Report on the Efficacy and Comparative Costs of Using Flow Devices to Resolve Conflicts with North American Beavers along Roadways in the Coastal Plain of Virginia

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Introduction

<u>Statement of problem</u>

The recovery of the North American beaver is one of the conservation movement's greatest success stories, but the re-colonization of a massive historical range that is now widely inhabited by humans has led to inevitable conflicts. Beavers fell trees and shrubs and impound waters that flood agricultural lands, timberlands, structures, buildings and roads. Arner and Dubose (1979) estimated that economic losses attributed to beaver activity exceeded 4 billion dollars in the southeastern U.S. over the previous 40 years, and Miller (1983) estimated that annual damage was between 75 and 100 million in the U.S.

Road damage caused by beavers is a costly problem for many transportation departments in the U.S. Beaver damming behavior is believed to be stimulated by the sound and feel of running water. As water flows through narrow channels and/or road culverts, especially metal culverts, which resonate the sound of flowing water, beavers respond by damming channels and culverts, impounding water against roadbeds and ultimately causing roads to flood and/or wash out (Langlois and Decker, 1997). Plugged culverts are difficult, dangerous and expensive to clear, and over time, if they remain "plugged," saturated roadbeds settle, become unstable and potholes form. Eventually, the road may wash out altogether resulting in expensive, time-consuming road repairs (Jensen and Curtis, 1999).

For these reasons, beavers are not tolerated at sites adjacent to roadways. Transportation departments throughout the U.S. appropriate funds and resources for trappers and maintenance personnel to remove beavers, demolish dams, and repair damaged roads. For example, from 2000 to 2005, Virginia Department of Transportation (VDOT) alone lost $800,000.00 in actual resources and spent more than $900,000.00 to have a federal agency remove over 1,000 beavers and 696 dams at 530 damage sites along roadways in Virginia (USDA-WS 2001; USDA-WS, 2002; USDA-WS, 2003; USDA-WS, 2004; USDA-WS, 2005). In addition, VDOT maintenance crews were required to repeatedly remove dams at sites that were not trapped and/or at trapped sites subsequently re-occupied by immigrants, not to mention the number of person hours and materials necessary to repair and upgrade roads damaged by beaver activity. With this in mind, it is reasonable to estimate that VDOT spent well over $1,000,000.00 attempting to reduce or eliminate damage attributed to beaver activity along state roads from 2000 to 2005.

Trapping and dam destruction are widely considered the most effective and economical methods for reducing and eliminating road damage caused by beavers. However, these are only short-term solutions for situations in which beavers plug culverts or build dams that raise water levels to undesirable heights (D'Eon, 1995). Removing beavers and dams may be the most cost-effective approach to mitigating beaver damage in cases where it is unlikely that immigrants will re-occupy trapped sites. However, in areas with dense concentrations of beavers, dams are quickly re-built due to rapid beaver immigration and re-colonization. Houston et al. (1995) reported that beavers in a bottomland forest in southwest Tennessee immediately and repeatedly re-colonized idle colony sites following eradication because the area still maintained preferred habitat. In northern Ontario where trapping is also the primary method for beaver control, maintenance crews revisit the same work sites annually to remove beavers and dams and to repair or rebuild roads and culverts damaged or destroyed by beaver activity (Ontario Ministry of Natural Resources, 1995).

Removing or breaching dams is also an immediate, but temporary solution to flooding problems caused by beaver. Demolishing dams, with explosives or by hand, is dangerous and expensive (Arner, 1964) and futile as beavers usually rebuild the dams within days (Miller, 1977) and may even create larger dams and/or step dams upstream and downstream of the damage site (Langlois and Decker, 1997).

In situations where removing beavers and dams provides only short-term solutions to problems associated with beaver activity, it may be more effective and affordable for transportation departments to identify chronic beaver damage sites and take proactive measures to protect road culverts and critical areas adjacent to roads.

<u>Water Flow Control Devices</u>

The installation and maintenance of water flow control devices designed to prevent problems associated with beaver damming activity are an alternative and potentially more efficient and cost-effective approach to manage beaver conflict along roadways than the expense of annual beaver population control, repeated road maintenance and repairs, and damage to property and buildings due to flooding and washouts. Over the years, state and federal wildlife agencies have developed, described and installed several types of effective water flow control devices (Arner, 1964; Laramie, 1963; Lisle, 1996; Roblee, 1987; and Wood et. al, 1994).

In 1952, the concept of installing perforated pipes in dams was introduced at the Northeastern Wildlife Conference as a solution for problem beaver ponds to control water levels (Leighton and Lee, 1952). Laramie (1963) reported that the New Hampshire Fish and Game Department had successfully installed and maintained “beaver pipes” in 46 dams. In 1978, the New York Department of Environmental Conservation began designing and testing various culvert protection devices, of which the T-culvert guard was most effective and cost-beneficial (Roblee, 1987). In 1994, Clemson University developed the Clemson Beaver Pond Leveler, a device that prevented beavers from damming areas of concern by directing water through existing dams using a strategically designed pipe system (Wood et. al, 1994).

Although these devices effectively prevented beavers from impeding water flow at some sites, the designs could not be modified to address flow problems that occur in a variety of different landscapes. For instance, the installation of Clemson Beaver Pond Levelers is limited to situations involving small watersheds, water input to ponds from small streams and springs, and where occasional flooding is acceptable due to the device’s inability to handle large amounts of water during periods of high rainfall (Langlois and Decker, 1997).

Then, in the 1990s, the Penobscot Indian Nation Department of Natural Resources in Old Town, Maine initiated a program to develop and install high-quality water flow control devices on tribal lands to prevent road damage caused by beaver activity and to create and enhance wildlife habitat (Lisle, 1999). The results of the effort led to the development of new, versatile flow device concepts known as Beaver Deceivers™, the Castor Masters™, and Round Fences™.

There are generally two categories of beaver damage sites: 1) narrow outlets, such as road culverts, that direct water through a manmade barrier (e.g. an embankment or roadbed) and 2) beaver dams that are not attached to manmade structures. To prevent beavers from damming road culverts, the Penobscot nation created the Beaver Deceiver™, a rugged, wooden-framed fence constructed of braced wooden posts and 4-gauge, steel mesh fencing installed on the upstream end of road culverts.

Because beaver damming behavior is stimulated by the sound and feel of running water, Beaver Deceivers™ are designed to not only deny beaver access to culverts, but to reduce or eliminate the "feel" of running water by spreading stream flow over a long perimeter. The perimeter of a Beaver Deceiver™ frame typically ranges from 40 to 120 feet and generally increases with stream and culvert size.

Beaver Deceivers™ are also strategically shaped to discourage damming behavior; their frames may be square, rectangular or pentagonal, but trapezoidal designs, four-sided with two parallel sides and two non-parallel sides, tend to be the most effective. From the road, trapezoid-shape Beaver Deceivers™ resemble upside-down triangles. Once in place, beavers may swim around the Beaver Deceiver™ and attempt to dam the corners of the fence closest to the culvert due to visual, auditory and tactile cues (e.g. the sight, sound and feel of water running through a metal culvert). The sides of the fence direct beavers away from the upstream side of the culvert at an unusual angle, and as the beavers work to dam the area, the fence side forces them away from the culvert opening, discouraging damming behavior.

Although the underlying concept remains the same, Beaver Deceivers™, unlike other flow devices, are extremely versatile and can be used in wide variety of different conflict site types because the devices are customized to correspond with a site's topography and landscape features (Lisle, 2003).

To address flooding problems that occur when beaver build dams that are not attached to manmade structures, the Penobscot Nation invented the Castor Master™, a pipe system that is used with a filter called the Round Fence™ to control water flow through an existing beaver dam (Lisle, 2003). A Castor Master™ consists of one or several 12 inch by 20 foot polyethylene pipes submerged and placed through an existing beaver dam with the upstream and downstream sides of the pipes protected with filters. Round Fences™ are filters made of 4-gauge, steel mesh fencing, typically between 2 to 4 feet height and 4 to 8 feet in diameter. Filters such as Round Fences™ prevent beavers and debris from plugging the pipe directing water through the dam and disperse flowing water over a broad area so that it is difficult for beavers to detect (Lisle, 2003). Castor Masters™ with Round Fences™ can also be attached to the upstream end of Beaver Deceivers™ to prevent beavers from attempting to dam the front end of the Beaver Deceiver™ (Lisle, 2003).

Beaver Deceivers™, Castor Masters™ and Round Fences™ have been used successfully to reduce and prevent damage to roads and other manmade structures at numerous beaver damage sites in the U.S., but few studies have been conducted to determine the effectiveness and cost benefits of using these versatile flow devices. Over a period of seven years, Lisle (1999 and unpublished data) eliminated maintenance at 20 damage sites in Maine near un-trapped beaver colonies where beavers frequently plugged culverts and flooded roads. In another study, Callahan (2003) reported that of 277 conflict sites, beaver damming was effectively controlled at 83% of sites where devices similar to a Caster Masters™ and Round Fences™ were installed and at 95% of sites where devices similar to a Beaver Deceivers™ were installed. The purpose of this study was to evaluate the efficacy and cost-effectiveness of using Beaver Deceivers™, Castor Masters™ and Round Fences™ to resolve conflicts with beavers on roadways in the Commonwealth of Virginia.

Methods

Study Area

Our study was conducted at chronic beaver damage sites along roadways in seven counties within the three Virginia Department of Transportation (VDOT) districts located in the Coastal Plain of Virginia (Figure 1). The Coastal Plain is bordered by the Piedmont to the west and the Chesapeake Bay and the Atlantic Ocean to the east. The terrain is mostly flat with deep, moist soils. Average rainfall is approximately 110 cm per year and average temperatures are 13-14ºC (McNab and Avers, 1994). Forest cover is predominantly loblolly pine-hardwood (1994) with the exception of the southeastern-most region which is primarily evergreen (Woodard and Hoffman, 1991). Streams in the Coastal Plain are small to intermediate in size and have very low flow rates (McNab and Avers, 1994).

VDOT districts in the Coastal Plain of Virginia were selected for this study because of the high number of reported beaver damage sites compared with Piedmont, Blue Ridge, Ridge and Valley and Appalachian Plateau districts (USDA-WS, 2001; USDA-WS, 2002; and USDA-WS, 2003), and to evaluate the premise that flow devices are effective in streams with higher gradients, i.e. Piedmont and Mountain regions, but are ineffective in streams with low gradients, e.g. Coastal Plain (Menke, USDA-WS, 2003).

Site Selection

To maintain objectivity, VDOT environmental and maintenance personnel from three districts with counties located in the Coastal Plain of Virginia—Hampton Roads, Fredericksburg and Richmond—selected chronic beaver damage sites (Figure 2), which were defined as sites where removing beavers and/or dams did not significantly reduce and/or prevent road maintenance, road repairs or beaver population control costs attributed to beaver activity along roadways. A total of 14 sites were selected for flow device installations: four in the Hampton Roads District (Figure 3), five in the Fredericksburg District (Figure 4) and five in the Richmond District (Figure 5).

Site Evaluations
To recommend and implement a course of action, site evaluations were conducted to acquire flooding and beaver damage history from VDOT personnel and/or adjacent landowners based on criteria established by Nolte et al (2000) and USDA-WS (2003). Documented information

included the number of years beavers have inhabited the site, flooding frequency, road maintenance and repair costs before and after beavers colonized the site, watershed characteristics, past and present beaver damage and population control activities, and finally, management objectives for the site (Table 1).

Prior to installations, VDOT personnel obtained "right of entry" permission from adjacent landowners, and in some instances, manually and/or mechanically removed beaver damming material from road culverts and other areas of concern.

Flow device installation

Selected beaver damage sites generally consisted of plugged culverts and/or high water resulting from free-standing beaver dams located upstream and/or downstream of affected roads. With the assistance of the principal investigator and several undergraduate students, wildlife biologist and flow device consultant Skip Lisle designed, constructed and installed 33 flow devices at 14 study sites. Beaver Deceivers™ were recommended primarily for treating plugged road culverts, and Castor Masters™ were installed to lower high water impounded by free-standing dams (Figures 6-22). In some cases, Castor Masters™ were installed with Beaver Deceivers™ to enhance flow efficiency.

Monitoring and Maintenance

Following installations, study sites were monitored by principal investigators and/or VDOT personnel and inspected at least once every four months to determine if the flow devices were functioning properly, to note any specific damage to the device or changes in the landscape, and if necessary, to remove any accumulated debris obstructing the Beaver Deceivers™ and/or Round Fences™. Any time spent manually removing debris from the site was recorded as less than 15 minutes, less than 30 minutes, less than 45 minutes, or less 60 minutes. If time spent cleaning the device exceeded 60 minutes, actual time cleaning the device was recorded.

Surveys

In March and April of 2006, we surveyed VDOT personnel from all three cooperating districts, as well as several landowners with property adjacent to study sites, to gather general data on what, if any, effect flow device installations had on previous flooding frequency, road maintenance, repair or beaver management costs. Information recorded included when the devices were installed, the status of the flow devices (including any flooding, road maintenance and/or repairs, beaver damage/population control activities, and any efforts made by VDOT and/or the landowner to maintain the devices following installation) and whether management objectives for the study site had been met.

Comparative Cost Analysis

A cost-benefit ratio formula utilized by USDA-Wildlife Services (2003) to compare beaver management expenditures to VDOT resources saved was used to test the differences in the costs to manage beavers and repairs roads before and after the installation of flow devices at the 14 selected study sites. For the purposes of this study, the estimated cost-benefit will be considered favorable if the ratio of expenditures to resources saved is greater than 1 to 2, or for $1 spent on beaver management activities or road repairs, $2 in VDOT resources are saved.

Results

From June 2004 to November 2005, 33 flow devices—18 Beaver Deceivers™ and 15 Castor Masters™—were installed at 14 beaver damage sites in seven counties in three VDOT districts in the Coastal Plain of Virginia. Installation costs per site ranged from $1,359.00 to $5,572.00 at an average cost of $3,160.00 per site and a total cost of $44,245.00 for installations at all 14 study sites (Table 2). Total installation time ranged from 10 to 50 hours with a total of 390 hours and an average installation time of 28 hours per site. The total costs for labor at the 14 study sites was $39,000, or $2,786.00 per site, and the total costs for materials was $5,244.52 or $374.61 per site.

Flow device maintenance time ranged from 1.0 to 4.75 hours per year and required a total of 19.75 hours per year, or 1.4 hours per site, and at $14.00 an hour, cost a total of $276.50 or $19.75 per site (Table 2). At the time that VDOT personnel and landowner surveys were conducted in April 2006, length of time following installations ranged from six months to 22 months with an average length of time following installations of 15 months per site.

Results of VDOT Personnel and Landowner Surveys

VDOT personnel and landowners reported that flooding occurred and preventative maintenance was conducted at all 14 sites prior to installation of flow devices at a total cost of $149,900.00 for preventative maintenance, or an average cost of $10,707.00 per site. Beaver population control activities were conducted at 10 of 14 sites prior to installations at an average cost of $5969.00 per year, or $994.90 per site, at the six sites where VDOT paid for beaver population control activities. Following preventative maintenance and beaver population control efforts, 100% of the study sites were re-occupied by beavers. VDOT personnel and landowners also reported that road repairs attributed to beaver-related damage were carried out at five sites prior to installations at a total cost of $145,000.00 and an average cost of $29,000.00 per site.

After flow device installations, VDOT personnel and landowners reported that the study sites had not flooded, that road maintenance, flow device maintenance and beaver population control activities had not been required or conducted, and that overall, they were satisfied with the performance of the flow devices (Table 2). One landowner with property adjacent to the site on Kingsale Swamp at Route 644 in the City of Suffolk occasionally removed debris from the Beaver Deceiver™ installed to protect the culvert directing water beneath the road (Figure 7).

Comparative Cost Analysis

Prior to flow device installations, the estimated beaver management costs at the 14 study sites, including preventative maintenance and population control activities, was $155,869.00, and the estimated beaver damage repair cost was $145,000.00 for a total cost to VDOT of $300,869.00 per year (Table 3). Following flow device installations, the estimated beaver management costs, including flow device installations and maintenance costs, was $44,526.00, and the estimated beaver damage repair cost was $0.00 for a total cost to VDOT of $44,526.00 per year (Table 3). The resources saved were estimated at $71,639.00 based on calculations in USDA-Wildlife Services (2003) (Table 3). We assumed that the same resources were saved after installation of flow devices. The total resources saved prior to flow device installations included resources saved ($71,639.00) in addition to funds VDOT saved by not installing flow devices ($44,526.00) for a total resources saved of $116,165.00. Total resources saved following flow device installations included resources saved ($71,639.00) in addition to funds VDOT saved in beaver management costs ($155,869.00) and road repair costs ($145,000.00) saved by installing flow devices for a total resources saved of $372,508.00.

The cost-benefit ratio at the 14 study sites (total costs divided by total resources saved) prior to flow device installations 1 to 0.39, or $ 0.39 in resources saved for every $1 VDOT spent. Following flow device installations, the estimated cost-benefit ratio was 1 to 8.37, or for every $1 spent, VDOT saved $ 8.37.

Discussion and Recommendations

The results of our study show that flow devices such as Beaver Deceivers™, Castor Masters™ and Round Fences™ are efficient, cost-beneficial tools for resolving conflicts with beavers along roadways in the Coastal Plain of Virginia. To date, based on the most current survey information, of the 33 devices installed at 14 beaver damage sites over the past 22 months, including 18 Beaver Deceivers™ and 15 Castor Masters™, 100% are functioning properly and are meeting VDOT and landowner beaver management objectives.

These results concur with data published recently by Callahan (2005) who reported an 87% success rate using Flexible Pond Levelers (devices with designs similar to Castor Masters™) at 156 beaver damage sites in New York and Massachusetts, and a 97% success rate using upright trapezoidal or rectangular culvert fences (devices similar to Beaver Deceivers™) at 227 sites in the same geographic region. Several factors may have contributed to the slightly higher flow device success rates in our study, the most influential of which may have been our study's relatively small sample size (14 sites) compared to Callahan's study (383 sites). Climate, weather, topographic and landscape differences may also have contributed to differences in success rates since our study was conducted in the Coastal Plain of Virginia and Callahan's devices were installed throughout New England. Nonetheless, the flow device success rates reported in both studies were significantly higher than rates reported by other researchers who conducted similar studies on other flow device designs.

Nolte et al. (2001) reported a 50% success rate after installing 40 Clemson beaver pond levelers at beaver damage sites in Mississippi between May 1995 and August 1999. Hamelin and Lamendola (2001) had a far better success rate (84%) than Nolte et al. with 45 Clemson beaver pond levelers at beaver damage sites in the St. Lawrence Plain of New York from 1992 to 2000, but reported a success rate of only 45% on 29 deep water fences installed in the same geographic region.

Nolte et al. (2001) also reported that beaver population control activities were conducted prior to and following flow device installations at 95% of successful sites, leading them to infer that population control activities contributed to flow device success at these sites. In contrast, we found no correlation between beaver population control activities and the success rate of flow devices. While beaver population control activities were conducted at 71% (10 of 14) sites prior to flow device installations, VDOT personnel and landowners reported that beaver population control measures were not conducted, recommended or required following installations. Callahan (2005) recommended beaver population control at 69 of 482 sites evaluated between 1998 and 2005, but he did not conduct beaver population control activities following installation of flow devices at 373 successful sites. Callahan (2005) also indicated that beaver removal was only recommended at sites where landowners did not want beavers, in reservoirs, and in areas where the installation of flow devices were not feasible due to development and topography issues, but he did not describe these issues in detail.

Although Callahan reported high success rates of flow devices compared to studies conducted on other flow device designs, such as Clemson Beaver Pond Levelers and deep water fences (Nolte et al, 2001; Hamelin and Lamendola, 2001), flow devices did fail at a small percentage of sites for a variety of reasons. At 383 sites managed with flow devices from November 1998 to February 2005, pond leveler failure rate was 13.5% while culvert fence failure rate was only 3.1%. Pond levelers generally failed due to the construction of new dams downstream by beavers (11 sites or 7.1%), insufficient pipe capacity (6 sites or 3.8%), lack of maintenance (2 sites or 1.3%) and dammed fencing (2 sites or 1.3%). Culvert fences failed due to lack of maintenance (4 sites or 1.8%), dammed fencing (2 sites or 0.9%) and vandalism (1 site or 0.4%). Other factors that contributed to failure included inexperienced installers, poor site selection and/or flow device design (Callahan, 2003).

Results of a previous study conducted by Callahan (2003) also showed that when flow devices did fail, they failed within the first two to 12 months following installation. In 2003, 221 successful devices in Callahan's study had been in place longer than twelve months. The failure rate for our 14 study sites was 0%, and therefore, we have no data for comparison. However, Callahan's observations differ from Nolte et al. (2001) who reported that successful Clemson beaver pond levelers were installed more recently than unsuccessful devices, indicating that that device's life-span may be relatively low.

Since the flow devices referenced by Callahan (2005) have been in place in New England an average of 36.6 months, and similar devices installed in our study in the Coastal Plain of Virginia have been in place an average of 15 months, it is reasonable to attribute the high success rate of flow devices in these two respective studies to the installation of Beaver Deceivers™, Castor Masters™ and Round Fences™ as opposed to Clemson Beaver Pond Levelers and other flow device designs that lack versatility, cannot be modified to address the flow characteristics of different landscapes, may have comparatively short life-spans. As a result, such flow devices can only be used effectively in a small percentage of beaver conflict sites.

The results of our study also demonstrated that the flow devices we used can be extremely cost-beneficial due to relatively low installation and maintenance costs compared to the time and expense of repeated road maintenance, repair of road damage, and annual beaver population control required for other flow device designs. Prior to installation of our flow devices, VDOT spent $300,869 a year on preventative maintenance ($149,900.00), road repairs ($145,000.00) and beaver population control ($5969.00) at an average cost of $21,490.64 per site per year (Table 3). To install our 33 flow devices at 14 study sites, VDOT spent a total of $44,526.00 for labor and materials, at an average cost of $3,180.00 per site. Following installation, annual flow device maintenance cost a total of $276.50, or an average of $19.75 per site per year, and preventive maintenance, road repairs and beaver population control cost a total of $0.00.

Consequently, the cost comparison revealed that for every $1 VDOT spent on preventive maintenance, road repairs and beaver population control activities at the 14 study sites prior to the installation our flow devices, the agency saved $0.39 in resources, whereas after installing and maintaining our flow devices, VDOT saved $8.37 for every $1 spent, for a total of $372,508.00 of resources saved per year (Table 3). Additionally, the cost-benefit comparison represents both actual damages that occurred at a site 12 months prior to installations and potential damages expected to occur within 12 months without flow device installations. Since the predicted life expectancy for each successful device is at least 10 ten years (Callahan, 2005) with an average maintenance cost of $19.75 at each site per year, compared to $21,490.64 per site per year for maintenance, repairs and beaver population control prior to the installation of our flow devices, we believe the value of resources saved by installing flow devices at these sites will continue to increase over time.

During the course of our study, we also discovered several benefits to using flow devices that are difficult to quantify, but nonetheless significant. For instance, opening blocked culverts—manually, or by using heavy equipment or explosives—is an expensive, arduous and potentially dangerous endeavor compared to the routine maintenance required for Beaver Deceivers™. VDOT personnel noted that culverts are often damaged in the process of cleaning with heavy equipment and explosives, decreasing the life expectancy of these road structures and forcing the transportation department to replace them more frequently. By denying beaver access to the culvert, heavy equipment and explosives are not required for maintenance, and Beaver Deceivers™ protect the road structures and reduce the need for costly replacements.

Cleaning a culvert manually generally involves having one or more people inside the culvert disassembling the dam using their hands or hand tools (a cultivator for instance) to remove the blockage piece by piece, until the pressure of the dammed up water finally pushes the remainder of the dam out the downstream side of the culvert. Under these circumstances, the dam could easily give way while a worker is in the culvert and could lead to serious, life-threatening injuries. Compared to clearing a plugged culvert, routine maintenance on a Beaver Deceiver™ is relatively easy and safe as it simply requires removing any leaves, sticks, twigs or branches that have accumulated on the upstream side of the receiver fence once or twice a year. Maintenance workers are never subject to the risk of an unpredicted release of large volumes of dammed water.

In its "Report of Beaver Damage Management Activities for the Virginia Department of Transportation March 7, 2002 – March 6, 2003", USDA-Wildlife Services defines a successful flow device as one that, among other factors, does not require maintenance. However, eliminating the need for maintenance at beaver damage management sites is not a realistic goal since any beaver management program requires regular, prolonged attention and maintenance. For example, as stated previously, VDOT spent $300,869 a year on preventative maintenance, road repairs and beaver population control at the 14 beaver damage study sites prior to flow device installations. Now, following flow device installations, it is estimated that VDOT will spend approximately $276.50 a year to maintain these devices. Furthermore, maintenance can be accomplished by workers with minimal training and by hand. Based on our data, the economic incentive for using these tools where feasible is undeniable. High quality flow devices such as ours do achieve the goal of minimal effort and maximum benefit for VDOT. No other program of beaver management that we know of can match this level of efficacy and efficiency.

One potential concern for us when using flow devices to manage beavers near roadways is the development of new conflict sites following flow device installations. In 2003, Callahan published data showing that of the 177 beaver colonies present where flow devices were installed in New England between 1998 and 2003, there were 277 conflict sites, or an average of 1.56 conflict sites per beaver colony. Since data published two years later in 2005 showed the average conflict sites per colony remained constant, Callahan concluded that by using flow devices to treat a small number of critical beaver conflict sites, a large watershed can be managed without contributing to the development of new problem sites or removing beavers from the community. In the future, it may be beneficial to generate data on the ratio of beaver conflict sites per colony at our study sites in Virginia to test Callahan's findings.

Given the demonstrated low costs to install and maintain flow devices compared to the high costs of preventative maintenance, road repairs and beaver population control activities, a compelling case can be made to install flow devices in freestanding dams near roads or to protect culverts that beavers could potentially plug. Nevertheless, a more prudent approach may be for transportation agencies to identify conflict sites and install flow devices at sites that have the largest impact on road maintenance and beaver management budgets.

In addition to the aforementioned economic advantages, using flow devices to resolve conflicts with beavers also has tremendous potential ecological and environmental benefits. Every year, transportation departments spend millions of dollars to replace wetlands destroyed in the process of developing new roads. For most wetland restoration projects, the cost per acre is extremely high while success rates are generally low. On the other hand, beavers are successfully restoring wetlands at little to no cost to transportation departments and landowners, except when conflicts occur. In 2001, Lisle (2001) examined the total wetland acreage created by beavers at six sites managed with flow devices and determined that the average beaver colony created and maintained 18.5 acres of wetlands. Using this information as a guide, we could estimate that almost 120 acres of wetlands have been preserved through the use of flow devices in our study. In the future, it may be useful for us to calculate the total wetland acreage created by beavers at present and future beaver damage study sites in Virginia and compare our results with Lisle's findings.

Meanwhile, in order to advance the "no net loss" wetlands conservation program instituted by U.S government, federal agencies should explore developing programs that reward state transportation departments and cooperating landowners for using non-lethal methods, such as flow devices, to manage beavers while permitting these animals to restore and create valuable wetlands (National Research Council, 2001). An incentive-based program could result in a substantial increase in the restoration of natural wetlands while reducing property damage and maintenance costs.

References

Arner, D.H. 1964. Research and a practical approach needed in management of beaver and beaver habitat in the Southeastern United States. Trans. North. Amer. Wildl. Nat. Resour. Comm. 29:150-158.

Arner, D.H., and J.S. Dubose. 1979. The impact of the beaver on the environment and economics in the southeastern United States. Pages 241-247 in Proc. XIV International Wildlife Congress.

Asdell, S.A. 1964. Patterns of mammalian reproduction. 2nd ed. Ithaca: Cornell University Press, Comstock, New York, U.S.A.

Blackwell, W.P. The status of the beaver in Virginia, 1947. Master’s thesis, Virginia Polytechnic Institute and State University, Blacksburg.

Brenner, F.J. 1962. Foods consumed by beavers in Crawford County, Pennsylvania. Journal of Wildlife Management 26:104-107.

Bailey, V. 1927. Beaver habits and experiments in beaver culture. U.S. Department of Agriculture Technical Bulletin 21. Washington D.C.: U.S. Department of Agriculture.

Callahan, M. 2003. Beaver Management Study. Association of Massachusetts Wetland Scientists (AMWS) Newsletter 44:12-15.

_____. 2005. Best Management Practices for Beaver Problems. Association of Massachusetts Wetland Scientists (AMWS) Newsletter 53:12-14.

D’Eon, R. et al. 1995. The Beaver Handbook: A Guide to Understanding and Coping with Beaver Activity. Northeast Science & Technology Field Guide FG-006, NEST, Timmins, Ontario, Canada.

Gard, R. 1961. Effects of beaver on trout in Sagehen Creek, California. Journal of Wildlife Management 25:221-242.

Hamelin, D.L. and J.E. Lamendola. 2001. The use of devices to control water levels in beaver impoundments and improve landowner tolerance for beaver. Northeast Association of Fish and Wildlife Agencies. Poster Present. Saratoga, New York, U.S.A.

Handley, C.O., Jr. 1979. Mammals. Pp. 483-621. In: Linzey, D.W. (editor), Proceedings of the symposium on endangered and threatened plants and animals of Virginia. Blacksburg: Virginia Polytechnic Institute and State University.

Hanson, W.D., and R.S. Campbell. 1963. The effect of pool size and beaver activity on distribution and abundance warm-water fishes in a North Missouri stream. American Midland Naturalist 169:136-149.

Harris, D, and S.E. Aldous. 1946. Beaver management in the northern Black Hills of South Dakota. Journal of Wildlife Management 10:348-353.

Hodgdon, K.W., and J.H. Hunt. 1953. Beaver management in Maine. Maine Department of Inland Fisheries and Game, Game Division Bulletin 3:1-102.

Houston, A.E., M.R. Pelton, and R. Henry. 1995. Beaver immigration into a control area. Southern Journal of Applied Forestry, 19(3):127-130.

Jenkins, S.H. 1979. Seasonal and year-to-year differences in food selection by beavers. Oecologia 44:112-116

Jensen, P.G, P.D. Curtis, and D.L. Hamelin. 1999. Managing Nuisance Beavers Along Roadsides: A Guide for Highway Departments. Cornell Cooperative Extension Service, Ithaca, NY. 14pp.

Kwon, H.Y. 1997. The return of the beaver. Watershed Protection Techniques 2(3):405-410.

Langlois, S.A. and L.A. Decker. 1997. The Use of Water Flow Devices and Flooding Problems Caused by Beaver in Massachusetts. MA Division of Fisheries and Wildlife. 13pp.

Larson, J.S. 1967. Age structure and sexual maturity within a western Maryland beaver (*Castor canadensis*) population. Journal of Mammalogy 48:408-413.

Leighton and Lee. 1952. Proc. Northeastern Wildl. Conf. 8:1-4.

Linzey, D.W. 1998. The Mammals of Virginia. The McDonald & Woodward Publishing Company, Blacksburg, Virginia, U.S.A. 459 pp.

Lisle, S. 1996. Beaver deceivers. Wildl. Control Tech. Sept.-Oct. pp.42-44.

_____. 1999. Wildlife programs at the Penobscot Nation, In: R. McCabe & S. Los (eds.), Transactions of the 64th North American Wildlife and Natural Resource Conference:466-477. Wildlife Management Institute, Washington, D.C. U.S.A.

_____. 2001. Beaver Management at the Penobscot Indian Nation, USA: Using Flow Devices to Protect Property and Create Wetlands. IN: Czech & Schwab (eds.), Proceedings of the 2nd European Beaver Symposium: 147-156. Carpathian Heritage Society, Krakow, Poland.

_____. 2003. The Use and Potential of Flow Devices in Beaver Management. Lutra 46(2):211-216.

McNab, W.H. and P.E. Avers. 1994. Ecological subregions of the United States. Technical Report WO-WSA-5, U.S. Forest Service, Washington DC.

Miller, J.E. 1977. Beaver-friend or roe. Univ. of Ark. Coop. Ext. Service. Bull. No. 5M-7-77. 15pp.

_____. 1983. Control of beaver damage. Proc. East. Wildl. Damage Control Conf.

1:177-183.

Muller-Schwarze, D. and L. Sun. 2003. The Beaver: Natural History of a Wetlands Engineer. Cornell University Press, Cornell, New York, U.S.A.

National Research Council. 2001. Compensating for wetland losses under the Clean Water Act, a report of the National Academy of Sciences. National Academy Press, Washington, D.C., U.S.A.

Nickelson, R.R., J.D. Rodgers, S.L. Johnson, and M.F. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (Oncorhynchus kisutch) in Oregon coastal streams. Canadian Journal of Fisheries Aquatic Sciences 49:783-789.

Novak, M. 1977. Determining the average size and composition of beaver families. Journal of Wildlife Management 41:751-754.

Nolte, D.L., S.R. Swafford, C.A. Sloan. 2001. Survey of factors affecting the success of Clemson beaver pond levelers installed in Mississippi by Wildlife Services. Proc. Ninth Wildl. Damage Conf. Pennsylvania State University, University Park, Pennsylvania, U.S.A.

Patenaude, F. 1982. Une annee dans la vie du castor. Les Carnets de Zoologie 42:5-12.

Roblee, K.J. 1983. A wire mesh culvert for use in controlling water levels at nuisance beaver sites. Proc. East. Wildl. Dam. Control Conf. 3:25-33.

_____. 1984. Use of corrugated plastic drainage tubing for controlling water levels at nuisance beaver sites. N.Y. Fish Game J. 31: 63-80.

_____. 1987. The use of T-culvert guard to protect road culverts from plugging damage by beavers. Proc. East. Wildl. Damage Control Conf. 3:25-33.

Rue, L.L., III. 1968. World of the beaver. J.B. Lippincott. Philadelphia, Pennsylvania, U.S.A.

Slough, B.G. 1978. Beaver food cache structure and utilization. Journal of Wildlife Management 42:644-646.

Svendsen, G.E. 1980. Seasonal change in feeding patterns of beaver in southeastern Ohio. Journal of Wildlife Management 44:285-290.

U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services (USDA-APHIS-WS). 2000. Pre-decisional Environmental Assessment: Reducing Aquatic Rodent Damage Through an Integrated Wildlife Damage Management Program in the Commonwealth of Virginia. Moseley, Virginia, U.S.A.

_____. 2000. Decision and Finding of No Significant Impact for Reducing Aquatic Rodent Damage Through an Integrated Wildlife Damage Management Program in the Commonwealth of Virginia. Moseley, Virginia, U.S.A.

_____. 2000. Report of Beaver Damage Management Activities for the Virginia Department of Transportation (November 7, 2000-November 7, 2001). Moseley, Virginia, U.S.A.

_____. 2002. Report of Beaver Damage Management Activities for the Virginia Department of Transportation (November 7, 2000-November 7, 2001). Moseley, Virginia, U.S.A.

_____. 2003. Report of Beaver Damage Management Activities for the Virginia Department of Transportation March 7, 2002-March 6, 2003 (Additional Appendix November 8, 2001-March 6, 2002). Moseley, Virginia, U.S.A.

_____. 2004. Report of Beaver Damage Management Activities for the Virginia Department of Transportation March 7, 2003-March 6, 2004. Moseley, Virginia, U.S.A.

_____. 2005. Report of Beaver Damage Management Activities for the Virginia

Department of Transportation March 7, 2004-March 6, 2005. Moseley, Virginia, U.S.A.

Virginia Department of Game and Inland Fisheries. 2005. Virginia’s comprehensive wildlife conservation strategy. Virginia Department of Game and Inland Fisheries, Richmond, Virginia.

Willson, L. 1971. Observations and experiments on the ethology of the European beaver (*Castor fiber* L.). Viltrevy 8:115-266.

Wood, G.W., L.A. Woodward and G.K. Yarrow. 1994. The Clemson beaver pond leveler. AFW Leaflet 1, Clemson Cooperative Extension Service, Clemson, S.C.

Woodward, S.L. and R.L Hoffman. 1991. The Nature of Virginia. *in* K. Terwilliger, editor. Virginia’s endangered species. McDonald and Woodward Publishing, Blacksburg, Virginia.

Table 1. Data from surveys conducted with Virginia Department of Transportation (VDOT) personnel and adjacent landowners before flow device installations at 14 beaver damage study sites in the Coastal Plain of Virginia. For each site, individuals surveyed reported whether flooding occurred prior to flow device installations (yes [Y] and no [N]), and the costs per year for maintenance, road repairs and beaver removal due to beaver activity.

Study Sites	Prior Flooding	Maintenance Cost/Yr	Repair Costs/Yr	Beaver Removal Costs/Yr
Lake Cohoon	Y	$43,500.00		$1,891.44
Kingsale Swamp	Y	$6,000.00		$1,891.44
Corrowaugh Swamp (South)	Y	$7,000.00		$763.25
Corrowaugh Swamp (North)	Y	$7,000.00		$799.05
Craney Creek	Y	$5,600.00	$1,000.00	
Briary Swamp	Y	$10,800.00	$300.00	
Pope's Creek (South)	Y	$21,600.00	$132,500.00	$117.89
Pope's Creek (North)	Y	$21,600.00		
Newtons Pond	Y	$400.00		
Winterpock Creek	Y	$11,000.00		
Swift Creek	Y	$4,000.00	$10,000.00	$506.32
Blackwater Swamp	Y	$3,600.00		
Second Swamp	Y	$4,800.00		
Indian Swamp	Y	$3,000.00	$1,200.00	
	Totals:	**$149,900.00**	**$145,000.00**	**$5,969.40**

Table 2. Data from surveys conducted with Virginia Department of Transportation (VDOT) personnel and adjacent landowners following flow device installations at 14 beaver damage study sites in the Coastal Plain of Virginia. For each site, individuals surveyed reported whether flooding occurred following flow device installations (yes [Y] and no [N]), the total cost for materials and labor to install flow devices, maintenance costs per year following installations.

Study Site	Current Flooding	Installation Costs	Maintenance Costs/Yr*
Lake Cohoon	N	$2,371.05	$17.50
Kingsale Swamp	N	$1,825.32	$31.50
Corrowaugh Swamp (S)	N	$1,340.13	$14.00
Corrowaugh Swamp(N)	N	$1,359.41	$14.00
Craney Creek	N	$3,829.81	$14.00
Briary Swamp	N	$3,329.79	$14.00
Pope's Creek (S)	N	$5,571.76	$14.00
Pope's Creek (N)	N	$3,882.31	$14.00
Newtons Pond	N	$2,800.55	$14.00
Winterpock Creek	N	$4,464.43	$21.00
Swift Creek	N	$1,752.28	$14.00
Blackwater Swamp	N	$4,841.68	$14.00
Second Swamp	N	$2,344.70	$14.00
Indian Swamp	N	$4,531.30	$66.50
Total:		**$44,244.52**	**$276.50**

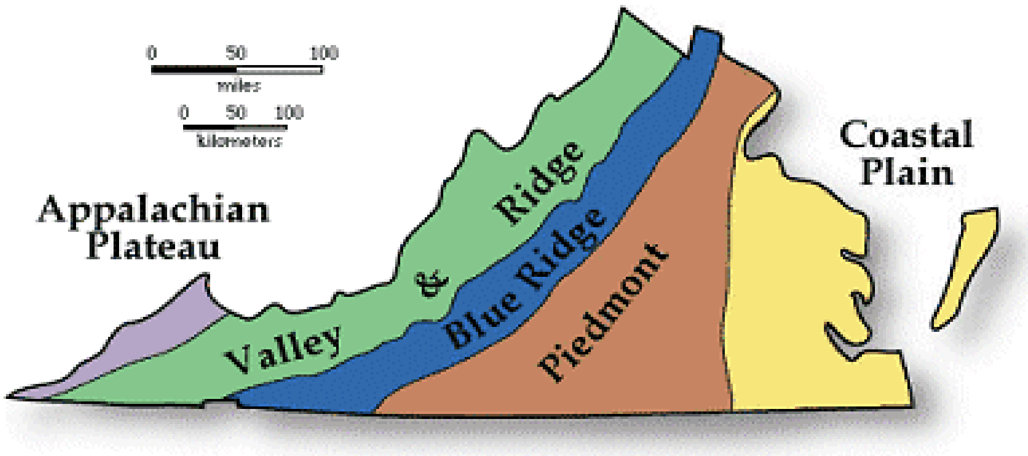
*** Based on an average wage of $14.00 / hour.**

Table 3. The ratio of total resources saved to total costs per year for beaver management and damage repairs before and with the installation of flow devices at 14 beaver damage sites in the Coastal Plain of Virginia. Total costs are the sum of beaver management costs (preventative maintenance and/or flow device installations and beaver population control activities), and beaver damage repair (funds used to repair roads). Total resources saved before flow devices is the sum of potential resources saved and the total costs with flow devices. The total resources saved with flow devices is the sum of potential resources saved and the total costs before flow devices.

Beaver Management Costs/Yr	Before Flow Devices	With Flow Devices
Beaver management	$155,869.00	$44,526.00
Beaver damage repair	$145,000.00	$0.00
Total Costs	**$300,869.00**	**$44,526.00**
Potential Resources Saved*	$71,639.00	$71,639.00
Total resources saved	**$116,165.00**	**$372,508.00**
Total resources saved/ Total costs	**$0.39**	**$8.37**

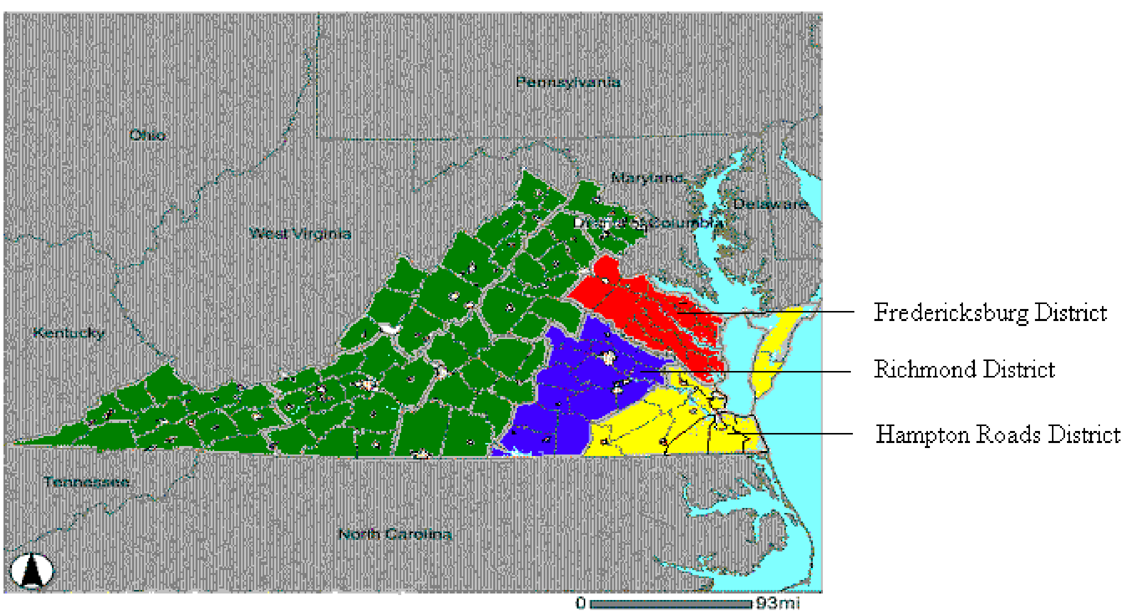
*** Based on data published by USDA-Wildlife Services (2003)**

Figure 1. Virginia with the Coastal Plain highlighted in yellow.



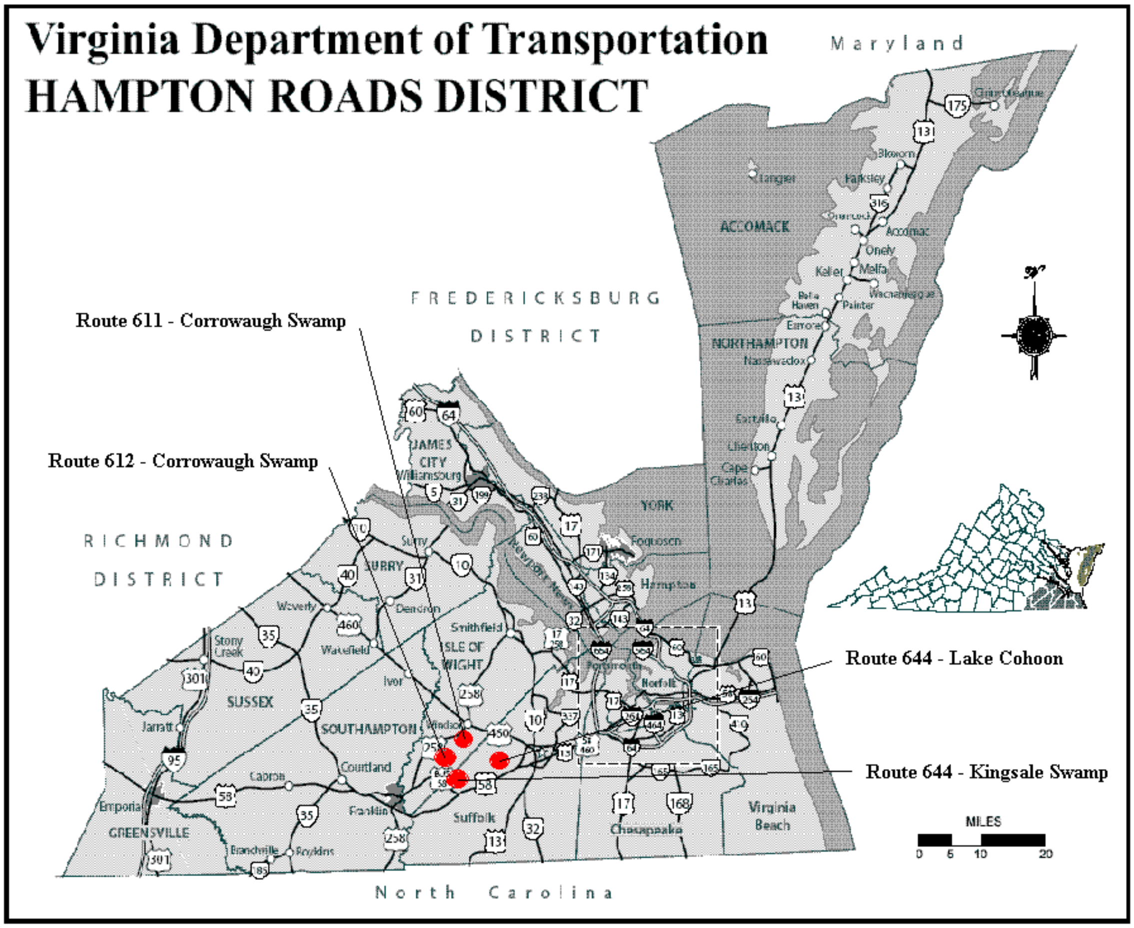
Map courtesy of the College of William & Mary

Figure 2. Virginia with the Virginia Department of Transportation (VDOT) districts located in the Coastal Plain highlighted: Hampton Roads (yellow), Fredericksburg (red) and Richmond (blue).



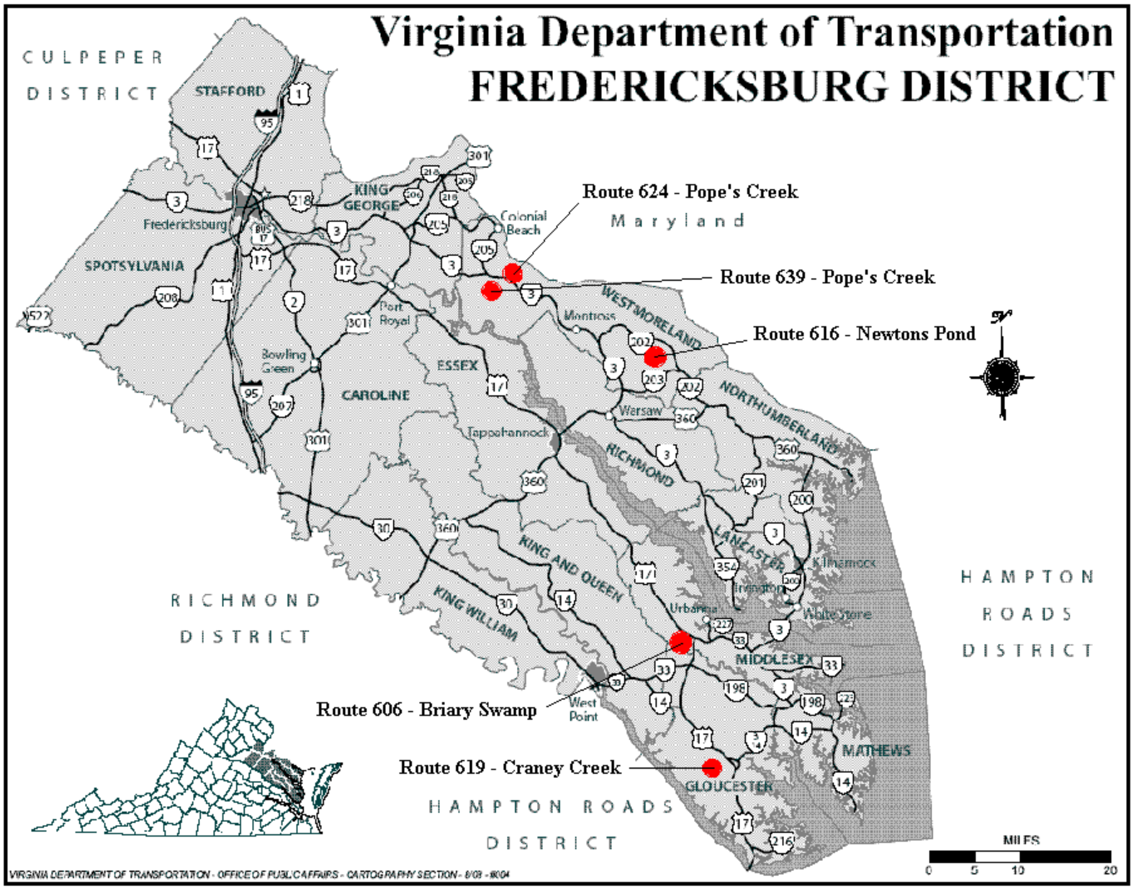
Map courtesy of the Virginia Department of Transportation

Figure 3. Locations of study sites (highlighted in red) in the Virginia Department of Transportation's (VDOT) Hampton Roads District.



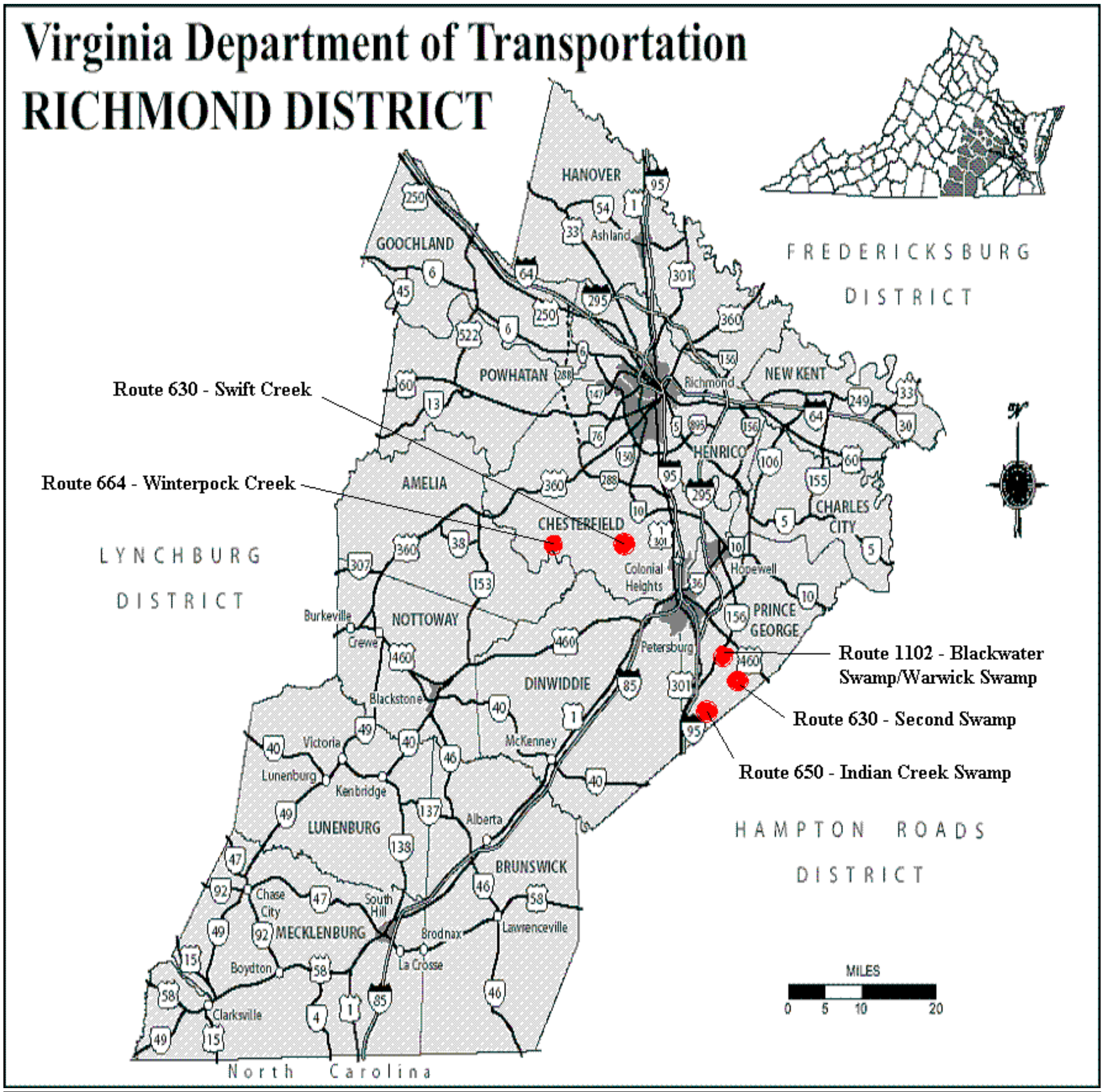
Map courtesy of the Virginia Department of Transportation

Figure 4. Locations of study sites (highlighted in red) in the Virginia Department of Transportation's (VDOT) Fredericksburg District.



Map courtesy of the Virginia Department of Transportation

Figure 5. Locations of study sites (highlighted in red) in the Virginia Department of Transportation's (VDOT) Richmond District.



Map courtesy of the Virginia Department of Transportation

Figure 6. Three Beaver Deceivers™ installed in June 2004 to protect five culverts directing water underneath Route 644 near Lake Cohoon in the City of Suffolk, Virginia. A Round Fence™ (left center) and a Castor Master™ (beneath the surface of the water between the Round Fence™ and the center Beaver Deceiver™) were attached to the upstream end of the center Beaver Deceiver™ to augment water flow if beavers attempted to dam the fences.

Figure 7. A Beaver Deceiver™ installed in June 2004 to protect a culvert directing water underneath Route 644 on Kingsale Swamp in the City of Suffolk, Virginia. A Round Fence™ (top center) and a Castor Master™ (between the Round Fence™ and the Beaver Deceiver™) were attached to the upstream end of the Beaver Deceiver™ to augment water flow.

Figure 8. A Round Fence™ (top left) and a Castor Master™ (located beneath the surface of the water between the Round Fence™ and the existing beaver dam) were installed in June 2004 to protect a bridge directing water underneath Route 612 on Corrowaugh Swamp in Isle of Wight County, Virginia.

Figure 9. The upstream (a) and downstream (b) views of a Round Fence™ (a) and Castor Master™ (b) installed through an existing beaver dam in May 2005 to protect a bridge directing water underneath Route 611 on Corrowaugh Swamp in Isle of Wight County, Virginia.

(a)

(b)

Figure 10. Two Beaver Deceivers™ installed in November 2005 to protect two culverts directing water underneath Route 619 on Craney Creek in Gloucester County, Virginia.

Figure 11. A Beaver Deceiver™ installed in November 2005 to protect two culverts directing water underneath Route 606 on Briary Swamp in Middlesex County, Virginia. A Round Fence™ (bottom center) and a Castor Master™ (beneath the surface of the water between the Round Fence™ and the Beaver Deceiver™) were attached to the upstream end of the Beaver Deceiver™ to augment water flow if beavers attempted to dam the fence.

Figure 12. Two Beaver Deceivers™ installed in January 2005 to protect two culverts directing water underneath Route 624 on Pope's Creek in Westmoreland County, Virginia. A Round Fence™ (right center) and a Castor Master™ (between the Round Fence™ and the large Beaver Deceiver™) were attached to the upstream end of one Beaver Deceiver™ to augment water flow if beavers attempted to dam the fences.

Figure 13. A Beaver Deceiver™ installed in November 2005 to protect four culverts directing water underneath Route 639 on Pope's Creek in Westmoreland County, Virginia. A Round Fence™ (bottom left) and a Castor Master™ (beneath the surface of the water between the Round Fence™ and the Beaver Deceiver™) were attached to the upstream end of the Beaver Deceiver™ to augment water flow if beavers attempted to dam the fence.

Figure 14. A diversion dam (left center), a Round Fence™ (lower right), a Castor Master™ (lower right) and receiver fence (lower center) installed in November 2005 to protect three culverts directing water underneath Route 616 on Newton's Pond in Westmoreland County, Virginia.

Figure 15. (a) The view looking upstream of a plugged culvert underneath Route 664 on Winterpock Creek in Chesterfield County, Virginia prior to flow device installations. (b) View looking downstream of a Beaver Deceiver™, a Round Fence™ (lower right), and a Castor Master™ (beneath the surface of the water between the Round Fence™ and the Beaver Deceiver™) installed in August 2004 to protect the culvert beneath Route 664.

(a)

(b)

Figure 16. (a) The view looking upstream above a plugged culvert beneath Route 664 on Winterpock Creek in Chesterfield County, Virginia in July 2004. (b) View looking upstream above a Beaver Deceiver™, a Round Fence™ (center left) and a Castor Master™ (beneath the surface of the water between the Round Fence™ and the Beaver Deceiver™) installed in August 2004 to protect the culvert beneath Route 664.

(a)

(b)

Figure 17. A Round Fence™ (top center) and a Castor Master™ (between the Round Fence™ and the receiver fence) attached to the upstream side of a receiver fence installed in May 2005 to protect a culvert directing water underneath Route 630 on Swift Creek in Chesterfield County, Virginia.

Figure 18. A Round Fence™ (a and b) installed in June 2004 to protect a vertical culvert directing water underneath Route 1102 on Blackwater Swamp in Prince George County, Virginia.

(a)

(b)

Figure 19. A Beaver Deceiver™ installed to protect an overflow culvert directing water away from Route 1102 on Blackwater Swamp in Prince George County, Virginia in June 2004. Photo (a) was taken in summer and photo (b) was taken in winter.

(a)

(b)

Figure 20. A Beaver Deceiver™ installed in May 2005 to protect culvert directing water underneath Route 1102 on Blackwater Swamp in Prince George County, Virginia.

Figure 21. A Beaver Deceiver™ installed in June 2004 to protect a culvert directing water underneath Route 630 on Second Swamp in Prince George County, Virginia. A Castor Master™ (center) and a Round Fence™ (beneath the surface of the water and attached to the upstream end of the Castor Master™) were attached to the upstream end of the Beaver Deceiver™ to augment water flow if beavers attempted to dam the fence.

Figure 22. (a) A Beaver Deceiver™ (right center) installed in August 2004 to protect three culverts directing water underneath Route 650 on Indian Swamp in Prince George County, Virginia. Two Round Fences™ (one is visible center left and the other is beneath the surface of the water) and two Castor Masters™ (beneath the surface of the water) were attached to the upstream end of the Beaver Deceiver™ to augment water flow. The top photo (a) was taken facing northeast and the bottom photo (b) was taken facing southwest.

(a)

(b)

Virginia Department of Transportation (VDOT)
Survey Questionnaire

1) Baseline for general road maintenance (general and per site)

- At site *x*, was there flooding before beaver activity was noticed? Yes or No?

- Does VDOT have an annual schedule for checking culverts for problems? If so, how often does VDOT monitor culverts?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- When and if VDOT checks/clears a culvert that is plugged with debris other than beaver damming material, how many person hours/equipment hours/operator hours are used to monitor/maintain/clear culverts where beaver activity is not an issue?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- At site *x*, how frequently does the site flood (without beaver activity)?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- At site *x*, was the road closed or impassable due to flooding (without beaver activity)? If yes, how often was it necessary to close the road?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- At site *x*, when and if VDOT closed the road (or a portion of the road), how long was the road closed (without beaver activity)? Hours? Days? Weeks?

- once a week
- once a month
- several times a year
- once a year
- other (please provide details)

- At site *x*, what road repairs (if any) have been conducted? What were they attributed to? Were they attributed to flooding?

- At site *x*, how frequently are road repairs (if any) conducted?

- At site *x*, how often are road repairs (if any) conducted?

- When VDOT cleans site *x*, what funds cover expenses for the work? Maintenance or special projects?

2) Pre-flow device installation

- At site *x*, did the road flood due to beaver activity? Yes or No?

- If yes, did VDOT experience road damage due to flooding attributable to beaver activity prior to device installation? Yes or no?

- At site *x*, how frequently did this area flood due to beaver activity prior to device installation?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- At site *x*, was the road closed or impassable due to flooding attributed to beaver activity prior to device installation? Yes or No?

- If so, how often was the road closed or impassible?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- At site *x*, approximately how long did VDOT close the road prior to device installation?

    - A day

- Several days
- A week
- Several weeks
- Other (please provide details)

- At site *x*, how often did VDOT clean the site prior to device installation?

  - once a week
  - once a month
  - several times a year
  - once a year
  - other (please provide details)

- At site *x*, what was the cost to clean the site once prior to device installation?

  person hours?
  Equipment hours?
  Operator hours?
  Other expenses?

- At site *x*, what road repairs (if any) have been conducted? What were they attributed to?

- At site *x*, how frequently are road repairs (if any) conducted?

  - once a week
  - once a month
  - several times a year
  - once a year
  - other (please provide details)

- What funds covered costs to repair the road?

- Have beavers been removed at this site before? Yes or no?

- If so, by who? USDA-Wildlife Services or a private contractor?

- How many times have beavers been removed from this site in the last five years (since 2000)?

- Following beaver population control activities, did beavers recolonize the site? Yes or no? If yes, quickly did beavers recolonize the site following population control activities?

  - Within a month
  - Within a few months
  - Within a year
  - More than a year later

- other (please provide details)

- What are your management objectives for this site?

3) Watershed characteristics

- Stream attributes (stream or intermittent stream?)

- Purpose of drainage system (directing water underneath road, etc.?)

4) Post flow device installation

- How long has it been since Christopher Newport University installed flow devices at site x?

- At site *x*, did VDOT experience flooding and road damage attributable to beaver activity following installations? Yes or no?

- At site *x*, how frequently does this area flood due to beaver activity following installations?

  - once a week
  - once a month
  - several times a year
  - once a year
  - other (please provide details)

- At site *x*, was the road closed or impassable due to flooding attributed to beaver activity following installations? Yes or no?

- At site *x*, approximately how often does VDOT close the road following installations?

  - once a week
  - once a month
  - several times a year
  - once a year
  - other (please provide details)

- At site *x*, how often does VDOT remove beaver damming material from this site following installation?

  - once a week
  - once a month
  - several times a year
  - once a year
  - other (please provide details)

- At site *x*, what is the cost to clean the site following device installations?

  Person hours?
  Equipment hours?
  Operator hours?
  Other expenses?

- At site *x*, what road repairs have been conducted following device installation? What were they attributed to?

- At site *x*, how frequently are road repairs conducted following device installation?

  - once a week
  - once a month
  - several times a year
  - once a year
  - other (please provide details)

- Has it been necessary to remove beavers since flow device installations?

- If beaver population control activities were conducted, was the work conducted by USDA-WS, a private contractor or a private individual?

- Why was population control conducted?

- Overall, are you satisfied with performance of the devices thus far? Yes or no? Why or why not?

Landowner
Survey Questionnaire

1) Baseline for flooding, road maintenance and repairs

- How long have you lived at your present address?

- At site *x*, was there flooding before beaver activity was noticed? Yes or No?

- At site *x*, how frequently did the site flood (without beaver activity)?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- At site *x*, how frequently did VDOT close the road due to flooding (without beaver activity)?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- At site *x*, when VDOT closed the road (or a portion of the road), how long was the road closed (without beaver activity)?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- What property damage, if any, did you sustain due to road flooding?

2) Pre-flow device installation

- When did you first notice the presence of beavers at this site?

- At site *x*, how frequently did this area flood due to beaver activity prior to device installation?

    - once a week
    - once a month

  - several times a year
  - once a year
  - other (please provide details)

- At site *x*, how frequently did VDOT close the road due to flooding attributed to beaver activity prior to device installation?

  - once a week
  - once a month
  - several times a year
  - once a year
  - other (please provide details)

- At site *x*, approximately how often did VDOT close the road prior to device installation?

  - once a week
  - once a month
  - several times a year
  - once a year
  - other (please provide details)

- At site *x*, how often did VDOT clean the site prior to device installation?

  - once a week
  - once a month
  - several times a year
  - once a year
  - other (please provide details)

- What property damage, if any, did you sustain due to road flooding?

- Have beavers been removed from this site in the past? If so, by who? USDA-WS or a private contractor? How many times have beavers been removed from this site in the last five years (since 2000)?

- Did trapping/dam destruction solve problems you were experiencing with beaver activity?

- What were your management objectives for this site?

3) Post flow device installation

- How long has it been since Christopher Newport University treated the site?

- At site *x*, did you experience flooding and/or property damage attributable to beaver activity following installation? Yes or no? If so, how often?

- once a week
- once a month
- several times a year
- once a year
- other (please provide details)

- At site *x*, how frequently does VDOT close the road due to flooding attributed to beaver activity following installation?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- At site *x*, approximately how long does VDOT close the road following installation?

    - a day
    - several days
    - a week
    - several weeks
    - other (please provide details)

- At site *x*, how often does VDOT clean the site following installation?

    - once a week
    - once a month
    - several times a year
    - once a year
    - other (please provide details)

- Have you done anything to help maintain the device following installation?

- Has beavers been removed from this site following installation? If so, by who? USDA-WS or a private contractor? How many times has this site been trapped since installation?

- Overall, are you satisfied with performance of the device(s) thus far?