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# Investigating the Cost-Effectiveness of Nutrient Credit Use As an Option for VDOT Stormwater Permitting Requirements

http://www.virginiadot.org/vtrc/main/online_reports/pdf/15-r9.pdf

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Final Report VCTIR 15-R9

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**www.VTRC.net**

**Standard Title Page - Report on Federally Funded Project**

| 1. Report No.: FHWA/VCTIR 15-R9 | 2. Government Accession No.: | 3. Recipient's Catalog No.: |
|---|---|---|
| 4. Title and Subtitle: Investigating the Cost-Effectiveness of Nutrient Credit Use As an Option for Stormwater Permitting Requirements | | 5. Report Date: August 2014 |
| | | 6. Performing Organization Code: |
| 7. Author(s): Alicia L. Nobles, Hillary D. Goldstein, Jonathan L. Goodall, Ph.D., and G. Michael Fitch, Ph.D. | | 8. Performing Organization Report No.: VCTIR 15-R9 |
| 9. Performing Organization and Address: Virginia Center for Transportation Innovation and Research 530 Edgemont Road Charlottesville, VA 22903 | | 10. Work Unit No. (TRAIS): |
| | | 11. Contract or Grant No.: 105218 |
| 12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219 | Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825 | 13. Type of Report and Period Covered: Final |
| | | 14. Sponsoring Agency Code: |
| 15. Supplementary Notes: | | |

16. Abstract:


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Data, including a database of existing BMPs, construction plans, and detailed cost estimates, were provided by VDOT. To assess the potential credit demand, details of existing BMPs were reviewed for eligibility to participate in WQT. For the cost comparison, a cost estimate for select linear development projects with BMPs was calculated and then compared to credit costs.

Based on 19 years of historical data, VDOT could have used between 1 and 63 pounds of phosphorous credits per year and a median of 11 pounds of phosphorous credits per year for the James River watershed if current WQT guidelines had been in place over this period of time. In the hypothetical scenario where VDOT's participation in the WQT program was allowed in lieu of VDOT's construction of nine BMPs, VDOT would have realized a cost savings of 5% to 75%, with an average cost savings of 51%. These results suggest that participating in WQT at current market rates in lieu of constructing onsite structural BMPs is an economically feasible solution for VDOT to manage stormwater quality. It should be noted that market rates for phosphorus credits may change in the future.

VDOT's Location and Design Division should continue purchasing stormwater credits for those projects that are eligible for WQT.


| 17 Key Words: Nutrient credits, water quality trading, stormwater, BMPs | | 18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161. | |
|---|---|---|---|
| 19. Security Classif. (of this report): Unclassified | 20. Security Classif. (of this page): Unclassified | 21. No. of Pages: 20 | 22. Price: |

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

**FINAL REPORT**

# INVESTIGATING THE COST-EFFECTIVENESS OF NUTRIENT CREDIT USE AS AN OPTION FOR VDOT STORMWATER PERMITTING REQUIREMENTS


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In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Center for Transportation Innovation and Research
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

August 2014
VCTIR 15-R9

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## ABSTRACT

The purpose of this study was to determine the feasibility of the Virginia Department of Transportation (VDOT) participating in water quality trading (WQT) in lieu of constructing onsite structural best management practices (BMPs) to achieve compliance with Virginia water quality standards for stormwater runoff for linear development projects. The objectives of the study were (1) to assess the potential credit demand for VDOT projects, focusing on the James River watershed as a case study; and (2) to compare the costs to VDOT of constructing BMPs and participating in WQT.

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Based on 19 years of historical data, VDOT could have used between 1 and 63 pounds of phosphorous credits per year and a median of 11 pounds of phosphorous credits per year for the James River watershed if current WQT guidelines had been in place over this period of time. In the hypothetical scenario where VDOT's participation in the WQT program was allowed in lieu of VDOT's construction of nine BMPs, VDOT would have realized a cost savings of 5% to 75%, with an average cost savings of 51%. These results suggest that participating in WQT at current market rates in lieu of constructing onsite structural BMPs is an economically feasible solution for VDOT to manage stormwater quality. It should be noted that market rates for phosphorus credits may change in the future.

VDOT's Location and Design Division should continue purchasing stormwater credits for those projects that are eligible for WQT.

**FINAL REPORT**

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## INTRODUCTION

In Virginia, linear development projects are required to manage and treat stormwater runoff from increased impervious surfaces in accordance with post-development requirements for water quantity and quality to prevent a reduction in water quality, erosion, and flooding of streams.[1,2] Traditionally, stormwater management has focused on onsite structural best management practices (BMPs) with the capacity to temporarily hold and treat runoff.[3] Structural BMPs are physical structures that are constructed onsite to mitigate the impacts of stormwater runoff. As areas become more urbanized and environmental regulations become more stringent, structural BMPs are becoming more expensive.[3] As a result, stormwater professionals must consider the economic feasibility of achieving compliance with stormwater regulations using only onsite structural BMPs.[4]

In December 2010, the U.S. Environmental Protection Agency established a Total Maximum Daily Load (TMDL) for the Chesapeake Bay that established the maximum allowable annual nitrogen, phosphorus, and sediment loads permitted to enter the bay.[5] Water quality trading (WQT) can be a tool to help achieve TMDL requirements. Recently, the Virginia Department of Environmental Quality expanded its WQT program. Now, in addition to trading between point sources (PS-PS) or between point and nonpoint sources (PS-NPS), it is possible to trade between nonpoint sources (NPS-NPS).[6] WQT allows sources with higher costs of reducing pollutant load to purchase equal or greater pollution reduction credits from sources with lower costs of reducing pollutant load.[7,8]

For the Virginia Department of Transportation (VDOT), participating in WQT in lieu of constructing onsite structural BMPs may offer a more economical means of achieving compliance with Virginia water quality standards. The costs of constructing onsite BMPs include costs for project development, permitting, purchases of right of way (ROW), regulatory review time, construction efforts, and required operations and maintenance (O&M). Although there is a perceived opportunity for savings with participating in WQT in lieu of constructing onsite BMPs, no studies have attempted to quantify these potential costs savings by performing a detailed assessment of BMP construction, operation, and maintenance costs and comparing them to credit pricing in the WQT market.

## PURPOSE AND SCOPE

The purpose of this study was to determine the economic feasibility of VDOT participating in WQT in lieu of constructing onsite structural BMPs to achieve compliance with Virginia water quality standards for stormwater runoff for linear development projects. The objectives of the study were (1) to assess the potential credit demand for VDOT projects, focusing on the James River watershed as a case study; and (2) to compare the costs to VDOT of constructing BMPs and participating in WQT.

## LITERATURE REVIEW

Market-based approaches are increasingly being used to achieve compliance with environmental quality regulations.[9,10] Several approaches, including trading of air emissions, lead emissions, and heavy duty motor vehicle engine emissions, have been successfully implemented in the United States.[10,11] In contrast to these trading programs, the experience with WQT for pollutants is more limited.[10,12] WQT can occur between PS-PS, NPS-NPS, and PS-NPS. The greatest percentage of trading activity by dollar volume has been between PS-PS.[8] Most studies for WQT focus on an overview of trading programs, credit generation, and trade ratios (e.g., Newborn and Woodward[9] and Earles et al.[13]).

According to Fisher-Vanden and Olmstead,[12] there are currently 13 active trading and 8 active offset programs for water quality in the United States. Trading programs involve multiple recipients and multiple sources. Offset programs involve a single recipient of water quality credits from one or multiple sources. In general, users of offset credits directly invest in credit-generating projects rather than purchase credits from another source.[12] These programs trade or offset nitrogen, phosphorus, salinity, sediment, biochemical oxygen demand, temperature, and ammonia through PS-PS and PS-NPS trades, with the most commonly traded nutrients being nitrogen and phosphorus.[8, 12,14] Transactions for these programs have occurred through three market structures: (1) individual negotiations between the purchaser and generator; (2) clearinghouses where a single intermediary generates credits; and (3) an exchange market where purchasers and generators trade transparently.[12] The use of clearinghouses and exchange markets reduces transaction costs.[11] Despite the number of active programs, only a few are trading on a large scale.[12,14]

In the same study, Fisher-Vanden and Olmstead[12] also identified 12 inactive trading and offset programs in the United States for which either a very small amount of trading or offset activity occurred before the program became inactive; early studies concluded trading would be unsuccessful; or a delay occurred because of other factors including development of regulations, lack of credit demand, or lack of a driver such as a TMDL. According to the authors, one program, the Grassland Area Farmers Tradable Loads Program, established in California, conducted nine NPS-NPS trades for selenium between 1998 and 1999; however, the authors reported that a regional irrigation reuse program was implemented that reduced selenium levels below the cap on the total allowable regional selenium discharge, eliminating the incentive to trade.[12] The authors also reported that research was conducted in 2006 to examine NPS-NPS trading of water temperature in the Vermillion River in Minnesota; however, according to the authors, agricultural BMPs do not affect temperature and therefore the pool of potential trading participants was reduced, effectively increasing transaction costs among participants.[12]

In 2009, the New Jersey Department of Transportation (DOT) conducted a feasibility study to assess water quality credit demand and identify a watershed for water quality mitigation banking.[15] Water quality mitigation banking is similar in concept to wetland mitigation banking; i.e., one offsite water quality BMP or "bank" will address the cumulative impacts of multiple DOT projects. The study identified a future credit need in the Hackensack River watershed and proposed a stormwater wetland facility to treat total suspended solids for 1 imperious acre at a cost of $71,300 with 100% removal.[15]

The Maryland State Highway Administration implemented a stormwater quality mitigation banking program under a memorandum of understanding with the Maryland Department of Environmental Quality. According to Agrawal et al.[15] and Fekete,[16] the banking program can be used for deferral of water quality for new pavement areas of up to 5 acres located in metropolitan areas and 2 acres located in rural areas with a ratio of 1.20 acres treated for every 1 acre of impact. Similarly, the Delaware DOT implemented a stormwater quality mitigation banking program under a memorandum of agreement with the Delaware Department of Natural Resources and Environmental Control. Under this program, banking is confined to projects within the watershed where onsite BMPs are difficult to construct. As noted by Agrawal et al.,[15] both Maryland's and Delaware's banking programs are for water quality only. Water quantity must be controlled onsite.

## METHODS

### Assessment of Potential Credit Demand for VDOT Projects

To assess the potential credit demand for VDOT projects, details of existing BMPs constructed by VDOT for linear development projects located in the James River watershed were reviewed for the project's eligibility to participate in WQT to achieve compliance with Virginia water quality requirements. The impervious acreage treated by each BMP was converted into the pounds of phosphorus removed annually by each BMP. Then the regulatory requirements for eligibility to participate in WQT were applied for each project to determine credit demand.

A database containing 1,783 stormwater BMPs constructed in Virginia from 1977 to 2014 was provided by VDOT's Location and Design Division. The database included details for each BMP such as type, date installed, location (coordinates and 8-digit hydrologic unit code [HUC]), and treatment purpose (water quality or quantity). The BMP coordinates were mapped in GIS, and the 8-digit HUC listed in the database was compared with the 8-digit HUC boundaries obtained from the U.S. Geological Survey[17] to ensure accuracy of the BMP location. A query of the database identified 1,336 BMPs that were constructed to treat water quality, with 314 of them located in the 6-digit HUC James River basin. Figure 1 presents the 6-digit HUC basins in Virginia. BMPs that provided both water quality and water quantity treatment were excluded from analysis under the assumption that the BMPs would be required to mitigate water quantity regardless.

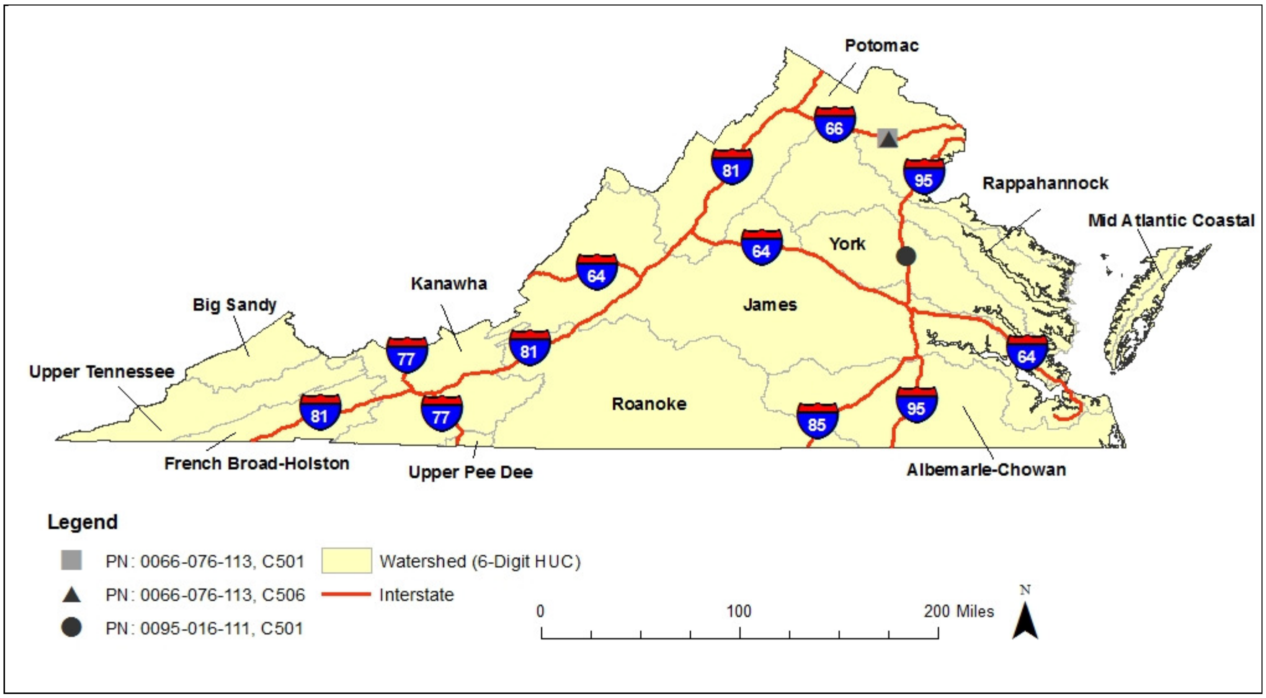


**Figure 1. Map Showing Virginia's 6-Digit Hydrologic Unit Code (HUC) Basins and the Locations of the Three Construction Projects Used in the Cost Comparison. PN = project number.**

## Annual Phosphorus Removal

The Simple Method is an empirical calculation that uses easily obtained variables to estimate planning level pollutant loading of stormwater runoff for urban development sites.[18] The method, provided in Equation 1, estimates the annual phosphorus load attributable to stormwater runoff in urban areas.

$$L = P \times P_j \times [0.05 + (0.009 \times I)] \times C \times A \times 2.72 \div 12 \qquad \text{[Eq. 1]}$$

where

L = annual phosphorus load (pounds)
P = average annual rainfall (inches) = 43 inches

$P_j$ = unitless correction factor for a storm with no runoff = 0.9
I = percent impervious cover
C = flow-weighted mean pollutant concentration = 0.26 mg/L
A = applicable area (acres).

Using a simplified version of Equation 1, the annual phosphorus load entering each BMP from runoff from 1 impervious acre was calculated using Equation 2.

$$\begin{aligned} L_{acre} &= [0.05 + (0.009 \times I)] \times A \times 2.28 \\ &= [0.05 + (0.009 \times 100\%)] \times 1 \text{ acre} \times 2.28 \\ &= 2.17 \text{ pounds/acre/year} \end{aligned} \quad \text{[Eq. 2]}$$

where

$L_{acre}$ = annual phosphorus load from 1 impervious acre (pounds).

The impervious acreage treated by each BMP was converted into the annual phosphorus load entering each BMP using Equation 3.

$$L_{BMP} = A_{BMP} \times L_{acre} \quad \text{[Eq. 3]}$$

where

$L_{BMP}$ = annual phosphorus load entering the BMP (pounds)
$A_{BMP}$ = impervious area treated by the BMP (acres).

To account for the removal efficiency of the BMP, the annual phosphorus load removed by the BMP was calculated using Equation 4 and the efficiencies provided in the *Virginia Stormwater Management Handbook*.[18]

$$L_{removed} = L_{BMP} \times Eff_{BMP} \quad \text{[Eq. 4]}$$

where

$L_{removed}$ = annual phosphorus removal by a BMP (pounds)
$L_{BMP}$ = annual phosphorus load entering the BMP (pounds)
$Eff_{BMP}$ = pollutant removal efficiency of the BMP.

The annual phosphorus load removed for each project was calculated for each project site using Equation 5.

$$L_{removed,\, project_i} = L_{removed,\, BMP_1} + L_{removed,\, BMP_2} + \cdots L_{removed,\, BMP_n} \quad \text{[Eq. 5]}$$

where

$i$ = the project number
$n$ = the total number of BMPs for project $i$.

## Eligibility for WQT

In accordance with the *Code of Virginia,* § 62.1-44.15:35, WQT may be used to achieve compliance with Virginia water quality requirements for a specific linear construction project under the following three scenarios: (1) less than 5 acres of land are disturbed; (2) the post-construction phosphorus removal requirement is less than 10 pounds per year; or (3) at least 75% of the required post-construction phosphorus removal can be achieved using onsite BMPs but full compliance with Virginia removal requirements cannot practicably be met onsite. NS-NS credits are traded at a 1:1 ratio, are perpetual, and are available in 0.1-pound increments. Credits must be generated in the same or adjacent 8-digit HUC. A credit from the same tributary may be considered; however, credits from outside tributaries may not be used.

Scenarios 2 and 3 were applied to the existing projects in the James River watershed for the time period shown in Table 1. If the total phosphorus removed on a project was less than 10 pounds, it was assumed the entire amount was eligible for WQT. If the total phosphorus removed on a project was equal to or greater than 10 pounds, it was assumed that 25% of the amount was eligible for WQT.

# Cost Comparison of Constructing BMPs and Participating in WQT

For the cost comparison, a cost was estimated for nine BMPs across three linear development projects located in Virginia and then compared to the cost of nutrient credits.

## Cost of Constructing BMPs

Components of a structural BMP cost include pre-construction, construction, ROW, routine annual O&M, non-routine O&M, and demolition and disposal at the end of the BMP's useful life. In this study, *BMP cost* was defined as the total cost of pre-construction, construction, ROW, and routine annual O&M. Non-routine O&M and end-of-life costs were excluded because of the difficulty in predicting needs and estimating costs. BMP costs, expressed in both total dollars and unit costs, were determined for comparison to the cost of participating in WQT (i.e., credit costs).

Three linear development projects with a total of nine existing BMPs were selected for cost estimation (see Figure 1 for project locations and Table 2 for the BMP properties). These BMPs were selected to represent a range of BMP types and sizes and were limited to BMPs constructed in the past 10 years. Project Number (PN) 0066-076-113, C501, focused on improving I-66 by widening approximately 3.3 miles of high-occupancy-vehicle lanes. The project included construction of four extended detention basins for management of stormwater quality in 2006 (BMPs 4-7 in Table 2). PN 0066-076-113, C506, focused on reconstruction of an interchange for I-66. The project included construction of a sand filter and an enhanced extended detention basin for management of stormwater quality in 2004 and 2005, respectively

(BMPs 8 and 9 in Table 2). PN 0095-016-111, C501, focused on relocating Route 652 in Caroline County near I-95. The project included construction of three extended detention basins in 2008 (BMPs 1-3 in Table 2). In addition to the stormwater BMP database, VDOT's Location and Design Division provided construction site plans, construction materials and costs (including labor), and ROW parcel sizes and costs pertaining to these projects.

Six components of BMP cost were determined for the comparison.

1. *Pre-construction cost.* Pre-construction costs were defined as design, permitting, and contingency costs.[19] King and Hagen reported pre-construction costs of BMPs, which are defined as discovery, survey design, permitting, and planning, as ranging from 10% to 40% of construction costs.[20] A U.S. Environmental Protection Agency publication[1] reported pre-construction costs of BMPs as ranging from 25%[21] to 32%[22] of construction costs for design, contingencies, and permitting. The 32% value included erosion and sediment control during construction of the BMP. In this study, the pre-construction costs were assumed to be 32% of construction costs and inclusive of erosion and sediment control during construction of a BMP. It should be noted that retrofits may incur higher pre-construction and construction costs.[23]

2. *Construction cost.* For each of the nine BMPs, VDOT construction plans were used in the determination of the cost to construct the BMP. As part of the construction plan records, VDOT includes a detailed cost estimate with unit costs for all materials used in the linear development project and a stormwater management control summary sheet that itemizes materials used to construct each BMP. The unit costs provided in the detailed cost estimates were taken from the VDOT Transport system, a database of historical infrastructure costs. Construction costs were determined by summing the cost of the materials and labor used to construct each BMP.

3. *ROW cost.* ROW costs can be a significant contributor to the cost of a BMP, especially in urbanized areas.[24] Because of the variability in the land area requirements for each BMP and the cost of land, ROW costs for BMPs are difficult to estimate.[24] In this study, the minimum required ROW for each BMP was determined by measuring the BMP footprint provided in construction site plans. The footprint did not include additional land area required for access to the BMP, if needed. Using the parcel size provided by VDOT, the ROW cost for each BMP was determined by multiplying the parcel cost by the percentage of the parcel that the BMP footprint occupied.

4. *Annual O&M cost.* Annual O&M costs were assumed to be 1%, 4.5%, and 12% for extended detention basins, the enhanced extended detention basin, and the sand filter, respectively. These values were based on the average values provided by the U.S. Environmental Protection Agency.[1] A 20-year design life was assumed for each BMP to determine total O&M costs over the lifetime of the BMP. Annual O&M costs for a 20-year lifetime were discounted at a rate of 3% to determine the value of O&M at the time of construction. As recommended by the Federal Highway Administration,[25] the discount rate was selected based on the U.S. Office of Management and Budget's reported 10-year real discount rate of 2.5% and 30-year real discount rate of 3.2%. Real discount rates used by states historically have ranged from 3% to 5%.

5. *Total BMP cost.* Pre-construction, construction, ROW, and O&M costs were adjusted for inflation to 2014 dollars using the construction cost indexes from Engineering News-Record[26] and summed to determine BMP cost. The annual inflation rates ranged from 4.65% to 2.65% for years 2004 to 2014.

6. *Unit BMP costs.* In order to compare estimated VDOT BMP costs to BMP cost estimates reported in the literature, the VDOT construction and O&M costs were divided by the water quality volume (WQV) treated to determine the BMP cost per cubic foot of WQV and then compared to the construction and O&M costs reported by Weiss et al.[27] The WQV was determined using Equation 6.

$$\mathrm{WQV} = (\mathrm{P} \times \mathrm{R} \times \mathrm{A} \times \mathrm{DV} \times 43560\ \mathrm{ft^2/acre} \times 12\ \mathrm{in/ft}) \qquad \text{[Eq. 6]}$$

where

WQV = water quality volume ($ft^3$)
P = precipitation depth (inches) = ½ inch
R = ratio of runoff to rainfall = 0.95
A = impervious area (acres)
DV = design volume factor (extended detention basins = 2, enhanced extended detention basin = 2, and sand filter = 1).[18]

In order to compare BMP costs to phosphorus credit costs, the total BMP cost was divided by the annual phosphorus removal to determine the BMP cost per pound of annual phosphorus removal.

## Phosphorus Credit Cost

Fixed prices for 1-pound phosphorus credits in the James, Potomac, Rappahannock, and York watersheds were provided by VDOT's Location and Design Division. The cost of a 1-pound phosphorous credit in the James and Potomac watersheds is $10,430 and $18,700, respectively. The cost of a 1-pound phosphorous credit in the York and Rappahannock watersheds in on a sliding scale from $17,000 to $20,000 and $14,700 to $16,450, respectively. The cost of credits in the York and Rappahannock watersheds decreases as more credits are purchased. The credits are managed through a clearinghouse, which generates the credits by converting agricultural land to forest land or building urban BMPs.

# RESULTS

## Potential Credit Demand

Table 1 presents the calculated credit demand of existing BMPs in the James River watershed. Existing BMPs remove 1,147.6 pounds of phosphorus annually from runoff in the James River watershed. Approximately 41% of this annual removal would have been eligible for WQT under Scenarios 2 and 3 based on current regulations for WQT. For these BMPs, credits could have been purchased in lieu of onsite construction to achieve compliance with Virginia water quality requirements. Based on these historical data, approximately 24 pounds of credit demand may be generated per year in the James River watershed with a range in annual needs from 0.6 to 62.9 pounds. The average phosphorous removal eligible for credit trading during the 19-year period reflected in the BMP database was 24 pounds; 0.6 and 62.9 pounds were the minimum and maximum annual pounds of phosphorous eligible for removal by way of credit trading, respectively, during the same period.

**Table 1. Annual Phosphorus Removal Eligible for Water Quality Trading (WQT)**

| BMP Installation Date (Year) | Total Annual Phosphorus Removal by BMPs (lb) | Annual Phosphorus Removal Eligible for WQT | | |
|---|---|---|---|---|
| | | Scenario 2 (lb) | Scenario 3 (lb) | Total (lb) |
| 1991 | 0.6 | 0.6 | 0.0 | 0.6 |
| 1992 | 19.1 | 19.1 | 0.0 | 19.1 |
| 1993 | 11.0 | 11.0 | 0.0 | 11.0 |
| 1994 | 51.3 | 6.4 | 11.2 | 17.6 |
| 1995 | 75.6 | 25.2 | 12.6 | 37.8 |
| 1996 | 75.9 | 48.0 | 7.0 | 55.0 |
| 1997 | 74.0 | 14.1 | 15.0 | 29.1 |
| 1998 | 26.9 | 26.9 | 0.0 | 26.9 |
| 1999 | 133.4 | 29.3 | 26.0 | 55.3 |
| 2000 | 87.2 | 5.6 | 20.4 | 26.0 |
| 2001 | 231.0 | 6.8 | 56.1 | 62.9 |
| 2002 | 121.1 | 2.5 | 29.6 | 32.1 |
| 2003 | 37.4 | 22.6 | 3.7 | 26.3 |
| 2004 | 3.7 | 3.7 | 0.0 | 3.7 |
| 2005 | 126.0 | 7.4 | 29.7 | 37.0 |
| 2007 | 2.1 | 2.1 | 0.0 | 2.1 |
| 2008 | 1.2 | 1.2 | 0.0 | 1.2 |
| 2009 | 2.2 | 2.2 | 0.0 | 2.2 |
| 2010 | 0.8 | 0.8 | 0.0 | 0.8 |
| Unknown | 67.0 | 14.6 | 13.1 | 27.7 |
| Total | 1147.6 | 250.1 | 224.4 | 474.5 |
| Median | 37.4 | 6.8 | 3.7 | 10.5 |
| Average | 56.9 | 12.4 | 11.1 | 23.5 |

BMP = best management practice; Scenario 2 = post-construction phosphorus removal requirement is less than 10 pounds per year; Scenario 3 = a minimum of 75% of required post-construction phosphorus removal can be achieved onsite.

## Cost Comparison of Constructing BMPs and Participating in WQT

As discussed previously, Table 2 presents the properties of the BMPs selected for cost evaluation and Table 3 presents the results of the cost evaluation of the BMPs including pre-construction, construction, lifetime O&M, and ROW costs as described earlier. The costs are presented both with and without ROW costs given the variability in these costs. The costs are normalized by pound of annual phosphorus removal for comparison with WQT market prices.

Weiss et al.[27] conducted a survey of published BMP costs and established a relationship between the WQV treated by a BMP and the cost of construction and O&M of the BMP. The estimated costs for construction and O&M for each BMP developed in the current study

**Table 2. Properties of BMPs Selected for Cost Estimation**

| BMP ID | BMP Type | 4-digit HUC | Impervious Area Treated (acres) | WQV Treated ($ft^3$) | Annual Phosphorus Removal (lb) | Removal Efficiency |
|---|---|---|---|---|---|---|
| 1 | Extended detention basin[a] | York | 2.44 | 8414.34 | 1.85 | 35% |
| 2 | Extended detention basin[a] | York | 2.56 | 8828.16 | 1.94 | 35% |
| 3 | Extended detention basin[a] | York | 8.01 | 27622.49 | 6.08 | 35% |
| 4 | Extended detention basin[b] | Potomac | 4.27 | 14725.10 | 3.24 | 35% |
| 5 | Extended detention basin[b] | Potomac | 7.33 | 25277.51 | 5.57 | 35% |
| 6 | Extended detention basin[b] | Potomac | 7.42 | 25587.87 | 5.64 | 35% |
| 7 | Extended detention basin[b] | Potomac | 15.15 | 52244.78 | 11.51 | 35% |
| 8 | Sand filter[c] | Potomac | 4.40 | 7586.70 | 6.21 | 65% |
| 9 | Extended detention enhanced basin[c] | Potomac | 9.20 | 31726.20 | 9.98 | 50% |

BMP = best management practice; HUC = hydrologic unit code; WQV = water quality volume.
[a] Functional class: rural collector rolling undivided.
[b] Functional class: rural principal arterial.
[c] Functional class: urban minor arterial.

**Table 3. Component Costs of BMPs Selected for Cost Estimation**

| BMP ID | Pre-Construction | Construction | Lifetime O&M | ROW | Total | | Per Pound of Annual Phosphorus Removal | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Including ROW | Excluding ROW | Including ROW | Excluding ROW |
| 1 | $7,487.90 | $23,399.69 | $3,481.28 | $24,081.55 | $34,368.87 | $58,450.43 | $18,545.89 | $31,540.61 |
| 2 | $15,049.60 | $47,030.01 | $6,996.88 | $35,691.84 | $69,076.49 | $104,768.33 | $35,527.32 | $53,884.30 |
| 3 | $20,083.53 | $62,761.02 | $9,337.26 | $30,077.16 | $92,181.80 | $122,258.96 | $15,152.52 | $20,096.50 |
| 4 | $15,265.14 | $47,703.55 | $7,097.08 | $35,327.13 | $70,065.77 | $105,392.89 | $21,604.80 | $32,497.93 |
| 5 | $48,580.29 | $151,813.40 | $22,586.00 | $57,992.14 | $222,979.68 | $280,971.82 | $40,052.86 | $50,469.73 |
| 6 | $46,085.87 | $144,018.34 | $21,426.29 | $62,088.79 | $211,530.50 | $273,619.28 | $37,535.42 | $48,552.88 |
| 7 | $79,023.29 | $246,947.78 | $36,739.59 | $53,814.44 | $362,710.66 | $416,525.10 | $31,522.45 | $36,199.35 |
| 8 | $29,889.55 | $93,404.84 | $166,755.37 | $49,801.21 | $290,049.76 | $339,850.97 | $46,735.48 | $54,759.91 |
| 9 | $88,069.13 | $275,216.03 | $184,253.38 | $200,549.55 | $547,538.54 | $748,088.08 | $54,852.59 | $74,943.71 |

BMP = best management practice; O&M = operation and maintenance; ROW = right of way.

(specifically not including pre-construction costs) were compared to the published costs reported by Weiss et al. using the relationship established by Weiss et al.[27] Figure 2 presents the estimated costs compared to the average published cost of extended detention ponds. Table 4 presents the comparison for enhanced extended detention ponds and sand filters. The estimated costs for all BMPs with the exception of the enhanced extended detention basin were within the 67% confidence intervals (1 standard deviation) for published costs established by Weiss et al.[27] The cost of the enhanced extended detention basin was compared to that of a constructed wetland since there was no established relationship between WQV treated and the cost of construction and O&M for an enhanced extended detention basin.

Table 5 and Figures 3 and 4 compare the BMP estimated costs (pre-construction, construction, and O&M) excluding ROW (Figure 3) and including ROW (Figure 4) to the cost of

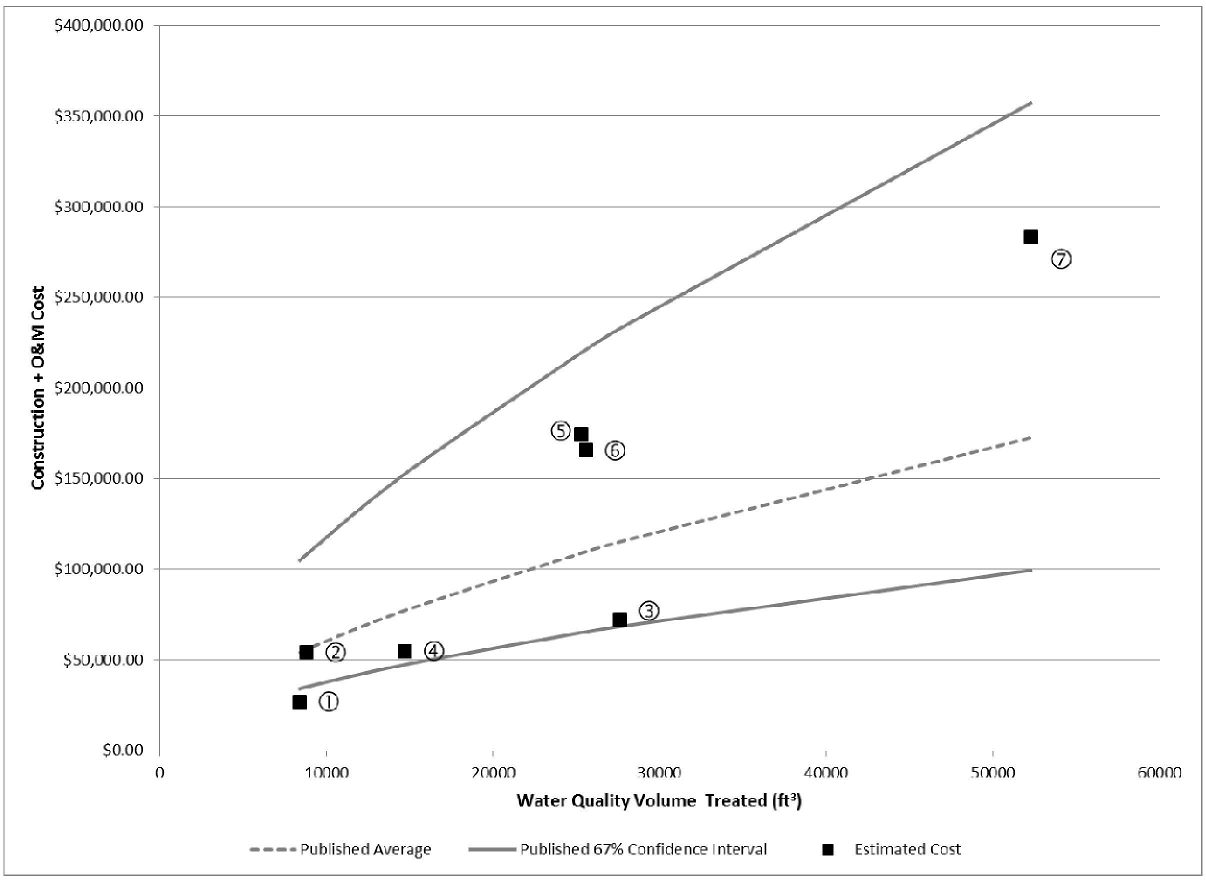


**Figure 2. Comparison of Estimated VDOT Construction and O&M Costs to Published Construction and O&M Costs[25] for Extended Detention Basins. Numbers in circles represent BMP ID numbers.**

**Table 4. Comparison of Estimated VDOT Construction and O&M Costs to Published Construction and O&M Costs[25] for the Sand Filter and Enhanced Extended Detention Basin**

| BMP ID | BMP Type | Estimated Cost | Published Cost | | |
|---|---|---|---|---|---|
| | | | Average | Upper 67% CI | Lower 67% CI |
| 8 | Sand filter | $260,160.21 | $196,720.33 | $440,089.49 | $110,547.15 |
| 9 | Enhanced extended detention basin | $459,469.41 | $93,025.10 | $181,433.73 | $54,614.21 |

BMP = best management practice; O&M = operation and maintenance; CI = confidence interval.

1 pound of phosphorus credit. In the hypothetical scenario where trades between nonpoint sources were allowed at the time of the BMP's construction, participation in the WQT program in lieu of construction of these BMPs would have resulted in a cost savings of 5% to 75%, with an average cost savings of 51% and a median cost savings of 62%. Obviously cost savings are substantially greater for scenarios including ROW.

**Table 5. Cost Savings of Participation in Water Quality Trading (WQT) In Lieu of Construction of BMPs**

| BMP ID | BMP Cost per Pound of Annual Phosphorus Removal | | Credit Cost | Cost Savings | |
|---|---|---|---|---|---|
| | Excluding ROW | Including ROW | | Excluding ROW | Including ROW |
| 1 | $18,545.89 | $31,540.61 | $20,000 | -7.84% | 36.59% |
| 2 | $35,527.32 | $53,884.30 | $20,000 | 43.71% | 62.88% |
| 3 | $15,152.52 | $20,096.50 | $19,000 | -25.39% | 5.46% |
| 4 | $21,604.80 | $32,497.93 | $18,700 | 13.45% | 42.46% |
| 5 | $40,052.86 | $50,469.73 | $18,700 | 53.31% | 62.95% |
| 6 | $37,535.42 | $48,552.88 | $18,700 | 50.18% | 61.49% |
| 7 | $31,522.45 | $36,199.35 | $18,700 | 40.68% | 48.34% |
| 8 | $46,735.48 | $54,759.91 | $18,700 | 59.99% | 65.85% |
| 9 | $54,852.59 | $74,943.71 | $18,700 | 65.91% | 75.05% |
| Median | | | | 43.71% | 61.49% |
| Average | | | | 32.66% | 51.23% |

BMP = best management practice; ROW = right of way.

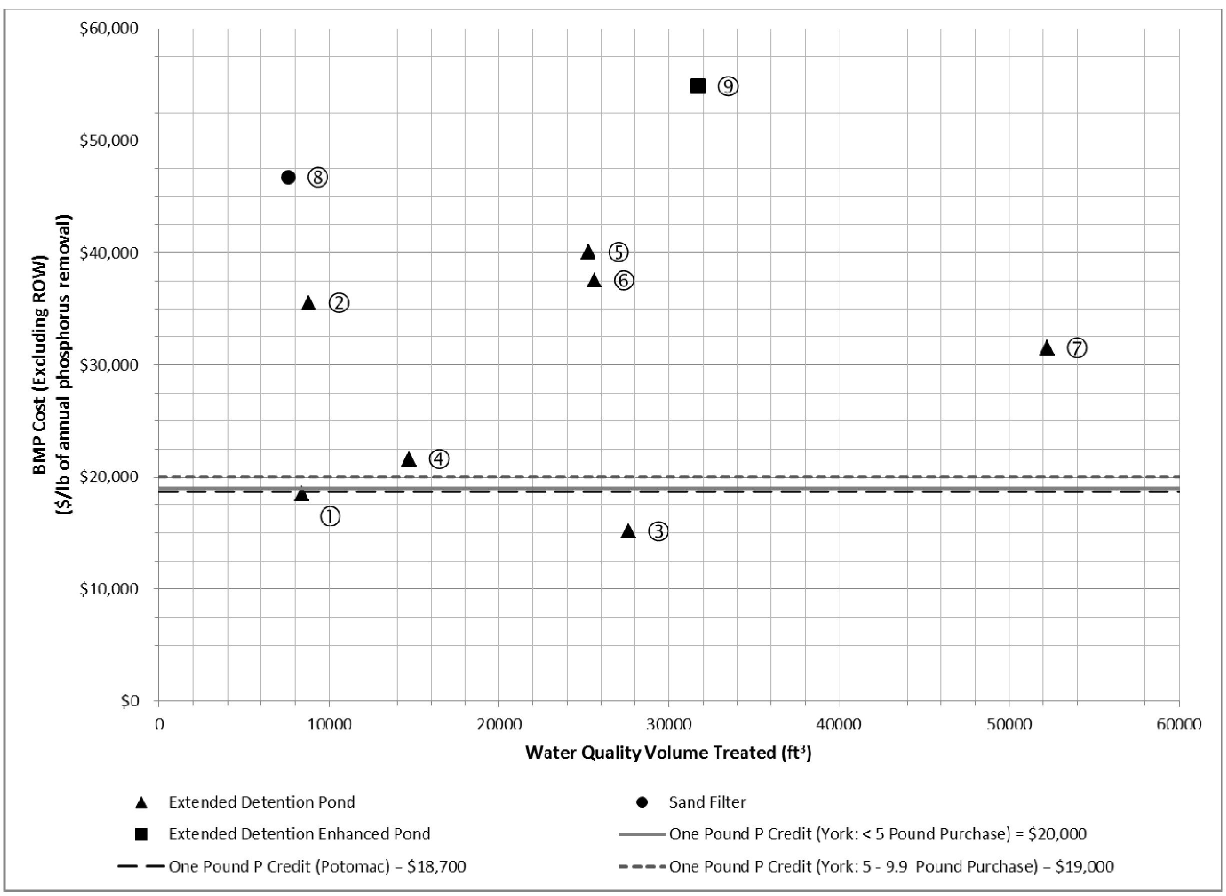


**Figure 3. Comparison of BMP Cost Excluding ROW to Credit Cost. BMP = best management practice; ROW = right of way.**

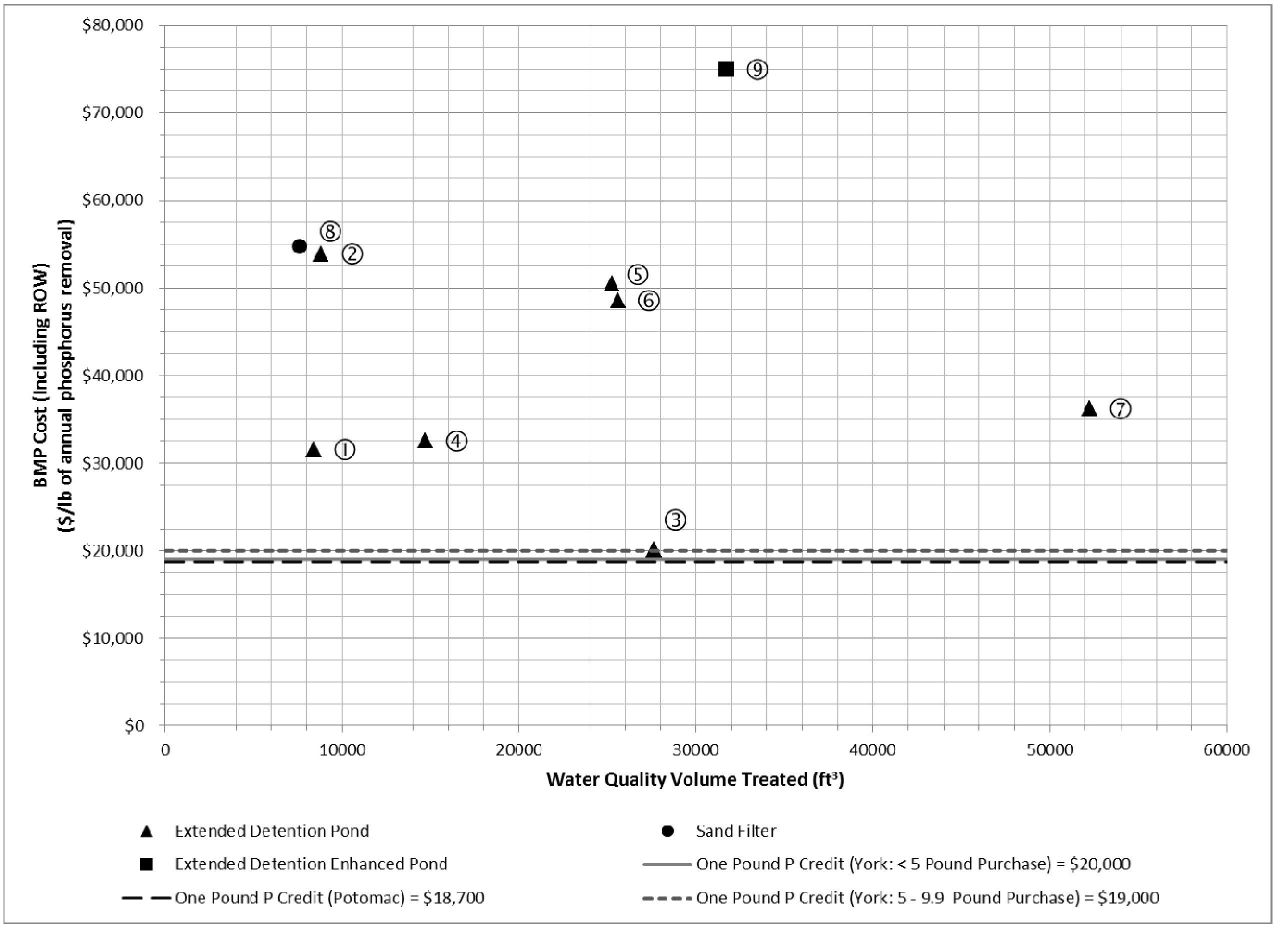


**Figure 4. Comparison of BMP Cost Including ROW to Credit Cost. BMP = best management practice; ROW = right of way.**

There are notable differences in some of the BMP costs despite similar WQV treatment sizes. These differences are attributable to site constraints. The higher cost of BMP 1 in comparison to BMP 2 is due to additional required excavation and the purchase of fill. The higher costs of BMPs 5 and 6 in comparison to BMP 3 are due to installation of a required clay liner. In addition, BMP 5 included a temporary sediment basin.

The recently revised stormwater management guidelines[2] provided by the Virginia Department of Environmental Quality focus on updating water quality treatment sizing; updating the efficiencies of select BMPs; and implementing low-impact development approaches such as vegetated filter strips, grass channels, permeable pavement, infiltration practices, bioretention facilities, filtering practices, constructed wetlands, wet ponds, and dry/wet swales. Water quality treatment sizing will be based on the first 1 inch of rainfall over the entire development site, rather than the previous treatment sizing of the first 0.5 inch of runoff from only the impervious area of the site.[2] These combined revisions to regulations may result in the need for multiple structural and non-structural BMPs to achieve compliance with Virginia water quality standards for stormwater runoff[28] and may make WQT an even more attractive alternative from an economic perspective.

## CONCLUSIONS

- *Based on 19 years of historical data, VDOT could have used between 1 and 63 pounds of phosphorous credits per year and a median of 11 pounds of phosphorous credits per year for the James River watershed if current WQT guidelines had been in place over this period of time.*

- *The results of this study suggest that WQT can be an economically feasible solution for VDOT to manage stormwater quality.* Given the current market rate for phosphorus credits, if VDOT had been able to use WQT in place of constructing the nine structural stormwater best management practices analyzed in this study, VDOT would have realized an average savings of approximately 50% based on the design, build, and maintenance costs. It should be noted that market rates for phosphorus credits may change in the future.

- *Variability in costs, which are dependent on the specifics of any given BMP including the type of BMP, land costs, and construction needs, makes it difficult to generalize savings for specific BMPs prior to construction.* However, the results of this study show that cost savings are magnified for projects that require additional ROW or pose site constraints for onsite BMPs or that require additional materials (e.g., clay liners) for construction of a BMP.

- *More stringent environmental regulations and increasing BMP and land costs are expected in the future and should result in increased cost savings to VDOT for participating in WQT assuming current market rates remain fixed.*

## RECOMMENDATIONS

1. *Based on the economic analysis presented in this study, VDOT's Location and Design Division should continue purchasing stormwater credits for eligible projects, focusing first on projects that require additional ROW or pose site constraints for onsite BMPs or that require additional materials for construction of a BMP.*

2. *Although WQT is economically favorable, to alleviate potential concerns related to overall sustainability (including environmental and social outcomes), VDOT's Location and Design Division should consider requesting further research on these issues.*

## BENEFITS AND IMPLEMENTATION PROSPECTS

The results of this study confirmed that VDOT's participation in WQT to meet part of Virginia's stormwater permitting requirements has the potential to result in considerable savings for VDOT. For all BMPs analyzed in this study, constructing and maintaining the BMP was more expensive than purchasing comparable nutrient credits.

Considering the findings presented here, VDOT will likely expand on its recently initiated practice of purchasing nutrient credits for those projects that are eligible for WQT.

## ACKNOWLEDGMENTS

This study was supported by funds from the Federal Highway Administration. The authors thank VDOT's Location and Design Division for providing the data for this study and Roy Mills and John Olenik of VDOT; Doug Beisch of Stantec; and Amy O'Leary, Linda Evans, and James Gillespie of the Virginia Center for Transportation Innovation and Research for their valuable guidance and feedback.

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