2020

Road-Stream Crossings: Sustainable Solutions for the Future

APPLIED POLICY PROJECT PREPARED FOR THE
VIRGINIA DEPARTMENT OF GAME & INLAND FISHERIES

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DISCLAIMER

The author conducted this study as part of the program of professional education at the Frank Batten School of Leadership and Public Policy, University of Virginia. This paper is submitted in partial fulfillment of the course requirements for the Master of Public Policy degree. The judgments and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, by the University of Virginia, or by any other agency.

HONOR CODE

On my honor, I have neither given nor received unauthorized aid on this assignment.

CLIENT PROFILE: VIRGINIA DEPARTMENT OF GAME AND INLAND FISHERIES

The Virginia Department of Game and Inland Fisheries (VDGIF) is the state agency responsible for the management of inland fisheries and wildlife in the state of Virginia. They have been stewards of Virginia's environment since 1916 through their mission of wildlife conservation and inspiring people to get outdoors.

Mission:

- Conserve and manage wildlife populations and habitat for the benefit of present and future generations.
- Connect people to Virginia's outdoors through boating, education, fishing, hunting, trapping, wildlife viewing, and other wildlife-related activities.
- Protect people and property by promoting safe outdoor experiences and managing human-wildlife conflicts. (Virginia Department of Game and Inland Fisheries, 2016)

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GLOSSARY

TERMS

- **AOP:** Aquatic Organism Passage. Refers to the impact that barriers have on the movement of fish and other aquatic organisms.
- **Culvert:** a (typically cylindric) structure that allows water to flow underneath a road
- **DCI:** Dendritic Connectivity Index. A habitat availability measure that assigns a quantitative measurement of connectivity within a given watershed. It is used to predict the ability of an aquatic organism to move freely within a watershed network.
- **EBTJV:** Eastern Brook Trout Joint Venture. A fish habitat partnership between state and federal wildlife agencies, non-profit organizations, and academic institutions
- **NBI:** National Bridge Inventory. Program run by the U.S. Federal Highway Administration that monitors the condition of bridges
- **NFPP:** National Fish Passage Program. A U.S. Fish & Wildlife road-stream crossing initiative
- **PEC:** Piedmont Environmental Council. A Virginia non-profit dedicated to the conservation of Virginia's northern Piedmont region.
- **SSD:** Stream Simulation Design. USDA Forest Service's preferred approach to designing road-stream crossings. The process mimics the characteristics of natural stream beds to facilitate greater AOP.
- **TU:** Trout Unlimited. A non-profit dedicated to the conservation of cold freshwater streams
- **VDGIF:** The Virginia Department of Game and Inland Fisheries
- **VDOT:** The Virginia Department of Transportation

1. EXECUTIVE SUMMARY

Road-stream crossings are an essential piece of US road infrastructure that provide extensive socio-economic benefits by allowing automobiles to cross over streams. However, cheap, poorly designed road-stream crossings inhibit fish passage and reduce viable fish habitat, and thus are a threat to the health of riparian ecosystems (Gibson et al., 2005). ***Consequently, environmental and transportation agencies with limited resources face significant challenges when confronted with the problem of repairing or removing road-stream crossings to further cost-effective restoration of aquatic habitat.***

Accordingly, this paper assesses common policy responses that address the issue of reduced stream connectivity arising from poorly designed road-stream crossings. In addition to allowing present trends to continue, this paper outlines three policy approaches to prioritizing road-stream crossing remediation efforts. These include:

1. Scoring & Ranking Model
2. Optimization Model
3. Conservation “Piggybacking” Approach

Each prospective policy is assessed according to its projected cost-effectiveness, equity, political feasibility, and ability to be implemented. These criteria are used to compare the relative efficacy of the policy alternatives in solving or mitigating the policy problem.

Ultimately, this paper recommends that policy makers adopt the Conservation “Piggybacking” Approach. The Piggybacking approach results in the most far-reaching gains in terms of increased stream-connectivity within watersheds, and it also provides policy makers with the most flexibility out of any of the policy options.

2. PROBLEM DEFINITION

PROBLEM STATEMENT: *Too many trout streams in Virginia suffer from reduced aquatic organism passage*.

Aquatic organism passage (AOP) is a term which refers to the ability of an aquatic organism to move between habitat areas. It is an important indicator of the health of riparian ecosystems because fish need access to different habitats across the various stages of their life cycle. Freedom of movement plays a crucial role in allowing fish to spawn, feed, and survive in harsh conditions (Goerig et al., 2016). Studies have further shown that the ability of fish to move freely in streams reduces population fragmentation (Winston et al. 1991), provides access to spawning grounds (Fausch and Young 1995), and aids in population recovery following disruptive weather events (Roghair and Dolloff 2005).

The ability of fish to move freely through river systems can be reduced by natural or man-made barriers such as waterfalls, dams, or road-stream crossings. Of these barriers, a particularly common and problematic type of road-stream crossing are culverts. A culvert is defined by the Virginia Department of Transportation (VDOT) as “a pipe or small structure used for drainage under a road, railroad or other embankment.” Culverts are commonly installed by transportation agencies because they are frequently more cost effective than bridges. Unfortunately, they can restrict the longitudinal movements of fish in small streams.

Studies have demonstrated that fish movement is an order of magnitude lower through culverts than in other types of road-stream crossings (Warren and Pardew 1998). Additionally, stream segments located beyond impassable culverts have be shown to have less than half the fish species and fish abundance of streams with passable culverts (Diebel et al., 2014; Nislow et al., 2011). The type of culvert (Goerig et al., 2016), height of a culvert’s outlet drop (Kondratieff and Myrick 2006; Park et al. 2008), and a culvert’s mean flow velocity (Burford et al. 2009; Johnson et al. 2012; Warren and Pardew 1998), have been shown to have an impact on the passability of the structure. In short, poorly designed road-stream crossings, particularly culverts, inhibit fish passage and reduce viable fish habitat, and thus remain a major obstacle towards improved stream connectivity (Gibson et al., 2005).

Many of Virginia’s state and privately-owned road-stream crossings were installed decades ago, before road engineers and environmental scientists were aware of the impact that road-stream crossings, particularly culverts, had on riparian habitats. Accordingly, a significant portion of the state’s wild trout streams suffer from reduced aquatic organism passage that stems in part from poorly designed road-stream crossings. Furthermore, while upgraded road-stream crossings can provide social, economic, and ecological benefits, transportation infrastructure is ultimately managed by transportation agencies that operate with limited resources under budget constraints (Levine 2013). **This dynamic has led to a market failure which has seen the most environmentally beneficial culverts be underprovided by both private landowners and the government.**

THE SCIENCE OF ROAD-STREAM CROSSINGS:

Road-stream crossings face a number of design challenges with respect to aquatic habitats. Thomson & Rahel (1998) have found that fish passage barriers frequently occur in culvert crossings, while Warren and Pardew (1998) found that culverts substantially reduced fish movement in comparison to other crossing types. This is typically due to the structure of culverts, which can have shallow water depths within their barrels, high stream flows, and reduced stream connectivity due to culverts being installed high above streambeds (Lang & Taylor 2003). Undersized crossings constrict streamflow and can lead to erosions, sediment aggregation, and ponding. Shallow crossings reduce stream connectivity and often lack the necessary water depth for the natural movement of aquatic organisms, water, and sediment (Levine 2013). Perched crossings are frequently located high above streams and thus isolate fish populations and render spawning and foraging habitat inaccessible (Warren & Pardew, 1998). Culvert crossings also generally provide little or marginal aquatic habitat within the culvert itself (Jackson 2003). In the context of Virginia policy, studies on Appalachian watersheds have shown that culverts create trout dispersal barriers and result in significant habitat loss for native brook trout (Poplar-Jeffers et al., 2009).

POLICY HISTORY:

The history of road-stream crossings dates back thousands of years to when human beings first started constructing structures to pass over streams. Structures involved in modern road-stream crossings include bridges, fords, and culverts. Culverts come in a number of different designs, including arch culverts, box culverts, and pipe culverts. Culverts are commonly installed by transportation agencies because they are generally more cost-effective than bridges. They also are typically cheaper to install, need less maintenance, and have a longer shelf-life (Gibson et al. 2005). These considerations have heavily influenced the policy history and ecological context of road-stream crossing design in the United States. Prior to the 1970s, transportation engineers placed an emphasis on economical construction costs and had minimal concern for aquatic organism passage (AOP), leading to a proliferation of box culverts in road-stream crossings. Gradually, fishery biologists recognized that undersized culverts inhibited the passage of aquatic organisms, sediment, and debris. This new consensus prompted the development of the U.S. Forest Service's **Stream Simulation Design** (SSD), which stresses that road- stream crossings be designed with characteristics similar to natural channels in order to improve aquatic organism passage. Stream simulation designed crossings also have better flood resiliency and ecological connectivity than conventional culverts. However, they are expensive and many transportation agencies operate with limited budgets. This creates a need for cost-effective policy alternatives.

3. IMPACT ON SOCIETY

ECOLOGICAL COSTS:

Wild brook trout occupy over 614 individual streams across 2,300 miles in Virginia. For wild rainbow trout, this number is 163 streams and ~700 miles, and for wild brown trout it is 92 streams and ~600 miles (VDGIF, 2018). A landmark survey of the spatial distribution and composition of wild trout populations across Virginia's 41 western mountainous counties found that of the 2028.9 miles surveyed, approximately 67% of stream miles contained native brook trout (Mohn and Bugas 1980). In addition to being the most populous salmonid in Virginia, the brook trout is also the state fish and only salmonid native to Virginia. Accordingly, among the three wild trout species present in Virginia, the brook trout is of the most ecological concern.

Unfortunately, the fish has experienced a significant decline in its current distribution in comparison to its historical range. A study carried out by the Eastern Brook Trout Joint Venture (EBTJV) has estimated that the fish is currently found in only 42% of the subwatersheds it once occupied in Virginia. Additionally, the Virginia Department of Game and Inland Fisheries (VDGIF) has identified population declines in its occupied habitat. Because of these developments, the 2015 Virginia Wildlife Action Plan listed the Brook Trout as a Species of Greatest Conservation Need (VDGIF 2015).

The reduction in habitat available for wild trout is likely negatively impacted by the presence of poorly designed road-stream crossings. Surveys of National Forests in Virginia have indicated that anywhere from half to two-thirds of road-stream crossings are barriers to fish passage (Gillespie & Encinas, 2017). Likewise, a study carried out by Trout Unlimited (TU) and the Piedmont Environmental Council (PEC) on trout habitat within the Rappahannock River Watershed found that of 133 road-stream crossings examined, 64 were determined to provide no or reduced AOP (Catlett, 2017).

Other states with significant brook trout populations have demonstrated similar findings. In Vermont, a study on culverts and aquatic organism passage carried out by the Vermont Fish & Wildlife Department found that of 1,501 culverts surveyed, under six percent provided full passage of aquatic organisms (VFWD 2007). A similar study on brook trout in West Virginia found that 97% of surveyed culverts were either obstacles or complete barriers to trout dispersal, and that 33% of brook trout reproductive habitat was isolated by culverts (Poplar-Jeffers et al., 2009).

ECONOMIC IMPACT OF TROUT FISHING:

Data from a 2006 nationwide survey on fishing in the United States indicates that around 13% of the U.S. population that is 16 years old and older fishes regularly. This represents close to 30 million anglers who spend on average 17 days fishing annually. Among this cohort, freshwater fishing remained the most popular kind of fishing, with close to 25.5 million anglers spending 434 million angler days out on the water.

Not surprisingly, fishing has a major economic impact on Virginia. The commonwealth plays host to over 800,000 anglers per year and fishing is responsible for more than $1.3 billion in economic impact in the state (How Fishing Benefits Virginians | Virginia DGIF, 2019). Other research from the American Sportfishing Association suggests that anglers spent $998 million annually while fishing in Virginia, supporting 9,786 jobs (Economic Impacts of Recreational Fishing in Virginia | ASA, 2019). Data from trout fishing licenses sold in Virginia indicate that residents purchased 51,915 trout licenses in 2019, while non-Virginia residents purchased 4,134 licenses. At $23 per trout license for Virginia residents and $47 per trout license for non-VA residents, this would indicate that VDGIF receives roughly $1.4 million in fees from anglers targeting trout. In terms of fishing for wild trout, a 2016 VDGIF survey on Virginia Freshwater fishing license holders found that 16.5% of anglers fish for wild trout. Per VDGIF, because ~ 345,000 freshwater fishing licenses are sold in Virginia, this would translate to an estimate of approximately 60,000 anglers fishing for wild trout in Virginia.

While at present we lack data on the economic impact of trout fishing in Virginia specifically, the 2016 National Survey on Fishing, Hunting, and Wildlife-Associated Recreation has useful national data on the average annual trips and daily expenditures for freshwater anglers. The survey notes that the typical freshwater angler averaged 13 days fishing per year and spent $36 per trip. It follows that a rough estimate at the Virginia level would indicate that 60,000 wild trout anglers fishing 13 days per year at $36 per day would have an economic impact of $28,080,000 in trip-related expenses alone. Assuming the survey's estimate of $933 annually spent per freshwater angler on trips and equipment, we could further extrapolate a rough estimate of ~ $55,980,000 generated in economic activity by wild trout anglers, although we should note that fishing equipment is not always bought locally.

Data from states comparable to Virginia suggest that these figures are reasonable estimates. A study by Responsive Management and Southwick Associates for the North Carolina Wildlife Resources Commission found that trout fishing supported 3,593 jobs and had an estimated economic impact of $383 million in North Carolina. Out of this total, an estimated $60,765,562 was generated by wild trout waters (Duda et al., 2015). Importantly, the study estimated direct effects, indirect effects, and induced effects of economic activity arising from trout fishing. For the purposes of the study, direct effect referred to dollars captured by businesses that provided goods and services purchased by anglers and consisted mostly of retail trade margins. Indirect Effects in the study referred to "the economic activity (e.g., output, employment, income) that occurs in the industries that supply those business that are stimulated by direct effect. Induced effect referred to the "economic activity that results from the household spending of salaries and wages by employees whose jobs are supported by the direct and indirect effects." Direct effects were correlated with $222.4 million in Output, $73.7 million in Income, and 2,304 jobs generated. The remaining $160.9 million in Output, $55.8 million in Income, and 1,289 jobs generated were split between the multiplier effects of the indirect effect and induced effect.

The study estimates that 18.5% of North Carolina fishing license holders fished for trout. This is similar to data from Virginia which suggests that 14% of all freshwater fishing in the commonwealth targeted trout (USFWS 2011). The North Carolina study further found that roughly 24,352 anglers fished for wild trout in North Carolina, representing around 16% of trout anglers in the state. Because of the similarities in percentages between wild trout fishers in Virginia (16.5% of trout fishers) and North Carolina (16% of trout fishers), it seems like a safe assumption that Virginia could expect a similar floor of economic activity generated by wild trout waters. Moreover, because Virginia has close to 60,000 anglers who fish for wild trout in comparison to roughly 25,000 in North Carolina, the economic activity generated by wild trout waters in Virginia could possibly be double that of North Carolina. As such, we expect that there is a range of $60 to $120 million in economic activity arising from wild trout waters in Virginia. This finding is supported by VDGIF's Wild Trout Management Plan, which noted that while wild trout streams generate a relatively small portion of overall fishing activity, that anglers report excellent catch rates and high satisfaction from the fisheries, indicating that Virginia's wild trout streams are economically important resources. (VDGIF 2018). It therefore stands to reason that the externalities stemming from poorly designed road-stream crossings possibly reduce Virginia's output and income due to their negative impact on economically important trout streams.

ECONOMIC AND SOCIAL COSTS OF POORLY-DESIGNED ROAD-STREAM CROSSINGS:

According to Peter Hujik, the Piedmont Environmental Council's Orange and Madison County field representative, many of the culverts found in Virginia mountain streams were installed in the early 1900's (Catlet 2007). As many are old and beginning to fail, this creates an opportunity to replace them with more environmentally friendly options. Additionally, old and poorly designed culverts have many potential adverse impacts on river and stream crossings. Improper design can block aquatic organisms, reduce access to reproductive habitat, and fragment populations. Other environmental concerns arising from poorly designed road-stream crossings include excessive water velocity, excessive turbulence, insufficient water depth, and discontinuity of channel substrate.

Existing cost-benefit analyses of conventional culverts versus AOP-friendly stream-simulation design culverts have identified a number of costs associated with conventional culverts. These include one-time costs such as replacement cost, wetland impacts, and water quality impacts. They also include annual costs, such as maintenance, fish passage impacts, flood damages, catastrophic failure, and road-user costs. In this model, total lifetime costs for a culvert are the sum of one-time and annual costs using a 3.5% discount rate. The cost-benefit analysis found the average net benefits associated with the replacement of a conventional culvert with a stream-simulation design culvert to have a net fiscal benefit (meaning strict financial outlay) of -$4,500 and net social benefits (incorporating the economic value of wetland restoration benefits, improved water quality, and improved fish passage) of $7,800:

BENEFITS OF AOP-FRIENDLY VS TRADITIONAL CULVERTS

Table 1. Net Benefits by Category (3.5% Discount Rate)

Category	Point Estimate of Benefit ($)	Standard Deviation ($)
Increased Project Lifetime	7,200	4,900
Reduced Wetland Impact	5,600	3,600
Increased Fish Passage	3,200	10,000
Reduced Road User Cost	2,000	1,300
Reduced Maintenance Cost	1,900	700
Reduced Flood Damages	1,700	1,100
Reduced failure rate	1,500	900
Improved Water Quality	1,300	2,900
Incremental Installation Cost	-16,600	14,600
Net Benefits	**7,800**	**16,500**

(Schwartz, 2014)

Accordingly, per Schwartz's research, each conventional culvert on average costs society $3,300 in possible net social benefits. Per VDOT's 2019 State of the Structure report, there are 8,006 large culverts maintained by the state. Of these, 4933 are in districts that harbor wild trout populations (Bristol, Salem, Lynchburg, Culpeper, & Staunton). If we do a very rough estimate and assume that each of these culverts is a conventional culvert and that each of these culverts thus costs Virginia $3,300 in possible net social benefits, then we could estimate that Virginia is forgoing $16,278,900 in net social benefits due to its use of conventional culverts.

4. REGULATORY FRAMEWORK

I) JURISDICTION

Generally speaking, the Virginia Department of Transportation maintains regulatory jurisdiction over road-stream crossings in Virginia. The state's drainage laws are rooted in civil law rules, which in turn are derived from previous court decisions that "place a natural easement on the lower land for the drainage of surface water to its natural course." Additional regulations that apply to drainage easements are derived from various VDOT policy manuals and the Virginia Administrative Code. Bridges, roads, and culvert design standards and regulations are dictated by the agency's Road and Bridge Specifications manual. Culverts' design criteria are also regulated through VDOT's Drainage Manual via their inclusion under "drainage facilities" – an umbrella term defined by VDOT as including "open channels, ditches, underdrains, culverts, gutters, catch basins, drop inlets, manholes, storm sewer pipes and stormwater management facilities."

VDOT also manages and maintains culverts on state operated roadways or within state owned right of way. VDOT will occasionally acquire access to additional land in the form of permanent drainage easements to ensure proper drainage for roads. In these instances, VDOT accepts drainage (and thus culvert construction and maintenance) responsibility for these areas. Other drainage easements are maintained by private landowners, or public bodies such as cities, counties, or homeowners' associations, in which case these parties are responsible for maintaining the drainage easements. The primary drainage responsibilities for these entities involve ensuring the free flow of stormwater runoff (*Drainage on Virginia Roadways* | VDOT, 2013).

According to the regulations and requirements of the Federal Highway Administration (FHWA) National Bridge Inventory (NBI), VDOT is required to conduct detailed inspections of bridges at intervals no greater than 2 years and of large culverts at intervals no greater than 4 years. Per this inspection program, VDOT is required to carry out inspections on all "Virginia Responsible NBI Structures," regardless of owner.

However, as noted in VDOT's 2019 State of the Structures Report:

> "VDOT is only responsible for the maintenance of VDOT-owned NBI structures, while localities, other state agencies, or other legal entities of the Commonwealth of Virginia are responsible for the maintenance of all other NBI structures. VDOT chooses to also inspect and maintain the Non-NBI structures through its Structure and Bridge Division.

Virginia Responsible Structures include structures that meet one of the following criteria:

- Structures in the NBI for which Virginia is responsible for reporting condition data to FHWA. These structures are described as NBI structures and include bridges and culverts with a length greater than 20 feet.
- Non-NBI structures that are shorter bridges with a length less than or equal to 20 feet; and large culverts that have a length less than 20 feet and total openings with an area greater than 36 square feet.

Virginia Responsible Structures excludes the following: Permanently closed structures and structure types that are not relevant to reports on the condition of highway bridges, such as pedestrian bridges, scales, and ferry docks. Structures that are outside the control of the Commonwealth of Virginia, such as bridges and culverts owned by federal agencies or legal entities directly managed by a federal agency, are also excluded. (Virginia State of the Structures Report 2019)"

II) FUNDING & CURRENT EXPENDITURES

VDOT is primarily funded by the Commonwealth Transportation Fund, which in turn receives funding from dedicated state and federal sources that are mostly derived from user fees on gasoline (Commonwealth Transportation Fund Budget, 2018). The CTF finances the commonwealth's Six Year Financial Plan, which totals $36.9 billion for FY2019-2024 and is Virginia's primary planning framework for funding roadways. VDOT's priority for funding is the maintenance of existing infrastructure, with revenues for maintenance predominately sourced from the commonwealth's financial plan's Highway Maintenance and Operating Fund.

In terms of road-stream crossings, in fiscal year 2019, VDOT spent $33.5 million inspecting 15,477 total structures. The inspections were carried out by both in house inspection staff and via consultant contracts with outside consultants. Of the total investigations, 7,172 were performed on bridges, 2,833 were performed on culverts, and 5,472 were performed on ancillary structures. Accordingly, applying a rough estimate of the percentage of culverts to the total percentage of structures investigated (2,833/15,477 = 0.183 * $33.5 million), we get a total of $6,132,035 spent on culverts inspections.

Additionally, VDOT has two or more maintenance crews for each of its districts who are responsible for preventative maintenance, restorative maintenance, rehabilitation, and replacement of large culverts. Of the VDOT districts that include mountainous trout streams, Bristol has 6 bridge maintenance crews totaling 36 members, Salem has 6 crews totaling 35 members, Lynchburg has 4 crews totaling 28 members, Culpeper has 4 crews totaling 26 members, and Staunton has 5 crews totaling 36 members. This represents a total of 161 full-time employees dedicated to maintaining road-stream crossings. Moreover, in FY2019 these employees either preserved, rehabilitated, or repaired 2842 structures (VDOT 2019). Consequently, while we lack accurate data on maintenance expenditures, we can calculate labor expenditures by multiplying the number of bridge crew members (161) by the official average salary of VDOT maintenance persons ($39,764) to arrive at total labor expenditure of

$6,402,004 for FY2019. Assuming the U.S. Bureau of Labor Statistics state employee average of total benefits representing 37.7% of their total compensation, then we arrive at total benefits for this group totaling $2,413,556. The approximate combined total for wages and benefits of relevant maintenance workers is therefore $8,815,560.

While VDOT doesn't publish data on annual culvert replacement project costs, there are currently 1955 metal arches and metal culverts that VDOT tracks the condition of. Of these, 724 are listed as being in good condition, 1115 are listed as fair condition, and 116 are listed in poor condition, with VDOT guidelines defining poor structures as being characterized by deficient structural components that require the structure to be either monitored or repaired (VDOT 2019). Unfortunately, the costs associated with remediating and replacing culverts are highly variable and often contingent on site-specific factors. One study on American fish passage projects found that median project cost was $30,000, although the study failed to distinguish between expensive projects like large dams and comparatively more affordable projects on culverts (Bernhardt et al., 2005). Another study out of Canada found a range of average culvert costs between ~ $7800 and ~ $78,000 (after adjusting for inflation and converting to US dollars). However, the same study noted that average local costs were probably much lower, likely in the range between ~ $7800 and ~ $11,700 (Oldford 2013). These figures are more in line with the Virginia statewide average construction cost for box culverts, which range from $900 to $1925 (VDOT District Averages 2017 - 2019). As such, if we use the mean project cost of $9750 from Oldford's range and multiply it by 116 (the total number of culverts listed as being in poor condition in Virginia), we arrive at a rough estimate of $1,131,000 spent in culvert replacement projects in Virginia.

Totaling maintenance, inspection, and replacement costs, **we estimate that VDOT currently spends approximately $16,078,595 in culvert related costs per year.**

III) VIRGINIA REGULATIONS AND CURRENT BEST PRACTICES

Culverts in Virginia are predominately regulated through Section 1000 of the Road and Bridge Standards and VDOT's Drainage Manual. The Road and Bridge Standards outline specific design criteria for box culverts, including recommended materials, dimensions, and construction guidelines. Most frequently these involve culverts composed of concrete and reinforced steel. The Drainage Manual has more general regulations, and only specifies that culverts be used in place of bridges when "bridges are not hydraulically required, where debris and ice are tolerable, where a culvert is more economical than a bridge, and where environmentally acceptable." When choosing between what type of culvert to install, the design criteria are supposed to take into account "cost comparisons, construction time, earth movement, maintenance, and service life expectancy (VDOT Drainage Manual)." Overall, the existing VDOT's design criteria for culverts typically emphasize structural concerns such as weight-bearing loads and water velocity, and generally fail to take into account aquatic organism passage.

In addition, while VDGIF does currently have a fish passage program in place that is responsible for the installation of fishways and the removal of multiple dams, these projects have emphasized migratory fish restoration for anadromous and catadromous fish species such as American shad, herring, alewife, striped bass, and American eel. At present, VDGIF lacks a comparable program for non-anadromous cold-water dwelling fish like trout.

To the extent that there are existing ecological best practices in Virginia related to improving aquatic organism passage in road-stream crossings, the best practices have been developed by local environment non-profits such as Trout Unlimited and the Piedmont Environmental Council. The current guidelines were outlined by TU and PEC in a stakeholder meeting on the Rappahannock Rivershed in December 2014, and consist of four ways to prioritize the removal of culverts that inhibit AOP. These guidelines are:

1. Pursue projects only in watersheds with allopatric (non-overlapping) populations of brook trout
2. Assign a value of potential stream miles reconnected to each AOP barrier
3. Assign a value to each AOP barrier that describes the stream's VDGIF-designated trout class
4. Add a field describing the distance of each barrier to Shenandoah National Park or the Rapidan Wildlife Management Area

IV) BEST PRACTICES IN OTHER STATES:

A. Proper Design Standards

Inconsistent and weak design standards in road-stream crossings have contributed to the widespread adoption of undersized culverts that restrict stream connectivity and fragment aquatic habitats (Gibson, Haedrich, & Wernerheim, 2005). In one survey of culvert passability, 56% round culverts and 57% of box culverts were founding impassable to fishes due to an outlet drop. Conversely, the same survey found that 97% of open-bottom arches and bridge were passable, due largely to their natural stream bottoms (Sleigh & Neeson, 2018). Current culvert design guidelines emphasize that standard culvert designs placed in streams with slopes exceeding 5% "consistently produce trout dispersal barriers and should be avoided during new construction (Poplar-Jeffers et al., 2009)." Alternatively, characteristics of suitable passability include:

- Road-stream crossing maintains a width which is greater than or equal to that of the adjacent upstream and downstream reaches
- Contains natural stream substrate and flow throughout
- Does not have a perched outlet.

Early research on culvert passability found that ford and open-box crossings showed little difference from natural reaches. The central problem identified for barriers to fish passage was increased water velocity through the culverts. Accordingly, in order to spur the installation of better designed road-stream crossings, state agencies could build culverts with improved design and regulatory standards such as the US Forest Service's Stream Simulation Design (SSD) process, which emphasizes that crossings be designed with characteristics similar to natural channels (US Forest Service, 2008). However, while many culverts can be either repaired or modified (such as by installing fishways or SSD friendly culverts) this is usually expensive and subject to budget constraints which inhibit restoration efforts (Gibson et al. 2005; Poplar-Jeffers et al. 2008). Replacing traditional box or round culverts with more AOP-friendly alternatives such as arch-culverts is similarly expensive, with one study from Maine estimating that high arch culverts cost between $28,000 and $50,000 (Long, 2009). Other cost estimates have projected the average cost of replacing impassible culverts at $78,000 (Fish Passage Technical Working Group, 2012). Unfortunately, the higher installation and construction costs associated with AOP-friendly culverts are frequently prohibitive for transportation agencies that operate with limited budgets (O'Shaughnessy et al. 2016).

B. Effective Implementation

Because of the high costs involved in culvert mitigation, several states have adopted a funding model that involve a cost-share structure. Cost-share programs involve state or federal agencies subsidizing road-stream crossing upgrades by having the state or federal government pay for a portion of the funding while local municipalities pay the remainder. In turn, the upgraded stream-crossings would address the negative externalities associated with poorly designed crossings (Levine 2013).

A number of cost-share programs are in existence, including state and county-level initiatives, and the US Fish & Wildlife Service's National Fish Passage Program (NFPP) at the federal level (Levine 2013). The NFPP provides funding and technical assistance to replace high priority barriers, has an average award of $70,000, and is responsible for reopening access to close to 200,000 acres of wetland habitat for fish and animals ("Fish Passage Reconnects Habitats for Healthier Fish and Wildlife," 2019)

State level cost-sharing initiatives have also demonstrated success. For example, Maine's Wildlife Habitat Incentive Program (WHIP) has resulted in the opening of 90 miles of Atlantic Salmon habitat by using cost-share funding to have the state cover 90% of the installation costs of replacing undersized culverts with better designed arch culverts (private landowners cover the remaining 10%). With the cost-share financing in place, the otherwise unaffordable installation costs resulted in both enhanced ecological benefits and reduced operation & maintenance costs for private landowners (Long, 2009).

Best practices other than cost-sharing initiatives include integrating design standards into permitting decisions and using grants to incentivize municipalities to adopt minimum standards. These involve states ensuring the installation of better designed road-stream crossings by integrating regulatory standards into permitting decisions and by implementing incentive programs that encourage local municipalities to adopt standards set at the state level. Massachusetts provides an example of a state that has successfully set robust state-level requirements that are tied to permitting decisions, while Vermont provides an example of a state that delivers grant matching to towns that have adopted minimum requirements related to road-stream crossing design (Levine 2013).

V) TECHNOLOGY & EFFECTIVE PRIORITY SETTING FOR REPLACEMENT AND REPAIR DECISIONS

While design standards and best practices remain important facets of culvert mitigation policies, increasingly new technological developments have aided state agencies in identifying and prioritizing culvert removal and repair decisions when these agencies evaluate which fish passage projects to pursue. Transportation and wildlife agency officials in a number of states have used computer software to help identify road-stream crossings that are both in need of repair or removal and that are also ecologically important in terms of aquatic habitat, flooding concern, or climate change impact. Once identified, these crossings are then targeted for repair or replacement with more ecologically-minded substitutes, thereby alleviating the harmful externalities of poorly designed crossings.

The systems of prioritization have occurred through a number of approaches, including scoring and ranking procedures, scenario analyses, or via optimization models - all of which have demonstrated the ability to successfully restore longitudinal connectivity (and thus improved aquatic organism passage) across a variety of river habitats (Perkin and Gido, 2011, Walters et al., 2014, Perkin et al., 2015b, Moody et al., 2017).

In the past, conservation agencies have typically made prioritization decisions through various forms of a scoring and ranking technique (McKay et all, 2016). Other studies have shown that more dynamic approaches, such as those based on integer programming techniques, can produce more optimal solutions at a quicker rate (O'Hanley & Tomberlin, 2005). Further studies have shown that using optimization models that involve data sharing and communication about candidate sites during infrastructure maintenance planning have been correlated with increases in conservation return-on-investment from 17% to 25%, without any concomitant increase in funding levels (Neeson et all, 2018).

One additional factor that influences culverts' impacts on fish passability is the ecology-wide context in which barriers function. Older studies on culverts and aquatic organism passage (AOP) typically focused on the effects of barriers on immediate stream systems, whereas more contemporary studies have employed concepts from landscape ecology to examine how barriers impact entire watersheds (Dunham et al. 1997; Jones et al. 2000; Park et al. 2008; Cote et al. 2009; Fullerton et al. 2010). One of these studies has indicated that using spatial and temporal coordination across an entire watershed region is "nine-times more cost-effective than local scale planning (Neeson et al., 2015)." Conversely, other simulations have found that variation in longitudinal connectivity among barriers had marginal impact on restoration priorities. In these models, "the same barrier was retained as the top priority >96% of the time," essentially indicating that multiple barriers are equal to the sum of their parts (Padgham and Webb 2010).

Nonetheless, prioritization models have emerged as the most cost-effective and efficient policy options to assist in assessing road-stream crossing repair and removal decisions. For example, one scoring and ranking model found that the removal of a single carefully chosen barrier had the same environmental impact as the removal of eight poorly chosen barriers within a given watershed (Cote et al., 2009). Prioritization models also have the advantages of generally not requiring legislation to be implemented and not being subject to cumbersome political processes. **For these reasons, this paper has limited its evaluation of potential road-stream crossing policy responses to a selection of different prioritization models.**

5. POLICY ALTERNATIVES

Listed below are brief synopses of common policy responses that have been employed by policy makers to address the problems associated with poorly designed road-stream crossings.

1) LET PRESENT TRENDS CONTINUE

One possible policy response would be allowing present trends to continue. In some respects, this response satisfies important considerations raised by the issues of poorly designed road-stream crossings. Impassable or obstructed culverts have been in place across the US for decades, yet states in which they are present have maintained recreational fishing opportunities and coped with flooding and degraded water quality. Additionally, from a financial standpoint, transportation agencies operate with limited budgets and face difficult choices when prioritizing between ecological issues like road-stream crossings and constructing new road infrastructure to either mitigate traffic or service new populations. Likewise, transportation agencies are funded by state governments that have other funding priorities such as education, healthcare, and public safety. Accordingly, it is entirely possible that the constituents of state governments would prefer to allocate scare resources towards causes they deem more important than road-stream crossings.

There is also the risk that the negative ecological externalities associated with road-stream crossings are either overblown or are less important than other, more pressing ecological concerns. In terms of the externalities being overblown, although the adverse impact of culverts on Aquatic Organism Passage (AOP) is well-documented (Warren & Pardew, 1998), many aquatic organisms have demonstrated a remarkable ability to recover from harsh ecological impediments. The fish species of most concern vis a vis culverts in Virginia, Eastern brook trout, are a remarkably resilient fish species, and it's possible that they could adapt to the flooding or climate change related problems associated with road-stream crossings. Indeed, one study on the Staunton River in Virginia found that the stream's brook trout population exceeded pre-flood levels just three years after a catastrophic flood eliminated the stream's entire trout population (Roghair, 1999).

To the point of there being possibly more pressing ecological threats, studies done on Eastern brook trout survivability have shown that the largest threat the species' faces are increasingly warm summer temperatures (Letcher 2017). Consequently, if increasing trout survivability is the policy goal, then it is possible that putting shade producing trees along river banks, adding logs into streams, and making sure that private wells don't siphon cold spring water are more effective courses of action than culvert mitigation efforts aimed at restoring habitat connectivity(Letcher 2017). Because of these possibilities, the policy goal of letting present trends continues could reasonably be expected to address the negative externalities related to poorly designed road-stream crossings.

2) SCORING & RANKING PRIORITIZATION MODEL

The most common repair and removal prioritization model employed by wildlife agencies is the scoring and ranking model. This model involves having agency officials collect data on the passability of all culverts in a given watershed via either field assessments or technological surveys, in conjunction with modeling software. Identifying impassible culverts and quantifying the scale of passability is difficult because "passability" is fundamentally a dynamic process. The capacity of fish to get through a barrier varies according to fish species, size, stream flow, and environmental conditions (Rolls 2011). In particular, there is huge variability in the ability of various fish species to swim in currents or traverse steep gradients (Peake, 2008). Likewise, there are several physical characteristics associated with culverts, such as structure length, water velocity, height, depth, and outlet drop that impact fish passage rates (Januchowski-Hartley et al., 2014). Other factors impacting passability include the installation and maintenance of culverts and the topography and hydrology of the local landscape (Kemp & O'Hanley, 2010). Once this data is collected and then inventoried, these values are then modelled to generate a score for a parameter known as the dendritic connectivity index (DCI), a measurement that estimates the overall passability of a watershed (please refer to the Criteria section for a more in-depth definition).

Agency officials compare prioritization decisions by simulating the restoration of one culvert at a time and seeing the simulation's effect on the watershed's overall DCI score based on the extent of newly connected habitat that becomes available when a barrier is removed. This allows agency officials to see the net gain associated with the restoration of each culvert in a given watershed. Typically, the culverts are then ranked according to which culvert had the largest impact, hence the scoring and ranking moniker. The nature of scoring and ranking models allows agency officials to conduct a cost-benefit comparison of each culvert evaluated. For example, it allows agency officials to determine if is more cost-effective to remove the second most optimal culvert instead of the most optimal culvert (Bourne et al., 2011). While there are several scoring and ranking models in use, this paper assumes the costs and methodology associated with the study by Cote et al in their 2009 paper "A new measure of longitudinal connectivity for stream networks," due to its use of the DCI framework.

3) OPTIMIZATION PRIORITIZATION MODEL

One limit to scoring and ranking models is that they typically assess net DCI gains in isolation (i.e., one culvert removal at a time) (O'Hanley & Tomberlin 2005). In contrast, optimization prioritization models can estimate the net gains associated with remediating multiple barriers at once. Optimization models due this by taking into account the spatial relationship between barriers and the interactive effects that multiple culvert remediation efforts have on a watershed's connectivity (King et al., 2017). In turn, this allows optimization models to calculate the net DCI gains from thousands of combinations of potential barrier remediation efforts.

However, in order to accurately predict this information, optimization models require robust computing power and many data inputs. This necessitates the use of software programs like

Python and ArcGis, and also requires ecological data gathered sources such as the National Hydrology dataset, the National Inventory of Dams, the National Bridge Inventory, and road data from TIGER/Line data in the US Census. Importantly, however, by using data from these sources, the optimization model largely eliminates the need for lengthy field assessments. While there are many optimization models in use, this paper assumes the costs and software requirements used by Nibbelink et al. in their 2017 paper "How to avoid death by 10,000 culverts: spatially-explicit tools for multi-scale prioritization to restore aquatic connectivity," due to its use of the DCI framework.

4) AGING INFRASTRUCTURE "PIGGYBACKING" PRIORITIZATION APPROACH

A piggybacking prioritization approach involves conservation organizations collaborating with infrastructure agencies to identify joint opportunities to mitigate environmental impacts. For culvert remediation efforts, this would entail using planned infrastructure maintenance to increase the cost-effectiveness of initiatives that aim to restore habitat connectivity within watersheds. One study on Oklahoma road-stream crossings found that 15% of road-stream crossing surveyed were in both poor condition and blocked fish passage, indicating that there is potentially significant environmental return on investment to be gained by adopting such an approach (Sleight & Neeson, 2018).

The piggybacking strategy typically works via a cost-sharing arrangement in which conservation agencies identify road-stream barriers of both high ecological importance *and* that are in poor condition/slated to be replaced. The conservation organization then pays the difference between an AOP friendly culvert and a traditional culvert. This results in net ecological benefits via improved fish passability, and also confers benefits to the infrastructure agency via the improved resilience of AOP-friendly culverts to high flow events (Melvin et al., 2017).

The piggybacking process requires open communication about objectives and priorities, collaboration, and data exchange between infrastructure agencies and conservation groups. It also requires complex technological and planning tools that can assess the cost and benefits of a multitude of remediation efforts. Usually the strategy involves combining spatial data on road conditions with an optimization prioritization model on culvert replacements. One simulation is run assuming all high-priority culverts are replaced at full cost by the conservation agency. Another simulation is then run in which the road-condition data acts as a proxy for maintenance needs, and joint opportunities for road maintenance and culvert replacement are identified. Then the total ROI from the full cost and piggybacking models are compared, to arrive at a figure which shows the possible savings from coordinating infrastructure maintenance with conservation projects (Neeson et al., 2018). This paper evaluates the piggybacking prioritization model used by Neeson et al in their 2018 paper "Aging infrastructure creates opportunities for cost-efficient restoration of aquatic ecosystem connectivity," due to its use of the DCI framework.

6. CRITERIA

Below we detail a set of four evaluative criteria that will be used to assess the potential impact of the various policy alternatives. These criteria are intended as measurable standards that will be used to compare the relative efficacy of the policy alternatives in solving or mitigating the policy problem.

1. **Cost Effectiveness** (weighted at 50 percent)**:** The most important (and thus most heavily weighted) criterion that will be used to compare the efficiency of policy alternatives in addressing the outcomes associated with poorly designed road-stream crossings is *cost effectiveness*. For our purposes, cost effectiveness is largely concerned with measuring the improvement in stream connectivity over a ten-year period that follows from the adoption of the proposed policy alternatives. **Stream connectivity is used as the outcome of interest because it is a reliable predictor of overall habitat health for stream-dwelling fish like brook trout** (Kanno et al 2014).

   The improvements in stream-connectivity will be calculated by comparing before and after scenarios involving Aquatic Organism Passage (AOP) rates for a given set of road-stream crossings within a watershed both prior to and following the adoption of hypothetical policy alternatives. Most studies that assess stream connectivity and AOP do so through benchmarks of stream length and connectivity called dendritic connectivity indices (DCIs). Because we are principally concerned with stream dwelling organisms, we will use the DCI recommended by the USDA for year-round stream resident organisms. This was developed by Cote et al. (2009) and quantifies "the longitudinal connectivity of river networks based on the expected probability of an organism being able to move freely between two random points of the network." It is calculated using the formula:

   $$\mathrm{DCI} = E\left[C\right] = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} P\left(C = c_{ij}\right).$$

   "Where *C* is a discrete random variable that denotes connectivity, c_{ij} is a realization of *C* for stream sections *i* and *j,* and where {*i*, *j*} = 1,…, *n,* where n is the number of stream sections, and is equal to the number of barriers plus one(Cote, 2009)."

   The maximum DCI value is 100, which indicates a watershed that is completely connected. Connectivity decreases from 100 downward, with a score of 0 indicating a watershed that is completely blocked/unconnected. With this in mind, our *effectiveness* outcome will be measured by totaling the theoretical difference in DCI before and after the adoption of the proposed policy alternatives. This will necessarily involve using rough estimates that are extrapolated from other studies across a diverse range of watersheds, but is the most reliable method for assessing the effectiveness of the various policy alternatives in increasing stream connectivity (which in turn expands the available habitat of aquatic organisms and is a reliable measure for AOP). **For costing**

purposes, the effectiveness of each alternative will be calculated using a standard 3% discount rate and a net present value over a 10-year period.

2. **Equity:** (weighted at 10 percent)**:** This criterion measures the extent to which each policy alternative involves inclusive, fair treatment to ensure that no sects of the population are disproportionately impacted by the environmental problems stemming from road-stream crossings. Because road-stream crossings are predominately located in mountainous terrain, particular emphasis will be placed on how alternative policies impact rural, low income communities. Equity will be assessed in terms of how each policy generates *High*, *Medium*, or *Low* equity.

3. **Political Feasibility** (weighted at 10 percent)**:** This criterion considers the political acceptability of each political alternative. It considers the political support each policy alternative has across a range of critical policy makers, stake-holders, and administrative bodies. The criterion also reflects whether or not a policy alternative requires legislation to be implemented and the favorability of the current political climate towards implementation. Each policy alternative will be measured as having *High*, *Medium,* or *Low* feasibility.

4. **Ability to Implement** (weighted at 30 percent): This criterion refers the relative complexity of implementing the policy alternatives. It takes into account the possible need for regulatory and rules changes associated with enacting the various policy alternatives. It also addresses five qualitative considerations:

    - Are there pre-existing funding streams available?
    - Are front-line workers on board with the policy and willing to implement it?
    - Is there the right mix of skills and experience (including leadership?)
    - Does it require a large or complex technological investment?
    - How many agencies are involved?

    Each policy alternative will be evaluated in light of these considerations and will be assessed as having *High*, *Medium,* or *Low* ability to implement.

Methodology for Cost-Effectiveness

Each policy alternative will be assessed for its overall cost-effectiveness across a ten-year period. The cost-effectiveness for each alternative will be calculated by combining the total costs of each alternative (including capital outlays, labor costs, infrastructure investments, and maintenance expenditures) and dividing this total by the change in stream connectivity (represented by the ΔDCI) generated by each policy alternative. Per OMB guidelines, the analysis will assume a 3% discount rate over the ten-year period projected.

Projecting Outcomes: In order to compare the effectiveness of the various barrier prioritization approaches, this paper references the results obtained by Sethi, O'Hanley, and Gerken in their 2017 paper "*High value of ecological information for river connectivity restoration.*" Their results and framework are used because they provide a standard of cost-savings per given benefit level (100% DCI) that allows for a direct comparison of the cost-effectiveness of each barrier prioritization framework. Importantly, Sethi, O'Hanely, and Gerken's study measures the habitat connectivity for Coho salmon within an urbanizing Alaskan watershed. This complication raises a number of issues for our purpose of extrapolating their results into the context of Virginia watersheds. To begin with, the ecological and environmental conditions in Alaska are obviously different from those found in Virginia. Additionally, because Coho salmon are diadromous fish while the various trout species in Virginia are all potadromous fish, substituting an analysis of habitat connectivity from one to the other species would fail to take into account important species idiosyncrasies that inform overall barrier passability. Still, Sethi, O'Hanely, and Gerken's study is useful because it provides us with a rough estimate of the effectiveness of the various barrier prioritization approaches.

Another key assumption made by this paper is the supposition that roughly half of the trout habitat in Virginia features inhibited aquatic organism passage. This assumption is predominately derived from a study carried out by Trout Unlimited and the Piedmont Environmental Council on trout habitat within the Rappahannock River Watershed. That study found that 48.1% of barriers surveyed provided little or no aquatic organism passage (Piedmont Environmental Council, 2015). Because the Rappahannock River Watershed includes land in Rappahannock, Madison, Greene and Albemarle counties, it is presumed that it is broadly representative of overall trout habitat in Virginia. Furthermore, while 42 of the 60 culverts (70%) surveyed in Sethi, O'Hanley, and Gerken's study provided little or no aquatic organism passage, their survey found that a little under half (49.2 DCI) of the river habitat examined was accessible for Coho Salmon. Accordingly, while the Alaska study is not a perfect one to one comparison for Virginia, it functions as an approximate estimation from which we can assess broad trends. These outcome assumptions are further detailed in *Figure 1* below.

Projecting Costs: Key costs include personnel costs and capital costs. Personnel costs were estimated using average salaries for VDOT maintenance workers found on GlassDoor and average salaries for VDGIF employees from *The Richmond Times Dispatch*. Assumptions about the labor and benefit costs associated with new hires were made using averages from the U.S. Bureau of Labor statistics. Capital costs associated with office equipment used data from a VDGIF audit. These include maintenance and depreciation costs. Costs associated with overhead used data from a VDGIF audit. Other capital expenses (including office expenses, travel expenses, and other incidental expenses) used data from GSA per diem guidelines. Capital costs associated with culvert mitigation used cost estimates that were generated by U.S. Fish and Wildlife Service engineers rather than existing VDOT data. This decision was made due to the fact that USFWS culvert costs reflect AOP friendly culverts whereas VDOT data refer to existing AOP-inhibiting box culverts. The USFWS culvert costs were also used by the Sethi, O'Hanley, and Gerkin paper. These cost assumptions are further detailed in *Figure 2* below.

FIGURE 1: KEY OUTCOME ASSUMPTIONS

STATUS	QUO
3% discount rate	Office of Management and Budget
~ 50% of trout habitat in Virginia features reduced or no AOP	Trout Unlimited and Piedmont Environmental Council Survey (Piedmont Environmental Council, 2015).
Mitigation of all problematic culverts (either replacement or removal) would result in 100% stream connectivity within a given watershed	Based on paper "High Value of Ecological Information for River Restoration" (Sethi et al., 2017).

SCORING & RANKING MODEL	
Assesses culvert removal outcomes and selects projects in rank order one by one	Methodology outlined in O'Hanley and Tomberlin (2005) and Cote (2009).

OPTIMIZATION MODEL	
Uses dendritic connectivity index to maximize stream connectivity via combined spatial & network effects from culvert remediation	Methodology outlined in King and O'Hanley (2016) and Cote (2009).

PIGGYBACKING MODEL	
Assumes the same outcome from the optimization model and adds an improvement of 25% in conservation return-on-investment without any funding increase	Methodology outlined in Neeson et al. (2018)

FIGURE 2: KEY COST ASSUMPTIONS

STATUS	QUO
$6,402,004 spent by VDOT on wages for culvert maintenance crews	Data for 161 full-time maintenance crew members from VDOT 2019 State of the Structures Report. Wage data was found on GlassDoor.
$2,413,556 spent by VDOT on total benefits for culvert maintenance crews	Uses U.S. Bureau of Labor Statistics state employee average of total benefits as 37.7% of overall compensation.
$1,131,000 spent on annual culvert replacement projects by VDOT	Data on culverts in poor condition from VDOT 2019 State of the Structures Report. Average culvert replacement costs were calculated from Oldford (2013) and VDOT District Average Construction Costs (2017-2019).
$6,132,035 spent on annual culvert inspections by VDOT	Data from VDOT 2019 State of the Structures Report.

SCORING & RANKING MODEL	
Assumes rapid field assessments lasting between 5 to 15 minutes are required for each culvert in a given watershed. Assumes that this work and DCI calculations can be carried out by an average salaried VDGIF employee.	Methodology outlined in O'Hanley and Tomberlin (2005), Cote (2009), and Bourne et all (2011).
Assumes no computer or software technology required for implementing.	Methodology outlined in O'Hanley and Tomberlin (2005), Cote (2009), and Bourne et all (2011).
Assumes a salary of $58,739 per average VDGIF employee. Assumes $22,145 in benefits per average VDGIF employee.	Data from 2018-2019 State of Virginia employee salaries from The Richmond Times Dispatch (2018). Benefits data from U.S. BLS.
Assumes an average of $7998 spent on equipment per VDGIF employee.	Data from VDGIF Audit Fiscal Year 2017 (Total equipment expenditures of $3,439,030/430 employees)
Assumes an average of $9690 spent on supplies and materials per VDGIF employee.	Data from VDGIF Audit Fiscal Year 2017 (Total supplies expenditures of $4,166,608/430 employees)
Assumes 44 barriers need to be mitigated to restore full connectivity in sample watershed. Total is $8,400,000 for full remediation efforts.	44 barrier number comes from (Sethi et al., 2017). Culvert construction, materials, and design costs are drawn from (Dekker & Rice, 2016)

OPTIMIZATION MODEL	
Requires usage of Python and ArcGIS so assumes the average salary of $88,203 per VDGIF Information Technology Specialist. Assumes $33,252 in benefits per VDGIF IT specialist.	Software requirements from Nibbelink et al (2017). Salary data from 2018-2019 State of Virginia employee salaries from The Richmond Times Dispatch (2018). Benefits data from U.S. BLS
Assumes an average of $7998 spent on equipment per VDGIF employee	Data from VDGIF Audit Fiscal Year 2017 (Total equipment expenditures of $3,439,030/430 employees
Assumes an average of $9690 spent on supplies and materials per VDGIF employee	Data from VDGIF Audit Fiscal Year 2017 (Total supplies expenditures of $4,166,608/430 employees)
Assumes 36 barriers need to be mitigated to restore full connectivity in sample watershed. Total is $7,600,000 for full remediation efforts.	36 barrier number comes from (Sethi et al., 2017). Culvert construction, materials, and design costs are drawn from (Dekker & Rice, 2016)

PIGGYBACKING MODEL	
Assumes the same costs from the optimization model and adds an improvement of 25% in key outcome without any funding increase	Methodology outlined in Neeson et al (2018.)

7. OUTCOMES MATRIX

OUTCOMES MATRIX

Criteria:	**Status Quo**	**Scoring & Ranking Model**	**Optimization Model**	**Piggybacking Model**
Cost-Effectiveness (50%)	NPV = -$468,309 DCI = 49.2 CE ~ -9518	NPV = -$8,871,180 DCI = 100 CE ~ -88,712	NPV = -$8,072,361 DCI = 100 CE ~ -80724	NPV = $8,072,361 DCI = 125 CE ~ -64579
Ability to Implement (30%)	*High*	*Medium*	*Medium*	*Medium*
Equity (10%)	*Medium*	*Medium*	*Medium*	*Medium*
Political Feasibility (10%)	*High*	*High*	*High*	*High*

8. FINDINGS

On the whole, most of the alternative policy options were rated with relatively high scores in regards to the political feasibility and ability to implement criterions. They were rated high in political feasibility because the policy options largely do not require extensive political changes to implement. Instead, all of the policy options could be implemented without any changes to the current legal and regulatory frameworks that govern VDOT and VDGIF. Similarly, all of the alternative policy options were rated as medium in ability to implement due to the fact that they require small-scaled labor and technological investments. Even the most complicated prioritization model would likely only require a sufficient understanding of Python and ArcGIS - qualifications that could be met by a single well-trained information technology specialist. For the equity criterion, each policy option was rated as having a medium score. This is because while culvert mitigation efforts can have extensive environmental benefits, in practice those benefits are not widely shared. Rather, they are most likely to effect either rural populations who fish for subsistence (a comparatively small part of the population) or affluent environmental recreationists (such as fly-fisherman). As such, it's likely that the benefits are not evenly dispersed across various racial and demographic groups.

In terms of costs, unsurprisingly, the status quo policy option was rated as the most cost-effective option available to policy makers. This is because it doesn't require any major capital outlays related to extensive culvert remediation efforts. Instead, the status quo simply maintains current VDOT culvert related funding levels for 10 years. The status quo policy option also scores highly on the ability to implement and political feasibility parameters for this same reason: no major policy changes indicate that the existing state of affairs is readily implementable. Conversely, the scoring and ranking prioritization model scores lowest in the cost-effectiveness metric. This is because while it is relatively easy to implement from an administrative and technological standpoint, the model fails to take advantage of the spatial and networking effects that accrue higher stream connectivity gains to the optimization model.

Of the various alternative policies, the piggybacking model was rated as the most cost-effective. This is because it maintained the same funding level as the optimization model, while recording an additional 25% gains in DCI. Note that calculating the cost-effectiveness in this manner required a major assumption. Since a maximum DCI for a watershed can only be 100 (indicating full connectivity for a watershed), the cost-effectiveness denominator was listed as 125 to indicate 25% conservation gains that occur at the same spending level as the optimization model (and which can be applied to other watersheds).

9. RECOMMENDATION

In sum, after evaluating possible culvert mitigation efforts, we recommend that policy makers pursue the piggybacking prioritization model. The piggybacking approach stands out as the most effective policy option for a number of reasons. First, from an administrative and technological standpoint, it is relatively easy to implement. In terms of labor onboarding, implementing the policy would likely entail VDGIF either enlisting a currently employed information technology specialist or hiring a new one. This is a very important consideration, because VDGIF doesn't receive funds from Virginia's general tax dollars and is therefore constrained by the limited funding it receives from public spending on licenses, tags, and boat registrations. Another reason the piggybacking model is recommended is because the technological considerations associated with it are relatively minor obstacles. The optimization model software itself is freely provided on the internet. Python and ArcGIS are likewise free, widely used software. And the data inputs required by the optimization model (such as stream-flows, landscape characteristics, and Virginia road-condition data) are already available on various national and state-level databases.

Second, the key advantage of the piggybacking approach is that it maintains the funding levels and has all of the upside of the optimization model, while improving up to 25% of the overall conservation return-on-investment (here referring to miles of streams with improved connectivity). It accomplishes this via improved communication between conservation officials (VDGIF) and transportation agencies (VDOT) simply by aligning environmentally consequential culvert mitigation efforts with regular road maintenance. Correspondingly, while the cost-effectiveness calculations in this paper assume an initial capital outlay of $7,600,000 to restore full stream connectivity in the sample watershed, in reality, policy makers can improve the overall stream connectivity in any watershed without major capital outlays. They simply can piggyback on routine maintenance for road-stream crossings in poor condition and accrue stream connectivity gains at relatively minor expense (they would just need to have implemented the optimization model). Consequently, for all of these reasons, we believe that the piggybacking approach provides the most flexible, cost-effective policy option available to policy makers.

10. IMPLEMENTATION

1. **Next Steps:** Implementing the piggybacking approach will require coordination between VDGIF and VDOT. VDGIF will be responsible for hiring the information technology specialist who operates the optimization model. This hiring decision will be made by a General Administrative Manager at VDGIF and will therefore require buy-in from one of these individuals. Once the IT specialist is hired, the specialist will then have to run the optimization model and determine which environmentally important road-stream crossings are associated with poor road-conditions that are due for scheduled maintenance. Once this determination has been made, the specialist will then have to communicate their findings to the relevant District Environmental Managers at VDOT. It will then be incumbent upon the District Environmental Managers to designate projects for remediation and assign maintenance crews to carry out relevant work.

2. **Stakeholder Perspectives:** There are two primary stakeholder groups who will be principally affected by our policy recommendation. The first of these groups are environmental activists. These include non-profit organizations such as the Piedmont Environmental Council and Trout Unlimited. Both of these groups have worked on culvert remediation efforts in the past and would likely be highly amenable towards the piggybacking policy approach. Furthermore, the Piedmont Environmental Council has previously partnered with VDOT to replace aging stream-crossing infrastructure in Rappahannock County, and therefore could provide valuable working knowledge in regards to implementing culvert mitigation efforts (*VDOT PARTNERS WITH ENVIRONMENTAL COUNCIL | Virginia Department of Transportation*, 2018).

   The second pertinent stakeholder group affected by our policy recommendation is VDOT itself. While the agency's District Environmental Managers would likely be receptive to carrying out the piggybacking approach, they will need to exercise strategic leadership to ensure that maintenance resources are partially redirected towards culvert remediation efforts. This will likely entail lobbying the VDOT administrators who manage VDOT maintenance crews.

3. **Risks to Implementation:** The most consequential risk to implementation is the possibility of a significant budget shortfall that inhibits VDOT maintenance efforts. Because VDOT primarily receives their funding from gasoline taxes, their funding streams are particularly vulnerable to recessions or financial crises that reduce aggregate demand for gasoline. Scarce maintenance resources would necessitate that VDOT focus on high-priority maintenance projects (likely near major population centers) rather than less equitable environmentally-oriented projects. Thus, while financial crises are relatively uncommon, they represent a very significant risk to VDOT and would be a major obstacle to implementing culvert mitigation efforts.

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START-UP COSTS				
Your Office-Based Agency				January 1, 20xx
COST ITEMS	**MONTHS**	**COST/ MONTH**	**ONE-TIME COST**	**TOTAL COST**
Advertising/Marketing	3	$300	$2,000	$2,900
Employee Salaries*	4	$500	$2	$2,002
Employee Payroll Taxes and Benefits	4	$100	$1,500	$1,600
Rent/Lease Payments/Utilities	4	$750	$2,500	$5,500
Postage/Shipping	1	$25	$25	$50
Communication/Telephone	4	$70	$280	$560
Computer Equipment		$0	$1,500	$1,500
Computer Software		$0	$300	$300
Insurance		$0	$60	$60
Interest Expense		$0	$0	$0
Bank Service Charges		$0	$0	$0
Supplies		$0	$0	$0
Travel & Entertainment		$0	$0	$0
Equipment		$0	$2,500	$2,500
Furniture & Fixtures		$0	$0	$0
Leasehold Improvements		$0	$0	$0
Security Deposit(s)		$0	$0	$0
Business Licenses/Permits/Fees		$0	$5,000	$5,000
Professional Services - Legal, Accounting		$0	$1,500	$1,500
Consultant(s)		$0	$0	$0
Inventory		$0	$0	$0
Cash-On-Hand (Working Capital)		$0	$1,000	$1,000
Miscellaneous		$0	$2,000	$2,000
ESTIMATED START-UP BUDGET				**$26,472**

*Based on part-time employees. This may change once you hit your growth benchmark.

APPENDIX

COST-EFFECTIVENESS CALCULATIONS

POLICY OPTION	MONTHS	COST/ MONTH	ONE-TIME COST	TOTAL COST
Status Quo				
Employee Salaries				
Employee Payroll Taxes and Benefits				
Rent/Lease Payments/Utilities				
Postage/Shipping				
Communication/Telephone				
Computer Equipment				
Computer Software				
Insurance				
Interest Expense				
Bank Service Charges				
Supplies				
Travel & Entertainment				
Equipment				
Furniture & Fixtures				
Leasehold Improvements				
Security Deposit(s)				
Business Licenses/Permits/Fees				

START-UP COSTS													
Your Office-Based Agency													January 1, 20xx
REVENUE	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**YTD**
Estimated Product Sales													
Less Sales Returns & Discounts													
Service Revenue													
Other Revenue													
Net Sales													
Cost of Goods Sold													
Gross Profit													
EXPENSES	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**YTD**
Salaries & Wages													
Marketing/Advertising													
Sales Commissions													
Rent													
Utilities													
Website Expenses													
Internet/Phone													
Insurance													
Travel													
Legal/Accounting													
Office Supplies													
Interest Expense													
Other 1													
Total Expenses													
Income Before Taxes													
Income Tax Expense													
NET INCOME													

* In the service industry, Cost of Goods Sold is the monetized value of the time spent on the client.

Instructions for Getting Started on Profit & Loss Projections

Completing projections for Profit and Loss of a new company is a good exercise to understand and communicate when the company will begin to break even and see how sales and profits will grow. The top portion of the model to the left, Revenue, is a good way to forecast sales, month by month for the first year. The lower portion then applies estimated expenses for the same period of time to derive the business' profitability.

Steps for preparation:

- **Step 1:** Enter the company name and the date this projection is being prepared.
- **Step 2:** For each month, beginning in January or whenever the start is estimated, enter the expected sales to be. This could be for a single service or multiple services. Add lines to this model for additional offerings. From this, subtract any product returns or discounts that are to be tracked (these should be shown as negative numbers, for example, -10). Below Net Sales, enter the Cost of Goods Sold. This refers to the monetized value of the time spent on a particular client.
- **Step 3:** For each month, enter the estimated salaries, marketing, utilities, and other items that are projected.
- **Step 4:** Once all of the costs have been entered, review the individual items and total amount to see where projections can be fine-tuned or move something out into the future when more revenue is coming in. The objective is to get to profitability and positive cash flow as quickly as possible.