity permit may be required if within a local jurisdiction that has adopted a local erosion and sedimentation ordinance. Visit the Georgia Department of Natural Resources Environmental Protection Division Municipal Stormwater website[10] for more information.

National Historic Preservation Act – Section 106

Bridges and culverts are assessed for eligibility in the national register under the National Historic Preservation Act. The Georgia Department of Natural Resources' Historic Preservation Division reviews projects that may impact historic culverts and bridges. There may be design limitations for structures that are identified as eligible. Section 106 requires Federal agencies issuing permits for culvert and bridge redesign or restoration projects to consider the effects of their undertakings on historic structures.

Coastal Zone Management Act (CZMA) of 1972

The Coastal Zone Management Act (CZMA) of 1972 established the National Coastal Zone Management Program, which is a voluntary partnership between the federal government and U.S. coastal and Great Lakes states and territories to address national coastal issues. The Georgia Coastal Management Program was approved by NOAA in 1998, with Georgia's Department of Natural Resources, Coastal Resources Division, serving as the lead agency. The Georgia coastal zone includes Chatham, Effingham, Bryan, Liberty, McIntosh, Long, Glynn, Wayne, Brantley, Camden and Charlton counties.

The Georgia Department of Natural Resources outlined strategies for "Enhancing Coastal Resilience with Sustainable Infrastructure" to improve flood resilience in coastal communities via the Georgia Coastal Management Program in the Section 309 Assessment and Strategy 2016 to 2020 (GA DNR, 2015). To plan for the increasing risk to culverts and tidal connectivity from sea level rise, project planners should evaluate existing tidal culverts and ensure that new designs allow for increased storm flows and tidal impacts with the goal of protecting communities, maintaining hydrologic connectivity and safe wildlife passage. New Hampshire outlined a strategy focusing on tidal culverts (New Hampshire Department of Environmental Services, 2015) synthesizing valuable information that can be adapted in Georgia. ■

7 rules.sos.ga.gov/gac/391-3-7
8 gaswcc.georgia.gov/urban-erosion-sediment-control/technical-guidance
9 atlantaregional.org/natural-resources/water/georgia-stormwater-management-manual
10 epd.georgia.gov/watershed-protection-branch/storm-water/municipal-stormwater

Cherokee darter (*Etheostoma scotti*) in Raccoon Creek, Paulding County. Credit: Bill Harbin

Section 6

Georgia's Imperiled Species

Well-designed and constructed crossings promote stream continuity and ensure that animals have access to important resources.

Thermal Refugia

Small streams with groundwater seeps and springs provide thermal refuge (access to cooler, more oxygenated water) during the summer. Species such as brook trout and striped bass will travel to these areas and congregate there. If barriers restrict the availability or access to this refuge, fish may be more susceptible to heat stress, overcrowding, disease and predators.

Access to Forage

Different habitats provide different feeding opportunities throughout the day or season, and species regularly travel to exploit these resources. Striped bass swim up tidal creeks to feed during high tide. Insect communities in small ponds, riparian wetlands and floodplains can be abundant at times, and stream fish will move into these habitats to feed during flooding. Stream crossings that fragment aquatic habitats can impede fish access to these areas or strand aquatic wildlife as flood waters recede.

Robust redhorse (*Moxostoma robustum*) spawning in the Ocmulgee River, Monroe County. Credit: Brett Albanese/GA DNR

Genetic Diversity

Movement of species within streams is vital for maintaining healthy populations that are genetically diverse. Where aquatic habitats are fragmented into small population segments, whole populations may be eliminated, reduced or genetically damaged through the effects of isolation and inbreeding. Movement within and between populations is necessary to ensure genetic diversity that enables species to adapt to changing conditions.

Southern rainbow (*Villosa vibex*) in Holly Creek, Murray County. Credit: Alan Cressler

Access for Reproduction

Many aquatic species travel long distances to find suitable breeding habitats. For example, the Trispot Darter of northwest Georgia moves from large creeks and rivers into small tributary streams each spring for breeding. Many minnow species, which often constitute the most diverse and abundant component of forage for larger game species, migrate into smaller creeks for reproduction. Similarly, large sucker runs involve the movement from the lower reaches of large rivers to upstream gravel bars in the spring for spawning. Shoal bass, trout, shad and other sport fishes are also known to move long distances for reproduction. Barriers that prevent such species from accessing their spawning habitats not only decrease these fishes' abundance, they may threaten the population's survival.

Natural Dispersal and Population Recovery

Some salamanders, turtles and frogs spend most of their lives near streams and travel in and along a stream's length. Crossings not designed for passage may force them to climb over an embankment and cross a road, where vehicles and people can endanger their lives. Freshwater mussels disperse by having larvae that attach to the fins or gills of a fish, so if a stream crossing blocks fish, then it also blocks upstream dispersal of mussels. If a stream is damaged by a catastrophic event (such as pollution, flooding or severe drought), then natural dispersal is required to allow aquatic populations to recover to pre-disturbance levels.

Habitat Alteration

In addition to effects on movement, many stream crossings degrade nearby habitat, making conditions inhospitable for some native plants and animals. Undersized culverts often create both upstream and downstream streambed and bank erosion problems, widening stream channels and increasing fine sediment deposition that affects stream habitats. Impacts are also evident in tidal creeks. By limiting tidal flow, culverts alter water levels and chemistry, diminish sources of ocean nutrients and can degrade entire tidal environments (Becker et al., 2018). Culverts can also alter habitat by preventing natural changes. Streams are not static; they are dynamic. Streams change upstream or downstream of a culvert, but the part of the stream in the culvert is unable to adapt, resulting in culverts becoming barriers to wildlife passage.

Summer and Winter Bat Roosts

Georgia is home to 16 species of bats (georgiawildlife.com/GeorgiaBats). Bats can be found roosting in crossing structures year-round and statewide, especially in areas with limited cave habitat in the Piedmont and coastal plain regions. Wildlife biologists with the Georgia Department of Natural Resources have been studying the use of culverts by bats (learn more at youtu.be/2MGb9LSKJyw), finding them in structures as small as 4 feet in diameter.

Gray bat (*Myotis grisescens*) hibernating in a culvert under an interstate in Carroll County. Credit: Laci Pattavina/USFWS

At-risk Species in Your Project Area

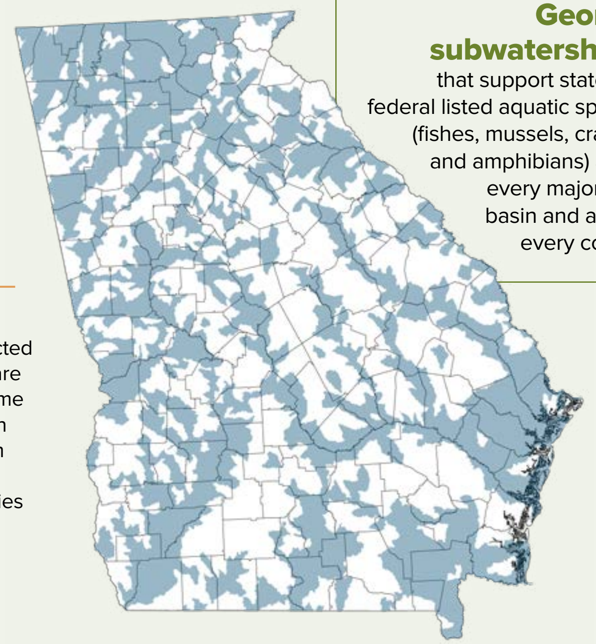
Many of Georgia's streams provide habitat for imperiled species of fish and other wildlife. Careful consideration should be given in these areas to avoid or minimize impacts to these species. Many of these imperiled species are listed on the Federal Endangered Species List (fws.gov/endangered). Listed species have special protection under the law and consultation with the USFWS is necessary when disturbance activities are occurring within these species' ranges. To learn about state and federally listed species that may occur in your project area, please visit the GADNR Environmental Review Page (georgiawildlife.com/environmental-review) and FWS Information for Planning and Consultation tool (ecos.fws.gov/ipac). ■

Short-ranging endemics like the Etowah and goldline darters are limited in their distribution. One of the two remaining goldline darter populations can be found in the Coosawattee River. The Etowah darter (female pictured) is endemic to the Etowah River. Negative impacts to their limited habitat have implications to the survival of these species.

Credit: Andrew Nagy/UGA

Endemic bass like the Suwannee bass (pictured left), Chattahoochee bass and Bartram's bass are among Georgia's unique and rare sport fishes. These species are almost extirpated due to barriers that limit fish movements and fragment populations, as well as hybridization with other bass species.

Credit: Ryan Hagerty/USFWS



Georgia subwatersheds that support state and federal listed aquatic species (fishes, mussels, crayfish and amphibians) are in every major river basin and almost every county.

Crustaceans and other aquatic invertebrates also rely on connected waterways. Although all crayfish are capable of overland dispersal, some species like the Chatooga crayfish are essentially limited to in-stream dispersal. Thus, barriers to fish passage could similarly limit species distribution and abundance.

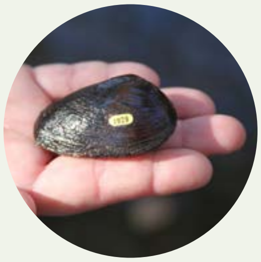
Credit: Alan Cressler

Migratory species like the robust redhorse rely on free flowing rivers and streams to complete their life cycles or travel between daily or seasonal habitats. Barriers to fish passage (e.g., reservoirs, poorly designed culverts, poor water quality) can impede their ability to migrate to spawning habitat.

Credit: USFWS

Tidal species like the West Indian manatee travel upstream and downstream via tidal creeks. Manatee calves and their mothers have become entrapped in small culverts, but exclusion devices may act as barriers to fish movement and decrease habitat connectivity. Coastal culverts require consideration of their unique ecosystem dynamics.

Credit: USFWS



Freshwater mussels like the oval pigtoe have experienced drastic population declines due to changes in water quality and quantity and habitat fragmentation. These relatively sedentary invertebrates rely on host fishes, such as the blacktail shiner, to disperse their glochidia (larvae) throughout the watershed.

Credit: Tom MacKenzie/USFWS

White-tailed deer skull observed during a barrier assessment workshop. Credit: Sara Gottlieb/TNC

Section 7

Helping Aquatic and Terrestrial Species Pass Through

Designing a safe and practical stream crossing that allows for aquatic and terrestrial wildlife passage requires basic knowledge of the project needs, stream geomorphology and hydrology, and Georgia's local fauna. Identifying any species of concern in the project area and gathering baseline data on movement behaviors are important steps to designing a usable, wildlife-passable crossing.

A few considerations when (re)designing crossings to work for the use of fish and wildlife include:

- Location, location, location! Is suitable habitat available in the surrounding area? Will the proposed crossing be located within or near natural movement corridors? Positioning crossings in areas already used as transportation thoroughfares can save human lives as well as facilitate safe wildlife passage by reducing the risk of human-wildlife collisions on the road.
- Consider multispecies crossings. What would be the appropriate sizing for local fauna and imperiled species? Will structures provide aquatic and terrestrial passage? Will they accommodate small and large terrestrial critters?
- Will funneling or directional fencing be important? Funnel fencing is important, especially at first, as it may take time for wildlife to grow accustomed to using a crossing structure. Should fencing be temporary or permanent? What height of fencing makes sense for the wildlife species being targeted?
- What kind of ongoing maintenance and monitoring will be necessary to maintain functionality?

Passage for Aquatic Organisms

Crossings should be essentially "invisible" to fish and aquatic organisms, maintaining the appropriate flow and substrate through the crossing and not constricting a stream. Stream crossings that are passable for aquatic organisms have been engineered for years in many states, and Georgia is among a growing number of states with policies aimed at producing aquatic organism passable crossings. All stream crossings in Georgia permitted under the Nationwide Permit (NWP) Program pursuant to Section 404 of the Clean Water Act should be designed in accordance with the most recent U.S. Army Corps of Engineers, Savannah District NWP Regional Conditions (ACOE 2021), which promote the passage of aquatic organisms by maintaining the existing dimension, pattern and profile of the stream above and below a stream crossing.

Army Corps of Engineers Savannah District Regional Conditions for all Nationwide Permit Culverts

- **Installing New or Replacement Culverts in Perennial Streams:**

a. Bottomless or Arch-Span Culverts: If there are any impacts to aquatic resources, the overall width of a bottomless or arch-span culvert shall be approximately equal to, but not narrower than, the typical bankfull width of the stream channel. Additional pipes or culverts may be used to receive flows exceeding bankfull, but the inlet(s) shall be baffled to or sit at the stream's bankfull elevation.

b. Box Culverts: The overall width of a single or multibarrel box culvert shall be approximately equal to, but not narrower than, the typical bankfull width of the stream channel. Additional pipes or culverts may be used to receive flows exceeding bankfull, but the inlet(s) shall be baffled to or sit at the stream's bankfull elevation.

c. Circular Pipes/Culverts: The overall width of a circular pipe/culvert shall be approximately equal to, but not narrower than, the typical bankfull width of the stream channel. Multiple circular pipes/culverts may not be used to accommodate flows at bankfull width except in scenarios where a culvert replacement would result in additional impacts to waters. Additional circular pipes/culverts may be used to receive flows exceeding bankfull but shall sit at the stream's bankfull elevation.

d. Culverts shall be of adequate size to accommodate flows exceeding bankfull in a manner that does not cause flooding of associated uplands or disruption of hydrologic characteristics that support aquatic sites on either side of the culvert. This may be accomplished by installation of equalizer culverts in the floodplain.

e. Unless specifically described in the PCN, use of undersized culverts to detain stormwater or for pollutant treatment is not authorized.

f. The upstream and downstream invert[11] of culverts (except bottomless or arch-span culverts) shall be buried/embedded to a depth of 20% of the culvert height to allow natural substrate to colonize the structure's bottom and encourage fish movement. Additional culverts used to receive flows exceeding bankfull are not required to be embedded.

g. Culvert slope shall be set within 25% of the streambed slope (e.g., if streambed slope is 2%, the designed slope of the culvert shall be between 1.5% and 2.5%). In situations where culvert slope exceeds 4%, interior baffles on the bottom of the culvert or other measures shall be used to allow for sediment colonization and/or velocity attenuation.

h. Nationwide permit applications should contain: (i) plan view diagrams of baseline and proposed conditions with proposed culvert information, including alignment, type and size, channel excavation, and outlet protection; (ii) longitudinal profile diagrams of existing stream channel (beginning ~100 ft upstream and downstream of the proposed culvert inlet and outlet) and proposed culvert, including proposed slope, type and size, invert elevations, and embedded depth, locations of channel excavation, headwalls, outlet protection, and energy dissipaters, as applicable; (iv) cross-sectional diagrams of existing stream channel and proposed culvert inlet and outlet, including stream channel, bank, culvert and road information.

[11] The term invert in this context refers to the part of a culvert below the spring line that represents the lowest point in the internal cross section. The spring line is the horizontal line at the midpoint of the vertical axis of the pipe.

- **Installation of Culvert Extensions in Perennial Streams:**

a. Existing conditions of box and circular pipe culverts and any proposed extension thereof shall be assessed to determine if aquatic life passage is accommodated (e.g., perched culvert inlet or outlet). Justification shall be provided for any culvert that will be extended instead of replaced that does not accommodate aquatic life passage.

b. Proposed culvert extensions shall be assessed to determine whether baffles or other measures may be used to improve conditions for aquatic life passage. Documentation shall be provided on whether measures to improve aquatic connectivity are practicable. When practicable, these measures shall be implemented.

These regulations are current as of the publication date of this document. Always check that you have the most recent version of the Regional Conditions before you design a crossing.

Passage for Marine Mammals, Terrestrial Wildlife and Bat Habitat

Freshwater organisms aren't the only types of wildlife that rely on connected stream corridors to access different habitats for reproduction, refuge and food. This section addresses some considerations for some of these species.

Tidal Crossings and Manatees

Tidal marshes and creeks in coastal Georgia have a dynamic and complex hydrology, where salinity, depth, velocity and flow direction can vary depending on the location of a proposed crossing within a tidal system, tidal range and the time of day. Designing effective crossings in tidal systems presents unique

Tidal crossing incorporating bagged oyster shells for bank stabilization on Little St. Simons Island. Credit: Sara Gottlieb/TNC challenges,[12] yet many of the passage threats (e.g., velocity, turbulence, depth, inlet and outlet perch) are similar to those of non-tidal crossings. One distinct consideration for designing tidal crossings is the potential for structures to either lessen or intensify tidal ranges upstream or downstream, as well as shifting the timing of tidal ebb and flow. Altered tidal regimes can influence habitat conditions (e.g., salinity, depth) for coastal wildlife.

In coastal areas, manatees may become entrapped due to culverts and other water control features (e.g., gates, flaps, pipes, etc.) since they cannot swim backwards or turn around in culverts less than 8 feet wide. When the water level changes due to rising or falling tide, this can leave the manatee stranded on the inland side of the culvert or inside the culvert, where flooding can drown the animal. There has been an increase in documented manatee strandings in Georgia and South Carolina in recent years as individuals are staying longer into the fall and seeking warmwater refuge inland.

In Florida, all culverts 8 inches to 8 feet in diameter must be grated with bars or rods (spaced a maximum of 8 inches apart) strong enough to prevent manatee entrapment, unless the culvert or pipe is less than 200 feet long and connected to navigable waterways. In Georgia, this presents additional challenges to consider. Without proper maintenance, grates can create a passage barrier and lead to upstream flooding when wrack[13] and detritus build up. Furthermore, grating culverts could prevent access to essential habitat (forage resources, calving sites, freshwater, migratory corridors, warmwater refugia, refuge from watercraft) during times of high tide. The decision to exclude manatees must be based on culvert length and size, location, water level, available habitat and other risk factors. Bridges or box culverts are thus the most preferred crossing types in manatee areas. Because manatees may still become stranded in culverts greater than 8 feet in diameter during low tide, a minimum 3-foot water depth in the culvert at low tide stage is recommended when planning new culverts in tidal waters. Based on documented manatee movement, the maximum recommended culvert length is no longer than 200 feet.

Terrestrial Wildlife Passage

Many terrestrial species use stream crossings for safe passage under busy roads, making them important for species conservation as well as public safety. Researchers have found that different terrestrial animals tend to prefer certain sizes and types of culverts. Learning more about the species that use surrounding habitats can inform culvert design and maximize conservation opportunities.

Certain design elements that allow fish to pass are also important for terrestrial wildlife to pass. For example, providing a natural benthic substrate and gradients rather than ledges would provide refuge from predators. Ensuring that inlets and outlets are level with the surrounding streambed can enhance culvert usage for aquatic and terrestrial wildlife alike. Perched structures are also difficult for many small mammals, snakes and amphibians to use. Similarly, culverts characterized by a gentle slope not only facilitate water flow and structural stability, they are easier for wildlife to navigate. For any new or replacement culverts, a longitudinal profile of the streambed should be completed both upstream and downstream see how well the bed elevations match.

Additional measures can further improve designs to support terrestrial wildlife passage. Culverts should be appropriately sized to accommodate species of concern. For larger mammals, water level within the culvert must be wadable for terrestrial species and navigable for aquatic species. Fluctuation in water levels related to seasonal or tidal variability or storm events can add another level of complexity to consider. For smaller animals (turtles, opossums, foxes), scaffolding or ledges built above water level can be included to provide a dry corridor. Ideally, the width of a stream crossing will provide ≥ 1.2 bankfull width to allow the building of banks for terrestrial wildlife crossing. It may take some time for wildlife to adjust to using a crossing structure. Directional fencing or contouring approach areas can encourage wildlife to navigate

[12] Note that two directional flows exhibited in tidal systems require more robust hydraulic modeling than stream simulation does. Good tidal crossing design is not possible using only the USFS stream simulation handbook.

[13] Wrack is the term for seaweed, surfgrass, driftwood and other organic materials that are produced by coastal ecosystems and wash ashore on the beach.

across a busy road by the safer corridor and prevent potential collisions. If fencing is installed temporarily or permanently, it should allow for escape areas so that wildlife can jump out of the road while limiting their access to the road.

Human activity that may deter wildlife from approaching crossing structures should be limited, especially at night when many animals are active. Structures should be regularly monitored and cleared of debris that can impede water flow and wildlife movement.

Bats in Bridges and Culverts

Bats use a variety of bridge and culvert structure types as roosting habitat throughout the year. Bats can be found in expansion joints, cracks, crevices and along rough surfaces of the structure (Keeley and Tuttle, 1999). In Georgia, winter use of culverts in areas where caves are not prominent appears to be of particular importance to some hibernating bat species, such as the tri-colored bat *(Perimyotis subflavus)*, a once common species now being considered for federal and state protections as a result of recent declines associated with white-nose syndrome. Tri-colored bats, as well as other species, often use small depressions in culvert structures because they provide a thermally stable environment during winter. These range from drainage holes (aka scuppers or weepholes) to structural gaps between concrete segments. When considering culvert design that supports Georgia's wildlife, "weephole" microhabitats that are already integrated into many current designs should be emphasized. The roughened concrete surfaces allow bats to grab on and use these microhabitats for roosting. Building these drainage holes with concrete rather than PVC piping (which is too slick for bats to grab) and establishing drop inlets or bat domes[14] especially for longer culverts, could also help support bats that use these unique anthropogenic habitats.

[14] A bat dome is a modified culvert design with a section raised in the center of the structure to accommodate large colonies of bats (see p. 37 in Keeley and Tuttle, 1999).

Colony of southeastern myotis (*Myotis austroriparius*) roosting in a culvert under an interstate in Carroll County.
Credit: Laci Pattavina/USFWS

Example of a culvert replacement designed using a stream simulation approach.
Credit: Katie Owens/TNC

Section 8

Stream Simulation

Aquatic connectivity at stream crossings is best maintained by mimicking, as much as possible, the same flow conditions through the structure that exist in the natural stream. Such a structure will have comparable water depths and velocities as those present in the channel upstream and downstream, and will allow for sediment transport through the crossing. This can be accomplished by maintaining similarity of four parameters: the stream alignment, stream profile, channel cross section and stream bed material. The process of identifying these parameters in the natural stream and replicating them in design is called the stream simulation method.

The principles of stream simulation are only briefly introduced here. The Army Corps of Engineers has permitting jurisdiction over most stream crossing projects, and the criteria found in their Regional Permit Conditions should be consulted during design. For further reference, the U.S. Forest Service (USFS) has produced the manual “Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings” (Forest Service Stream-Simulation Working Group, 2008), which contains extensive guidance for design professionals. The Federal Highway Administration has published a helpful guide on culvert design for aquatic organism passage (U.S. Department of Transportation, 2010).

The stream simulation method uses a reference reach approach to understand bed material, channel morphology and structures found within the natural channel. A crossing structure is then designed to match reference reach characteristics. This ideally creates a crossing that is self-sustaining and free to adjust similarly to the natural channel.

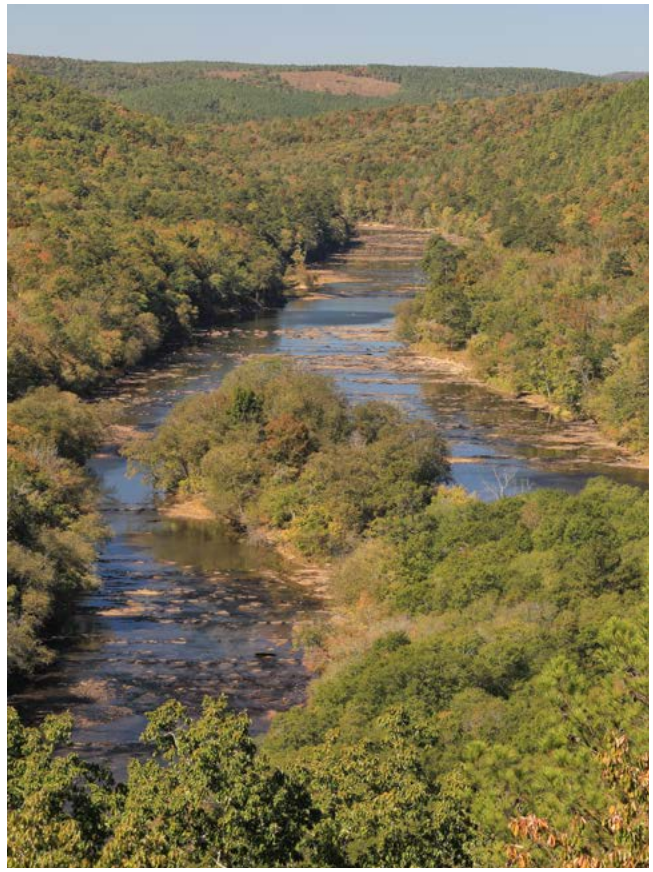
This approach is simplest for new installations, where open bottom structures can be placed to span the stream channel, leaving natural bed material and bedforms in place. In replacement installations, past channel degradation may require a culvert that is steeper than the natural channel. Replacement culverts and retrofits have a host of different criteria to consider (details follow in this section).

Not included in this manual are regional hydraulic geometry curves (aka regional curves). The development of regional curves typically includes an analysis of stream channel morphology at bankfull discharge (the water level stage that just begins to spill out of the channel into the floodplain). These curves are graphs depicting channel dimensions (top width, mean depth and cross-sectional area) at bankfull or effective discharge[15] versus drainage area, plotted on logarithmic scales. The use and analysis of the regional curves allows for a better understanding and assessment of field collected data described in Part Five of the USFS manual and therefore the development of a more complete geomorphic simulation model.

The development of regional curves typically includes an analysis of stream channel morphology at bankfull discharge. The following are useful sources of regional curve information by physiographic region:

- Piedmont (AL and W GA): Helms et al, 2016 mdpi.com/2073-4441/8/4/161/htm
- Piedmont (NC and GA); Mountains (NC and GA): bae.ncsu.edu/extension/srp/technical-resources
- Coastal Plain (GA): Glickauf et al, 2007 smartech.gatech.edu/handle/1853/47833
- Blue Ridge, Ridge and Valley, Southern Appalachians: TN Department of Environment & Conservation 2017 tn.gov/content/dam/tn/environment/water/natural-resources-unit/wr_nru_tennessee-ref-stream-morphology.pdf
- All US Regions: NRCS Regional Hydraulic Geometry Curves: nrcs.usda.gov/wps/portal/nrcs/detail/national/water/?cid=nrcs143_015052

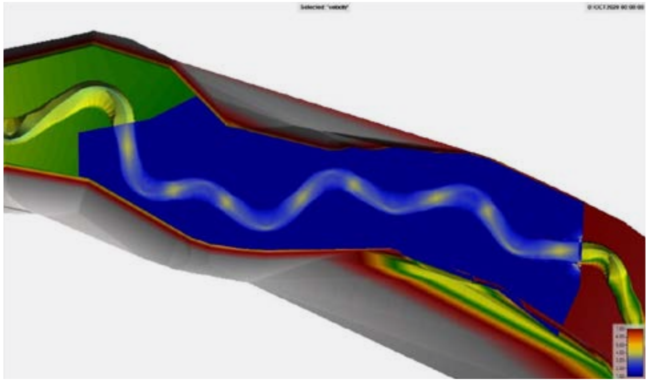
[15] The effective discharge is a geomorphic concept representing the flow or range of flows that transport the most sediment over the long term. The effective discharge has been equated with the bankfull discharge and in recent years both have been used more frequently in stream-restoration strategies.



Flint River at Pasley Shoals in Union and Talbot counties.
Credit: Alan Cressler

In conjunction with the resources provided above, a determination of bankfull discharge at the crossing location is advisable. Streamstats (streamstats.usgs.gov/ss), an online GIS-based analytical tool developed by the U.S. Geological Survey (USGS), allows users to determine various discharge events and watershed conditions at precise locations. It should be noted that Streamstats does not provide an estimated bankfull discharge. However, the regional curve documents cited above provide estimated bankfull discharges based on reference conditions assessed in the physiographic regions.

Every stream crossing design is unique, and site-specific conditions must be considered to select the proper design to achieve aquatic connectivity.



Stream section output from a stream simulation using HEC-RAS 2D modeling with Alabama Piedmont regional curves to determine pattern and sizing. Credit: Sean Miller/Nutter & Associates

A detailed survey, preferably by a surveyor trained in methods for documenting fluvial geomorphic characteristics (e.g. Harrelson et al., 1994) is an invaluable basis for a successful project. In every case, it should be kept in mind that all streams are dynamic, and their form and geometry have evolved into their present state and will continue to evolve over time. Well-intentioned projects may fail to achieve their goals because the stream's dynamics and geomorphology have not been properly accounted for in design.

In new installations, open-bottom structures are the preferred means of achieving geomorphic simulation. An arch or three-sided box installed well below scour depths as indicated by stream simulation[16] can simply be placed to span the existing stream channel, leaving the natural bed material and bedforms in place.

Replacement installations involve additional complexities, both for identifying the natural stream geometry and designing the structure to simulate it. For many existing culverts, poor design has caused local degradation of the channel upstream and downstream. Therefore, the channel may not be a suitable basis for proper geomorphic simulation design. A reference reach approach identifies a natural stream reach with similar conditions to the stream at the project site to use as the basis for design. This could be a nearby stream with similar watershed area and characteristics; often however, it is adequate to simply extend the project survey a sufficient distance upstream and downstream of the crossing such that the natural channel conditions can be discerned.

[16] Note that Federal Highway Administration calculations may indicate the need for a much deeper embeddedness than stream simulation (Benjamin Matthews, TNC-ME, personal communication, April 2021).

Free Software for Stream Simulation

FishXing allows users to evaluate multiple culvert designs and effects on fish passage. (fs.fed.us/biology/nsaec/fishxing)

HY-8, V-7.0, produced by the Federal Highway Administration, is intended for hydraulic capacity design. (fhwa.dot.gov/engineering/hydraulics/software/hy8)

HEC-RAS is a river modeling program produced by the Army Corps of Engineers. It facilitates hydraulic calculations across a network of natural and constructed channels. These simulations may be conducted in either a 1-dimensional or 2-dimensional model setup. The use of a 2D model in HEC-RAS allows for increased visualization of stream velocities and flows based on various design scenarios. These models will require data gathered during the site assessment stage and the analysis of baseflow and stormflow discharges. (hec.usace.army.mil/software/hec-ras)

River2D is a two-dimensional river modeling program created by Dr. Peter Steffler at the University of Alberta. The program lets users evaluate natural channel flow. Though the program does not directly allow for placing culverts within the model, the bed may be manipulated at the intended culvert location to allow for modeling of anticipated velocities. Most importantly, River2D uses Physical Habitat Simulation (PHABSIM) to determine usable habitat areas for specified fish species. The program contains many species habitat files; however, most are endemic to northern areas. The user may create their own species habitat files using the templates provided within the program. (https://i-ric.org/en/solvers/river2d/)

After: New bridge that replaced the multibox culvert on Raccoon Creek Road in 2019. Credit: Katie Owens/TNC

Section 9

Stream crossing Case Studies

Replacement (Concrete Box Culverts to Free-span Bridge) – Raccoon Creek

The stream crossing at Raccoon Creek Road over Raccoon Creek in Paulding County, formerly four large, concrete box culverts, was replaced with a free span bridge in 2019. The Nature Conservancy, in partnership with Paulding County, Georgia Department of Natural Resources, U.S. Fish and Wildlife Service, and Kennesaw State University, documented the positive effect of replacing this crossing on fish passage in Raccoon Creek, which contains more than 40 species of native fish, including the federally threatened Cherokee darter and federally endangered Etowah darter.

Before: 2016 photo of a multibox culvert with an impassible lip and flow underneath the structure on Raccoon Creek at Raccoon Creek Road, Paulding County. Credit: Katie Owens/TNC

Replacement (Metal Pipe Culverts to Bottomless Arch Culvert) – Mill Creek

The Rocky Flats Off-highway Vehicle Road over Mill Creek in the Chattahoochee National Forest in Murray County collapsed in 2017 when one of the two corrugated metal pipe culverts corroded and failed. In addition to the barrier these perched structures posed to the passage of aquatic organisms, the road collapse caused significant sedimentation in an otherwise high-quality mountain stream. The U.S. Forest Service, in partnership with the U.S. Fish and Wildlife Service Southeast Fish Passage Program, Georgia Department of Natural Resources, and The Nature Conservancy, obtained funding through the National Fish and Wildlife Foundation, Lyndhurst Foundation and Riverview Foundation to replace the failed structure with a bottomless culvert in 2019.

Before: Undersized and failing metal pipe culverts in 2017 on Mill Creek at Rocky Flats in the Chattahoochee National Forest. Credit: Sara Gottlieb/TNC

After: This open-bottom, prefabricated arch culvert replaced the failed Mill Creek stream crossing in 2019. Credit: Katie Owns/TNC

Replacement (Failed Pipe Culvert to Elliptical Culvert) – Hillabahatchee Creek

When streams cross private property, landowners often do not have the necessary financial means or technical services to properly install culverts. Outreach and technical assistance in these situations have been limited, but the Southeast Aquatic Resources Partnership, in coordination with U.S. Fish and Wildlife Service, has replaced multiple undersized and damaged crossings on private lands within the Hillabahatchee Creek system in Heard County. Landowners, especially farmers, install culverts to allow ingress/egress of themselves and livestock throughout the properties. Culverts, along with fencing, allow for hardened, single-point access and are part of agricultural best management plans for proper livestock management. However, without technical assistance, poorly installed and maintained culverts pose a threat to aquatic organisms by fragmenting populations, increasing erosion and impacting hydrologic resiliency. In this project, oversized elliptical culverts were installed and embedded 30% below stream grade to create natural substrate within the culvert, providing a continuous habitat profile for fish and other organisms passing through.

Before: A failed and undersized 24-inch round culvert that did not exclude livestock. Credit: Vance Crain/SARP

After: Newly installed 8-foot culvert allows aquatic and terrestrial passage (fencing to exclude livestock was added later). Credit: Vance Crain/SARP

Bridge over Big Sandy Creek at Indian Springs State Park in Butts County. Credit Alan Cressler

Conclusion

Stream crossings, when not designed, installed and maintained properly, can have severe impacts on stream health, wildlife populations and public safety. Design standards required in Georgia[17] through the U.S. Army Corps of Engineers permitting process are intended to maintain habitat continuity and minimize movement barriers in aquatic systems. Designs and prefabricated structures that meet these regulatory specifications are widely available and cost less over their lifetimes by reducing maintenance and the likelihood of failure.

For new construction, the reduced lifetime costs of properly designed stream crossings are their own incentives for meeting the regulatory requirements. Yet there are other monetary incentives, as well, because of decreased mitigation costs and faster permitting, especially where federally protected species are present.

It remains a challenge to finance replacing or retrofitting a crossing that has been identified as a priority barrier, although numerous case studies point to potential pathways for conducting these projects. States such as Massachusetts and Maine have pioneered programs to help municipalities replace undersized, perched or degraded culverts in areas of high ecological value through culvert replacement grants. Georgia would have to identify a source of funding, likely linked to community resilience, such as FEMA Building Resilient Infrastructure and Communities (BRIC) or water quality improvement measures such as 319 grants for nonpoint source implementation, to implement a similar program. In 2017, Fayette County voters approved a Special Purpose Local-Option Sales Tax[18] (SPLOST) to fund stormwater infrastructure projects, including numerous culvert replacements, following impacts of a major storm in 2015.

As knowledge grows about how poorly designed or degraded stream crossings hamper aquatic wildlife, regulations become more regionally appropriate and resources align to address existing infrastructure, we hope many more miles of Georgia rivers and streams will be restored and reconnected. Local governments, watershed groups, outdoor recreation enthusiasts, private restoration interests and others are invited to join our efforts to provide barrier-free waters so that future generations have abundant opportunities to experience the values and beauty of Georgia's streams. ■

17 Chapter 8.2.6 in the Georgia Department of Transportation's Drainage Design for Highways (GDOT 2020) specifies culvert design using stream simulation methods, including the USFS method and FHWA HEC 26 Stream Simulation Method

18 fayettecountyga.gov/splost-2017/index.php

Citations and Additional Sources

AASHTO Standing Committee on Environment. 2017. "NHCRP 25-25 Task 93: Long Term Construction and Maintenance Cost Comparison for Road Stream Crossings: Traditional Hydraulic Design vs. Aquatic Organism Passage Design" prepared by The Louis Berger Group Inc. onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25(93)_FR.pdf

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Useful Websites

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atlantaregional.org/natural-resources/water/georgia-stormwater-management-manual

Council on Environmental Quality National Environmental Policy Act:
ceq.doe.gov/index.html

FishXing Software:
fs.fed.us/biology/nsaec/products-tools.html#tools-fishxing

Georgia Aquatic Connectivity Team:
ga-act.org

Georgia Biodiversity Portal:
georgiabiodiversity.org

Georgia Department of Natural Resources Coastal Resources Division Coastal Management Program:
coastalgadnr.org/CoastalManagement

Georgia Department of Natural Resources Environmental Review:
georgiawildlife.com/environmental-review

Georgia Department of Transportation Project Search (GeoPI):
dot.ga.gov/BS/Projects/ProjectSearch

Georgia Department of Transportation Maps:
dot.ga.gov/DS/Maps

Georgia Environmental Protection Division Clean Water Act Monitoring:
epd.georgia.gov/watershed-protection-branch/monitoring

Georgia Environmental Protection Division Municipal Stormwater:
epd.georgia.gov/watershed-protection-branch/storm-water/municipal-stormwater

Georgia Erosion and Sedimentation Act of 1975 (as amended):
rules.sos.ga.gov/gac/391-3-7

Georgia Soil and Water Conservation Commission Technical Guidance on Urban Lands Erosion and Sediment Control:
gaswcc.georgia.gov/urban-erosion-sediment-control/technical-guidance

HECRAS Software:
www.hec.usace.army.mil/software/hec-ras

Regional Curves for the Three Physiographic Regions of North Carolina:
bae.ncsu.edu/extension/srp/technical-resources

River2d Software:
i-ric.org/en/solvers/river2d

SARP Southeast Aquatic Barrier Prioritization Tool:
connectivity.sarpdata.com

Streamstats:
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fws.gov/endangered

U.S. Fish and Wildlife Service, Georgia Ecological Services:
fws.gov/athens

U.S. Fish and Wildlife Service Fish Passage Program:
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U.S. Fish and Wildlife Service Information for Planning and Consultation (IPaC):
ecos.fws.gov/ipac

U.S. Fish and Wildlife Service Partners for Fish and Wildlife:
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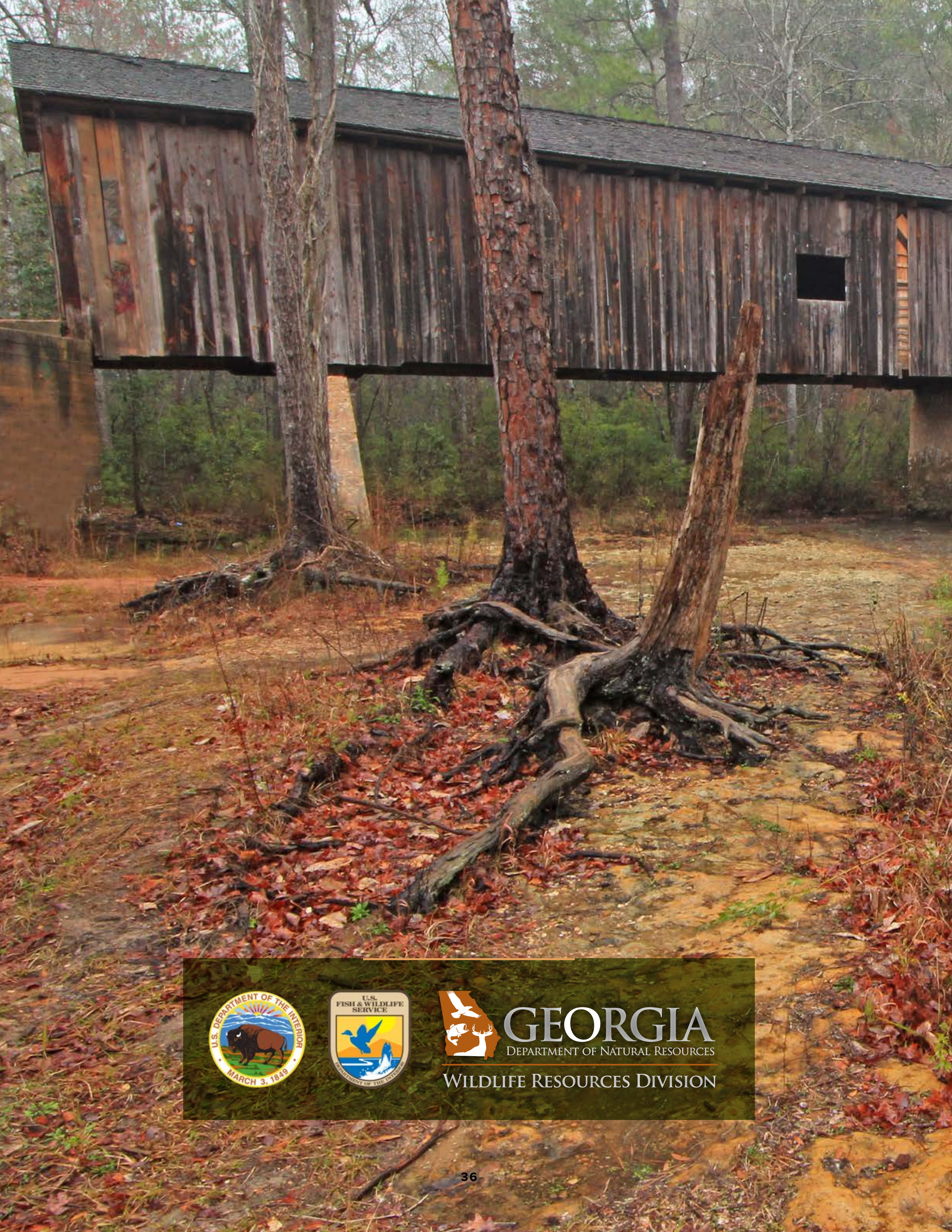

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