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

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Abstract

Water quality trading (WQT) offers a new option to the Virginia Department of Transportation (VDOT) for achieving sustainable transportation infrastructure systems. Rather than treat runoff from infrastructure projects on-site, as is the common practice now, WQT allows for off-site treatment for projects that meet certain regulatory guidelines. When evaluating WQT from a sustainability perspective, it is important to weigh the economic, environmental, and social impacts of the strategy. As a first step toward this longer term goal, the focus of this study is on the economic feasibility of the VDOT participating in WQT in lieu of constructing on-site structural best management practices (BMPs) to achieve water quality compliance for stormwater runoff for linear development projects. The study includes two objectives: (1) assess annual credit demand for VDOT projects, focusing on the James River watershed as a case study, and (2) conduct a cost evaluation of WQT in lieu of constructing on-site BMPs. Data, including a database of existing BMPs, construction plans, and detailed cost estimates, were provided by VDOT. To asses annual credit demand, details of existing BMPs were reviewed for eligibility to participate in WQT. For the cost evaluation, a cost estimate was calculated for select linear development projects with BMPs and compared to credit costs. In regard to the first study objective, results suggest that annual credit demand for VDOT projects in the James River watershed will be on average 24 pounds of phosphorus credits per year but range annually between one and 63 credits. In regard to the second study objective, results show that there is the potential for approximately 50% cost savings on average with a range of 5% to 75% across the nine BMPs analyzed in this study. Based on these results, we conclude that WQT is an economically attractive option for VDOT at current market rates for nutrient credits. The sustainability of WQT from an environmental and social perspective was not part of this study and should be addressed before broad adoption of WQT.

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1 Introduction

1.1 Background

In the commonwealth of 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 reduced water quality, erosion, and flooding of streams (*1, 2*). Traditionally, stormwater management has focused on on-site structural best management practices (BMPs) with the capacity to temporarily hold and treat runoff (*3*). Structural BMPs are physical structures that are constructed on-site to mitigate the impacts of stormwater runoff. As areas become more urbanized and environmental regulations become stricter, structural BMPs are becoming more expensive (*3*). As a result, stormwater professionals must consider the economic feasibility of achieving stormwater regulations using only on-site structural BMPs (*4*).

Recently a Total Maximum Daily Load (TMDL) was established for the Chesapeake Bay that establishes the maximum allowable annual nitrogen, phosphorus, and sediment loads permitted to enter the Bay (*5*). In response to the Chesapeake Bay TMDL, the Virginia Department of Environmental Quality has expanded its water quality trading (WQT) program. Now in addition to trading between point sources (PS-PS) or point source and nonpoint sources (PS-NPS), it is also possible to trade between nonpoint sources (NPS-NPS). 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 (*6, 7*).

For the Virginia Department of Transportation (VDOT), WQT in lieu of construction of on-site structural BMPs may offer a sustainable water quality management strategy. When considering sustainable stormwater management strategies, it is important to weigh the economic, environmental, and social impacts of the strategy. Within this larger sustainability context, the focus of this study is on the economic aspect of VDOT's participation in WQT, including potential annual credit demand and cost-effectiveness. Constructing on-site BMPs include costs for project development, permitting, purchases of right-of-way (ROW), regulatory review time, construction efforts, and required operation and maintenance (O&M). While there is a perceived opportunity for savings using WQT in lieu of on-site BMPs, no studies have attempted to quantify these potential cost savings by performing a detailed assessment of BMP design, construction, and operation and maintenance (O&M) costs compared to credit pricing in the WQT market.

1.2 Purpose and Scope

The goal of this study is to determine the economic feasibility of VDOT participating in WQT to achieve water quality compliance for stormwater runoff for linear development projects. To achieve this goal, the study includes two objectives: (1) assess potential credit demand for VDOT projects, focusing on the James River watershed as a case study, and (2) conduct a cost evaluation of WQT in lieu of constructing BMPs. This study does not address the environmental and social aspects of WQT, which should be addressed through future work to determine the sustainability of WQT for mitigating impacts due to transportation infrastructure systems.

1.3 Organization of Thesis

The remainder of this thesis is organized as follows. Chapter 2, Literature Review, presents a review of academic and gray literature regarding WQT, participation of other DOTs in WQT, and published costs of BMPs. Chapter 3, Methods, presents the methodology to (1) assess potential credit demand in the James River watershed, and (2) conduct a cost evaluation of WQT in lieu of constructing BMPs to achieve stormwater water quality requirements. Chapter 4, Results and Discussion, aggregates the results and provides a discussion of the results. Chapter 5, Conclusions, presents a summary of the study’s key findings. Appendix A presents a summary of BMP costs from published literature and Appendix B presents the details of the cost evaluation for the selected BMPs in this study.

2 Literature Review

2.1 Overview of WQT

Market-based approaches are increasingly becoming more common to achieve compliance with environmental quality regulations (*8, 9*). Several air quality trading programs, including trading of emissions from leaded gasoline, sulfur dioxide and nitrogen oxides contributing to acid rain, and carbon, have been successfully implemented in the U.S. (*9, 10*). In contrast to these trading programs, the experience with WQT for pollutants is more limited and inherently faces different challenges (*9, 11*). WQT can occur between PS-PS, NPS-NPS, or PS-NPS. To date, the greatest percentage of trading activity by dollar volume has occurred between PS-PS trading (*7*). The majority of studies for WQT focus on an overview of trading programs, credit generation, and trade ratios (*8, 12*), however, little is known about actual cost savings or the environmental (*9, 11, 13*) and social aspects of WQT.

Environmental challenges of WQT include the uncertainty of the equivalency of pollution reduction created by the NPS credit generator, difficulty monitoring NPS credit generators, and the potential creation of localized hotspots (e.g., areas of elevated impaired water quality) (7, *11*). The uncertainty of pollution reduction is attributed to the stochastic nature of runoff from nonpoint sources which can vary greatly spatially and temporally depending on topography, soil characteristics, geology, rainfall, temperature, and vegetative cover. For this reason, most trades are limited spatially (e.g., in the Commonwealth, trades are limited to within a 703 square mile 8-digit hydrologic unit code [HUC]) and may include trade ratios greater than 1:1 to reduce environmental risk. Additionally, monitoring of NPS pollution from credit generators can be difficult, if not impossible, and relies heavily on modeling to estimate pollution reductions (*8, 14, 15*). Modeling can be inaccurate because of the uncertainty of the effectiveness of the NPS pollution reduction strategy or, if the effectiveness is accurate, errors that occur during implementation or O&M of the strategy may lead to reduced efficiencies (*11*). Another inherent challenge to WQT is non-uniform mixing of a pollutant which can lead to localized hotspots, unlike air quality trading where one ton emitted from one location is equivalent to one ton emitted elsewhere (*11*). Trade efficiency issues may arise if impairment of the water quality is non-linearly related to the pollutant concentration (e.g., an endangered species that is sensitive to the pollutant) (*9*). Monitoring of water quality at a local and watershed levels would enable better assessment of environmental performance for areas with WQT (*14*).

Social challenges related to WQT include the willingness of participation in credit generation and public support for WQT. Agricultural farms, a potential source of NPS credit generation, may be hesitant to engage in credit generation for concern that WQT may be a precursor for increased regulation and/or the perception that generators are helping purchasers absolve their responsibility for polluting (*7*). The general public has an increasing interest in water quality, evidenced by the creation of volunteer monitoring programs. Jarvie (1998) suggested that participants work cooperatively with the general public to address concerns and increase transparency of trades to prevent public opposition (*16*).

According to Fisher-Vanden (2013), there are currently 13 active trading and eight active offset programs for water quality. Trading programs are defined as involving multiple recipients and multiple sources. Offset programs are defined as 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 purchasing credits from another source. 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 (*7, 11, 13*). 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 transparently trade (*11*). Clearinghouses and exchange markets reduce transaction costs (*10*). Despite the number of active programs, only a few are trading at a large scale (*11, 13*).

Fisher-Vanden (2013) identified 12 additional inactive trading and offset programs where either a very small amount of trading or offset activity occurred before the program became inactive, or early studies concluded trading would be unsuccessful, or were delayed due to other factors including development of regulations, lack of credit demand, or lack of a drivers such as a TMDL. One program, the Grassland Area Farmers Tradable Loads Program, conducted nine NPS-NPS trades for selenium between 1998 and 1999, however, a regional irrigation reuse program was implemented that reduced selenium levels below the cap eliminating the incentive to trade (*11*). In 2006, research was conducted to examine NPS-NPS trading of water temperature in the Vermillion River, however, agricultural BMPs do not affect temperature and therefore the pool of potential trading participants was reduced effectively increasing transaction costs among participants (*11*).

2.2 DOT Participation in WQT

In 2009, the New Jersey DOT (NJDOT) conducted a feasibility study to assess water quality credit demand and identify a watershed for water quality mitigation banking. Water quality mitigation banking is similar in concept to wetland mitigation banking, that is, that one offsite water quality BMP or "bank" will address the cumulative impacts of multiple NJDOT 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 one imperious acre at a cost of $71,300 with 100% removal (*17*).

The Maryland State Highway Administration implemented a stormwater quality mitigation banking program under a memorandum of understanding with the Maryland DEQ. The banking program can be used for deferral of water quality for new pavement areas of up to five acres located in metropolitan areas and two acres located in rural areas with a ratio of 1.20 acres treated for every one acre of impact (*17, 18*). Similarly, 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 on-site BMPs are difficult to construct. Both Maryland's and Delware's banking programs are for water quality only. Water quantity must be controlled on-site (*17*).

2.3 Cost of Structural Stormwater BMPs

The cost of implementing an on-site structural stormwater BMP includes the costs of 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.

Pre-construction costs may include the costs of site characterization, permitting, and BMP design (*1, 4*). King and Hagen (2011) reported pre-construction costs, defined as discovery, survey, design, permitting, and planning, as ranging from 10% to 40% of construction costs (*19*). EPA (1999) reported pre-construction costs as ranging from 25% (*20*) to 32% (*21*) of construction costs for design, contingencies, and permitting (*1*). The 32% value includes erosion and sediment control during construction.

Construction costs are highly variable and dependent on a number of parameters including design of the BMP, price of materials, labor rates, site conditions, drainage area, required sediment and erosion control during construction, and required landscaping (*1, 19, 22*). For example, identical BMP designs may incur different costs based on the site conditions including soil type, slope, and surrounding land use. If the surrounding land use is residential, then additional landscaping may be required for aesthetics. It should be noted that retrofits may incur higher pre-construction and construction costs (*23*).

ROW costs can be a significant contributor to the total cost of a BMP, especially in ultra-urban settings (*4, 19, 22*). An ultra-urban environment is a highly urbanized area that has little or no space available for new development due to existing development and land acquisition costs are high; the term was first used in Alexandria, Virginia (*4*). In contrast, land acquisition costs in rural areas can be minimal compared to the other costs of implementing a BMP. Due to the variability of the land area requirements for each BMP and land acquisition costs, ROW costs for BMPs are difficult to estimate (*22*). Weiss (2012) provided land area requirements for select BMP types as a percentage of impervious area treated.

Routine maintenance is critical to ensure the BMP is functioning at its desired performance level and its effectiveness is not being compromised (*4*). Routine O&M practices can include inspections, sediment management, trash and debris removal, and vegetation management (*4*). The costs of routine O&M depend on the BMP type, complexity and frequency of maintenance, and hydrology (*22*). Previous studies have not documented data with actual O&M costs for BMPs; however, often, O&M costs are estimated as a percentage of the construction cost (*1, 22*). Non-routine maintenance includes unpredictable repairs such as rehabilitation of a BMP following a major rainfall event. The useful lifetime of a BMP is strongly dependent on consistent maintenance; however, DOTs can lack the resources for consistent upkeep (*4*). The majority of studies define a BMP's design life as 20 years (*19, 22, 24*).

According to a National Cooperative Highway Research Program (NCHRP) report (2013), the majority of DOTs do not have an adequate system to track implementation costs of a BMP over its lifetime (*23*). In an interview of 12 DOTs, only two of the DOTs recorded BMP costs: North Carolina DOT (NCDOT) and Washington State DOT (WSDOT). As a requirement of NCDOT separate storm sewer system (TS4) permitting, NCDOT tracks design, capital, and O&M costs for retrofit projects. WSDOT tracks design, capital, and land acquisition costs every 3 years in their Environmental Mitigation Study and is developing a tracking system for O&M costs. Neither of these DOTs track the costs at the individual BMP levels; rather, capital and O&M costs are rolled into project-level or programmatic-level budgets (*23*).

Planning-level cost estimates are available for most agricultural and some urban BMPs, however, there is limited cost estimate data for linear development BMPs because no systematic reporting system exists due to differing regulatory requirements, design standards, and labor, land acquisition, and material costs (*19, 23*). As a result, cost estimates available for BMPs typically used in linear development projects tend to be site-specific. Appendix A presents a summary in tabular form of published cost estimates for BMPs that are typically implemented in linear development projects. Synthesizing the published data is difficult due to the inconsistent cost estimating approaches, reporting units, and BMP naming conventions (*23*).

3 Methods

3.1 Assessment of Potential Credit Demand

To assess potential credit demand, details of existing BMPs constructed by VDOT for linear development projects located in the James River watershed were reviewed for eligibility to participate in WQT to achieve 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 of 1,783 existing stormwater BMPs previously constructed in Virginia from 1977 to 2014 was provided by VDOT. The database included details for each BMP such as type, date installed, location (coordinates and 12-digit HUC), and treatment purpose (water quality or quantity). The BMP coordinates were mapped in a geographic information system (GIS) and the 12-digit HUC listed in the database was compared with 6-digit (3rd order) HUC boundaries obtained from the United States Geological Survey (*25*) and 12-digit (6th order) HUC boundaries obtained from the Virginia Department of Conservation and Recreation National (*26*) to ensure accuracy of the BMP location. A query identified 1,336 BMPs that were constructed to treat water quality with 314 of those BMPs being located in the 6-digit HUC James River basin. Figure 1 presents the 6-digit HUC basins in Virginia and the locations of the three linear development projects that contained the nine BMPs selected for a cost estimate as described in Section 3.2. BMPs that provided both water quality and water quantity treatment were excluded from analysis under the assumption that the BMP would be required to mitigate water quantity regardless.

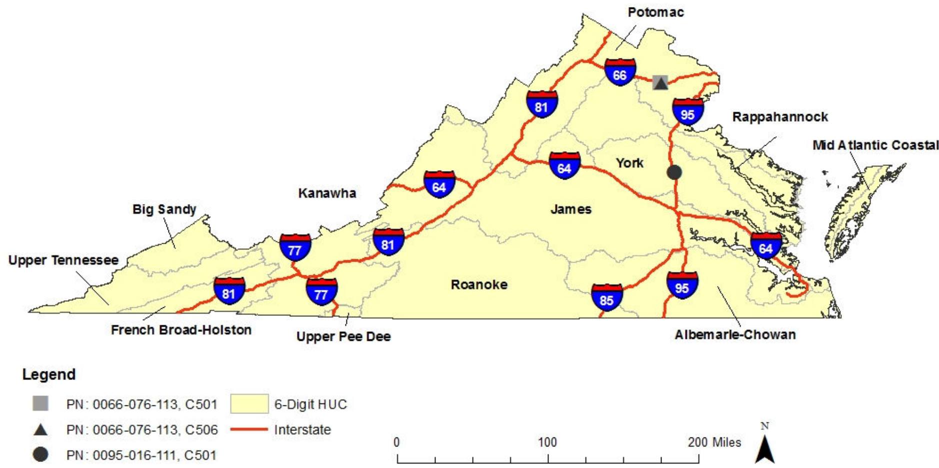

FIGURE 1 Watershed and BMP Locations

3.1.1 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 (*27*). The method is widely used in practice and is the preferred method of estimating pre- and post-development pollutant loading in accordance with the Virginia Stormwater Management Handbook (*27*). The method, provided in Equation 1, estimates the annual phosphorus load due to stormwater runoff in urban areas.

$$L = P \times P_j \times [0.05 + (0.009 \times I)] \times C \times A \times 2.72 \div 12 \quad (1)$$

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 estimated annual phosphorus load from runoff from one impervious acre was calculated using Equation 2:

$$L = [0.05 + (0.009 \times I)] \times A \times 2.28 = [0.05 + (0.009 \times 100\%)] \times 1\ acre \times 2.28 \tag{2}$$
$$= 2.17\ pounds/acre/year.$$

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

$$L_{BMP} = A_{BMP} \times L \tag{3}$$

where

L_{BMP} = annual phosphorus load entering the BMP (pounds),

A_{BMP} = impervious area treated by the BMP (acres),

L = annual phosphorus load from one impervious acre (pounds) = 2.17 pounds.

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 (*27*).

$$L_{removed} = L_{BMP} \times Eff_{BMP} \tag{4}$$

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:

$$L_{removed/project} = L_{removed/BMP_1} + L_{removed/BMP_2} + \cdots L_{removed/BMP_n} \quad (5)$$

3.1.2 Eligibility for WQT

In accordance with Code of Virginia § 62.1-44.15:35, WQT may be used to achieve water quality requirements for a specific linear construction project, under the following scenarios: (1) less than five 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 on-site BMPs, but full compliance with removal requirements cannot practicably met on-site. NPS-NPS credits are traded at a 1:1 ratio, are perpetual, and 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.

Trading scenarios (2) and (3) above were applied to the existing projects in the James River watershed. If the total phosphorus removed on a project was less than 10 pounds, then 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, then it was assumed that 25% of the amount was eligible for WQT.

3.2 Cost Evaluation of Stormwater Water Quality Compliance

In this study we define BMP cost as the 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 total dollars as well as unit costs, were determined for comparison to the cost of WQT. Unit costs are defined as the BMP cost per a water quality volume (WQV) and per a pound of phosphorus removal. The data used and steps taken to produce the cost estimates for the BMPs are described below.

A query identified 1,336 BMPs that were constructed to treat water quality with 1,193 of those BMPs identified as extended detention basins. Three linear development projects with a total of nine existing BMPs were selected for a cost estimate (see Figure 1 for project location and Table 1 for BMP properties). These BMPs were selected to represent a range of BMP types, sizes, and were limited to BMPs constructed in the past ten years. PN 0066-016-111, C501 focused on relocating Route 652. The project included construction of three extended detention basins for management of stormwater quality in 2008 (BMP IDs 1 – 3 in Table 1). Project Number (PN) 0066-076-113, C501 focused on improving I-66 by widening of 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 (BMP IDs 4 – 7 in Table 1). PN 0066-076-113, C506 focused on reconstruction of an interchange for I-66. The project included construction of an enhanced extended detention basin and sand filter for management of stormwater quality in 2004 and 2005 (BMP IDs 8 and 9 in Table 1). In addition to the BMP database, VDOT provided construction site plans, construction materials and costs (including labor), and ROW parcel sizes and costs pertaining to these projects.

TABLE 1 BMP Properties

ID	BMP Type	4-digit HUC	Impervious Area Treated (acres)	WQV Treated (ft^3)	Annual P Removal (lbs)	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%

Notes:
P = phosphorus
Superscript indicates PN and functional class. $_a$ = PN 0066-016-111, C501 (rural collector rolling undivided), $_b$ = PN 0066-076-113, C501 (rural principal arterial), and $_c$ = PN 0066-076-113, C506 (urban minor arterial).

3.2.1 Construction Cost

For each of the nine BMPs, we used VDOT construction plans to determine 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 include labor (John Olenik, personal communication, March 28, 2014). Construction costs were determined by summing the cost of the materials used to construct each BMP.

3.2.2 Pre-Construction Cost

In this study, pre-construction costs are defined as design, permitting, and contingency costs and were assumed to be 32% of the construction costs (*24*).

3.2.3 ROW Cost

In this study, we determined the minimum required ROW for each BMP by measuring the BMP footprint provided by 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 occupies.

3.2.4 Annual O&M Cost

In this study, 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 are based on the average values provided by the Preliminary Data Summary of Urban Storm Water BMPs (*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 for a 20 year lifetime was discounted using Equation 6 and a rate of 3% to determine the value of O&M at the time of construction.

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \tag{6}$$

where

P = present value ($),

A = annual payment ($),

i = discount rate (%) = 3%,

n = number of payment periods = 20.

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% (*28*). Real discount rates used by States historically have ranged from 3% to 5% (*28*).

3.2.5 Total BMP Cost

Pre-construction, construction, ROW, and O&M costs were adjusted for inflation to 2014 dollars using Equation 7 with Engineering News Record's construction cost indexes (CCI) and summed to determine BMP cost. The annual inflation rates ranged from 4.65% to 2.65% for years 2004 to 2014.

$$2014\ Cost = Installation\ Year\ Cost\ \times \frac{2014\ CCI}{Installation\ Year\ CCI} \tag{7}$$

where:

CCI for 2004 = 6957, CCI for 2005 = 7563, CCI for 2006 = 7695, CCI for 2008 = 8623, and CCI for 2014 = 9800.

3.2.6 Unit BMP Cost

3.2.6.1 Per Cubic Foot of WQV

For comparison to previously published BMP costs, the BMP cost was divided by the WQV treated to determine the BMP cost per cubic foot of WQV. The WQV was determined using Equation 6:

$$WQV = \left(\times P \times R \times A \times DV \times 43560 \frac{ft^2}{acre} \times 12 \frac{in}{ft}\right) \quad (8)$$

where

WQV = water quality volume (ft^3)

P = precipitation depth (inches) = ½,

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) (*27*).

3.2.6.2 Per Pound of Annual Phosphorus Removal

For comparison to phosphorus credit costs, the BMP cost was divided by the annual phosphorus removal to determine BMP cost per pound of annual phosphorus removal.

3.2.7 Phosphorus Credit Cost

VDOT procured fixed prices for one pound phosphorus credits in the James, Potomac, Rappahannock, and York watersheds labor (John Olenik, personal communication, June 25, 2014). A one pound credit in the James and Potomac watersheds cost $10,430 and $18,700, respectively. A one pound credit in the York and Rappahannock watersheds both have sliding scales ranging from $17,000 to $20,000 and $14,700 to $16,450, respectively. The cost of credits 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.

4 Results

4.1 Assessment of Potential Credit Demand

Table 2 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 on-site construction to achieve 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. Twenty-four pounds reflects the average phosphorous removal eligible for credit trading during the 19 year period reflected in the BMP database whereas 0.6 and 62.9 pounds are the minimum and maximum annual phosphorous removal eligibility for credit trading, respectively, during the same period.

TABLE 2 Annual Phosphorus Removal Eligible for WQT

BMP Installation Date (Year)	Total Annual Phosphorus Removal by BMPs (lbs)	Annual Phosphorus Removal Eligible for WQT		
		Scenario 2 (lbs)	Scenario 3 (lbs)	Total (lbs)
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

TABLE 2 Annual Phosphorus Removal Eligible for WQT

BMP Installation Date (Year)	Total Annual Phosphorus Removal by BMPs (lbs)	Annual Phosphorus Removal Eligible for WQT		
		Scenario 2 (lbs)	Scenario 3 (lbs)	Total (lbs)
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

4.2 Cost Evaluation of Stormwater Water Quality Compliance

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 significant variability in these costs. The costs are normalized by pounds of annual phosphorus removal for comparison with WQT market prices. Details of each BMP and the costs are provided in Appendix B.

TABLE 3 BMP Costs

ID	Pre-Construction	Construction	Lifetime O&M	ROW	Total		Per Pound of Annual P Removal	
					Excluding ROW	Including ROW	Excluding ROW	Including 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

The cost estimates for construction and O&M for each BMP were compared to previously published literature using an established relationship between WQV and BMP cost (*22, 29*). Figure 2 presents our cost estimates compared to published costs of extended detention ponds. The data points in Figure 2 represent our cost estimates, the dashed line represents the average published BMP cost, and the solid line on either side represents the 67% confidence interval of published BMP costs. Table 4 presents the comparison for enhanced extended detention ponds and sand filters. All BMPs, with the exception of the enhanced extended detention basin, are within the 67% confidence intervals of previously published costs. The enhanced extended detention basin was compared to a constructed wetland since there was no established relationship for an enhanced extended detention basin.

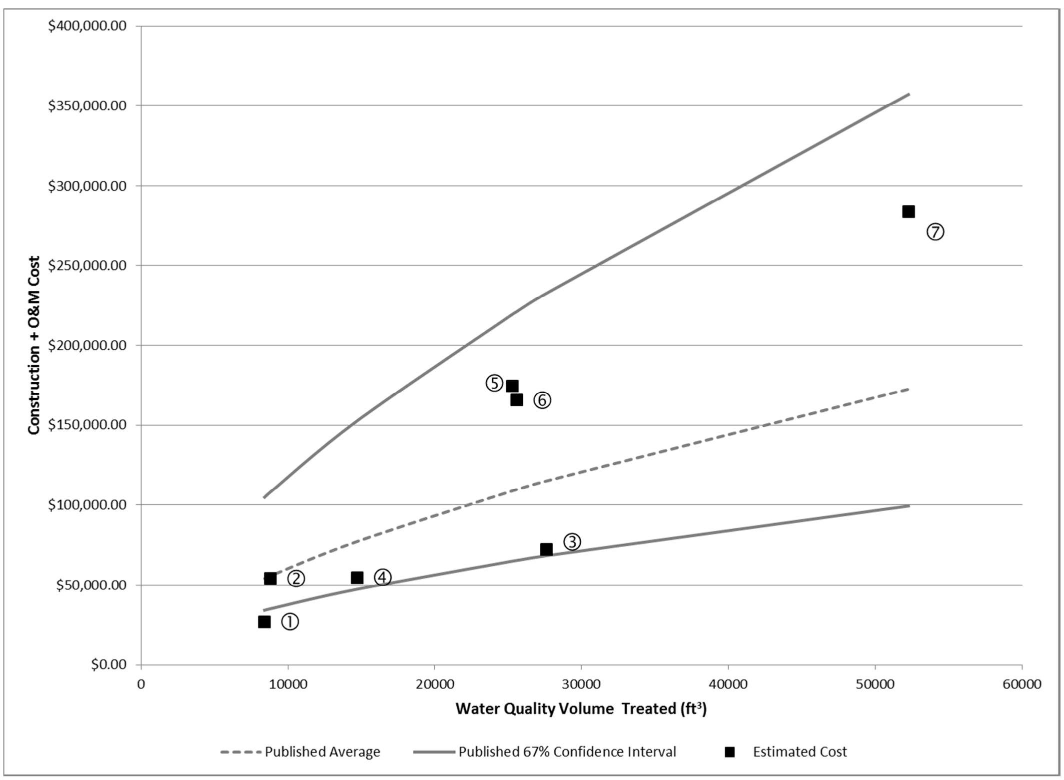

FIGURE 2 Estimated versus Published Costs of Extended Detention Basins

TABLE 4 Estimated versus Published Costs for Sand Filter and Extended Detention Enhanced Basin

		Construction + O&M Cost			
ID	BMP Type	Unit 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

Note: CI = confidence interval

Table 5 and Figures 3 and 4 compare the BMP cost estimates excluding and including ROW to the cost of one pound of phosphorus credit. In the hypothetical scenario where participation in WQT in lieu of construction of these BMPs were available at the time of the BMP's construction, participation in the WQT program 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%.

TABLE 5 Cost Savings

		Cost Savings	
ID	Credit Cost	Excluding ROW	Including ROW
①	$20,000	-7.84%	36.59%
②	$20,000	43.71%	62.88%
③	$19,000	-25.39%	5.46%
④	$18,700	13.45%	42.46%
⑤	$18,700	53.31%	62.95%
⑥	$18,700	50.18%	61.49%
⑦	$18,700	40.68%	48.34%
⑧	$18,700	59.99%	65.85%
⑨	$18,700	65.91%	75.05%
Median		43.71%	61.49%
Average		32.66%	51.23%

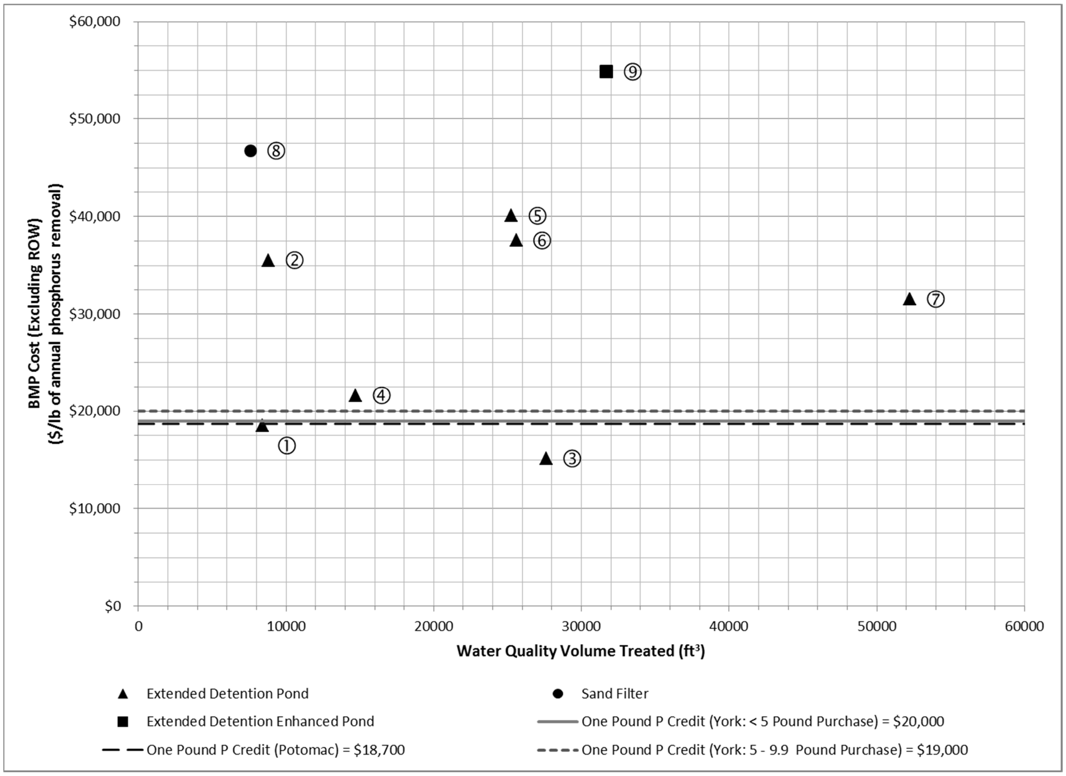

FIGURE 3 BMP Cost (Excluding ROW) versus Credit Cost

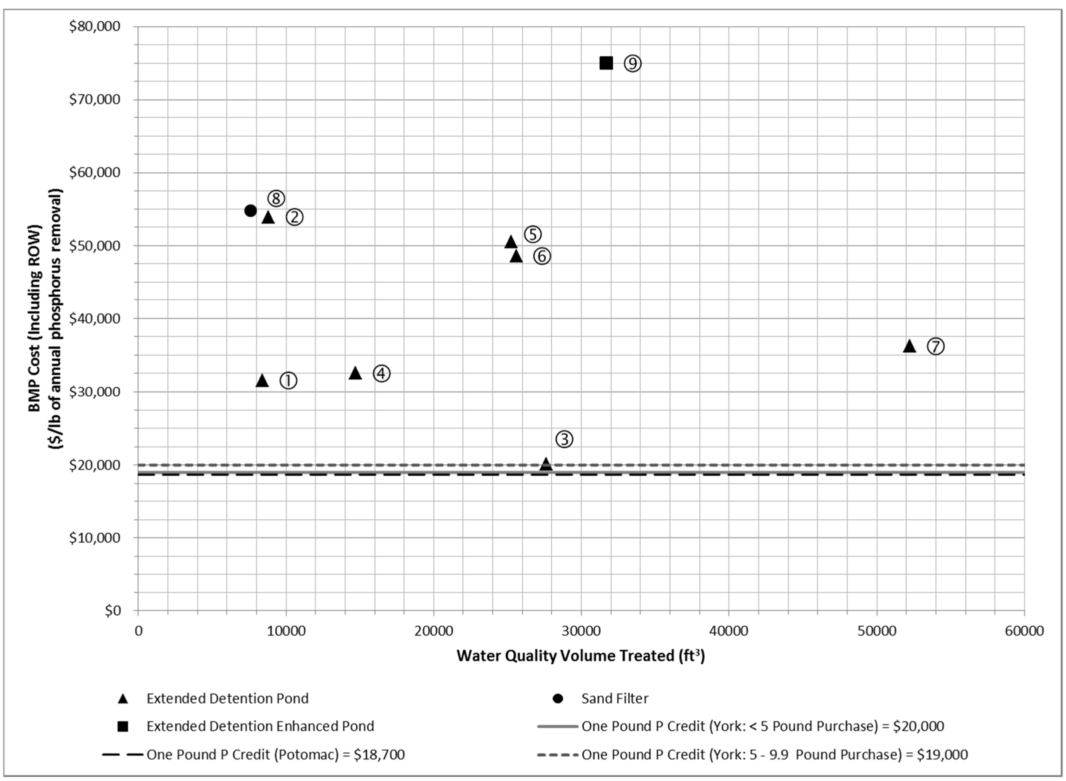

FIGURE 4 BMP Cost (Including ROW) versus Credit Cost

A number of variables influence BMP costs including location, type, WQV treatment size, purchase of ROW, and site constraints which control design and construction. In general, as BMP designs become more elaborate, the cost of the BMP increases. For example, in order of simple to more elaborate designs, the cost of an extended detention basin is less than the cost of a sand filter and both are less than the cost of an enhanced extended detention basin. Additionally, as the WQV treatment size increases, the footprint of an above-ground BMP increases. ROW costs can be a significant contributor to the overall cost of BMP, if additional land is required for construction of the BMP. For the nine BMPs analyzed in this study, ROW increased the cost of the BMP per pound of annual phosphorus removal by 15% to 70%. As mentioned previously, land acquisition costs in urban areas are more expensive in comparison to rural areas as illustrated by the 11% increase in the average parcel cost per acre in the more urbanized Potomac versus York watershed.

Despite similar WQV treatment sizes for some of the extended detention ponds, there are notable differences in some of the BMP costs. BMPs 1 and 2 were both constructed for PN 0095-016-111, C501 and have similar WQV treatment sizes, however, BMP 2 is 48% more expensive per a pound of annual phosphorus removal (excluding ROW) than BMP 1. The additional expense can be attributed to the following differences in construction: (1) BMP 2 required an excavation volume (460 yd^3) beyond the WQV (~327 yd^3), whereas BMP 1 required an excavation volume (233 yd^3) that was slightly less than the WQV (~312 yd^3), (2) BMP 2 required a partial purchase of 738 yd^3 of fill at approximately $15,000, whereas BMP 1 was able to reuse excavated material to meet its fill requirements, and (3) despite similar quantities of erosion control stone for both BMPs (12 tons for BMP 1 and 16 tons for BMP 2), the stone types used for BMP 2 were approximately 38% more expensive than the stone type used for BMP 1. Although BMPs 3 (PN 0095-016-111, C501) and BMPs 5 and 6 (PN 0066-076-113, C501) were constructed for different projects, the BMPs all have similar WQV treatment sizes, but BMPs 5 and 6 are 62% and 60%, respectively, more expensive per a pound of annual phosphorus removal (excluding ROW) than BMP 3. BMP 5 required an excavation volume (3,322 m^3) beyond the WQV (716 m^3) at a cost of approximately $42,000 in comparison to BMP 6 with a WQV of 724 m^3 and an excavation volume of 686 m^3 at a cost of approximately $8,700. Additionally, BMP 5 required excavation for a temporary sedimentation basin at a cost of approximately $21,000. A significant contributor to the overall cost of BMP 6 was the installation of a pond clay liner at approximately $86,000. Other additional construction items that were required for BMPs 5 and 6 in comparison to BMP 3 include concrete cradles, cable barricades, aggregate, rip rap, impervious clay liners and cut-off walls, riser structures, and excavation for siltation control. These differences in construction are likely attributed to site constraints.

Currently, Virginia is revising its stormwater regulations (*30*). The proposed regulations focus on updating water quality treatment sizing, updating the efficiencies of select BMPs, and implementing low-impact development approaches (LIDs) 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 size of the first 0.5-inches of runoff from only the impervious area of the site (*2*). Cost estimates with the updated BMP efficiencies are provided in Appendix B. These combined alterations to regulations may result in the need for multiple structural and non-structural BMPs to achieve water quality compliance (*30*) and may make WQT an even more attractive alternative from an economic perspective.

5 Conclusions

The first study objective was to estimate credit demands by analyzing past BMP construction projects and applying current regulatory guidelines to determine if these projects would have qualified for WQT if they were constructed today. Based on this analysis that included 19 years of historical data, VDOT could have used between one and 63 pounds of phosphorous credits per year and on average 24 pounds of phosphorous credits per year for the James River watershed alone. A similar analysis could be conducted for other river basins in Virginia in order to estimate state-wide annual credit needs.

The second study objective was to estimate cost savings of on-site stormwater treatment using BMPs versus off-site treatment through WQT. Judging from estimates of the total cost (including land acquisition, design, construction, and O&M) of nine BMPs analyzed in this study, there is the potential for approximately 5% to 75% and on average 50% cost savings when comparing nutrient credit trading to the total BMP cost. We found significant variability in costs even for BMPs designed to treat the same runoff volume that are dependent on the specifics of any given BMP including the type of BMP, need for additional ROW, land costs, and construction needs. This makes the task of estimating the cost of BMP cost prior to construction difficult. However, the primary variables driving construction costs for the nine BMPs analyzed in this study are excavation, fill, clay liners, and excavation for temporary sediment basins. Knowing these costs before constructing a BMP can aid the decision between on- and off-site treatment for a given project. Cost savings may be magnified for projects that require additional ROW or pose site constraints that require additional materials (e.g., clay liners) for construction of a BMP. Also, we caution that our results depend on the current WQT market rates that may increase in the future.

In conclusion, participation in WQT at current market rates in lieu of constructing on-site structural BMPs appears to be an economically attractive option for management of stormwater quality and should offer cost savings to VDOT. Despite the economic attractiveness of WQT, the overall sustainability of trading should be studied through future research including the benefits and drawbacks of WQT from both environmental and social perspectives.

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Appendix A
Published Construction and Operation and Maintenance Costs

Bioretention basin (bioretention filter, bioretention area)

		Construction Cost ($)							
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Units**	**Year**	**Location**	**Reference**
1	Bioretention (new construction in surburban area)	NA	NA	$46,875	NA	impervious acre treated	2011	Maryland	*16*
2	Bioretention (retrofit in urban area)	NA	NA	$183,750	NA	impervious acre treated	2011	Maryland	*16*
3	Bioretention	NA	NA	$5.30	NA	ft^3 of WQV	1997	20 cities average	*1*
4	Bioretention (treating 5 acres of commerical area with 65% impervious cover)	NA	NA	$60,000	NA	BMP	1997	20 cities average	*1*
5	Bioretention basin (900 ft^2 cell treating first ½ in of runoff)	NA	NA	$15,000	NA	½ impervious acre treated	2005	Chesapeake Bay Program	*27*
6	Bioretention basin	NA	NA	$76,748	27903x + 48785	BMP	2010	Unknown	*20*
7	Bioretention	NA	NA	0.0001 * WQV + 9.00022	NA	WQV	2006	Unknown	*20*
8	Bioretention	NA	NA	$10,000	NA	impervious acre treated	1996	Unknown	*28*
9	Bioretention filter	NA	NA	$\beta_0(WQV)^{\beta 1}$	NA	ft^3 of WQV	2005	USEPA rainfall zone 1	*19*

Notes:

[1] Includes pre-construction costs of $9,375 for site discovery, planning, design, surveys, permitting, etc.

[2] Includes pre-construction costs of $52,500 for site discovery, planning, design, surveys, permitting, etc.

[4] Base capital cost for typical implementation. Total capital cost can typically be determined by increasing by 30%.

[5] Includes 50% contingency to account for additional excavation and materials needed to provide storage for larger storm events.

[6] Where x = impervious drainage area (acres).

[9] Where WQV = water quality volume (ft^3) and Table 2.2 in reference provides β values.

NA = not applicable

Bioretention basin (bioretention filter, bioretention area)

No.	BMP Type Listed in Reference	O&M Cost ($) Min	Max	Avg	Actual	Fraction of Construction Cost	Units	Year	Location	Reference
1	Bioretention (new construction in surburban area)	NA	NA	$1,500	NA	NA	annually	2011	Maryland	*16*
2	Bioretention (retrofit in urban area)	NA	NA	$1,500	NA	NA	annually	2011	Maryland	*16*
3	Bioretention	NA	NA		NA	5-7%	annually	1999	Unknown	*1*
4	Bioretention (treating 1 acre)	NA	NA	$1,475	NA	NA	annually	2009	New Castle Co, Delaware	*31*
5	Bioretention basin (900 ft^2 cell)	NA	NA	$550	NA	NA	annually	2005	Chesapeake Bay Program	*27*
6	Bioretention	NA	NA	NA	NA	5%	annually	2006	Unknown	*21*
7	Bioretention	NA	NA	NA	NA	0.7-10.9%	annually	Unknown	Unknown	*19*

Notes:
NA = not applicable

Constructed wetland (wetland, stormwater wetland, emergent wetland)

No.	BMP Type Listed in Reference	Construction Cost ($) Min	Max	Avg	Actual	Units	Year	Location	Reference
1	Constructed wetland	$0.60	$1.25	NA	NA	ft^3 of WQV	1997	20 cities average	*1*
2	Wetland (treating 50 acre residential site with 35% impervious cover)	NA	NA	$125,000	NA	BMP	1997	20 cities average	*1*
3	Retention basin and wetland	NA	NA	$18.5V^{0.70}$	NA	BMP	1997	NA	*1*
4	Stormwater wetland	NA	NA	$75,407	25157x - 7191	BMP	2010	Unknown	*20*
5	Constructed wetland	NA	NA	$53.211 * WQV^{-0.3576}$	NA	WQV	2006	Unknown	*20*
6	Emergent wetland w/ sediment forebay	$26,000	$55,000	NA	NA	acre of wetland	1999	Unknown	*29*
7	Constructed wetland	NA	NA	$\beta_0(WQV)^{\beta 1}$	NA	ft^3 of WQV	2005	USEPA rainfall zone 1	*19*

Notes:

[1] Limited cost data on wetlands so construction cost is assumed to be 25% more than retention basin cost.

[2] Base capital cost for typical application. Total capital cost can typically be determined by increasing by 30%.

[3] Where V = total basin volume (ft^3).

[4] Where x = impervious drainage area (acres).

[7] Where WQV = water quality volume (ft^3) and Table 2.2 in reference provides β values.

NA = not applicable

Constructed wetland (wetland, stormwater wetland, emergent wetland)

		O&M Cost ($)								
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Fraction of Construction Cost**	**Units**	**Year**	**Location**	**Reference**
1	Retention basin and constructed wetland	NA	NA	NA	NA	3-6%	annually	1999	Unknown	*1*
2	Constructed wetland	NA	NA	NA	NA	2%	annually	1999	Unknown	*1*
3	Constructed wetland	NA	NA	NA	NA	4-14.1%	annually	Unknown	Unknown	*19*

Notes:
NA = not applicable

Dry swale (bioswale, bioinfiltration swale)

		Construction Cost ($)							
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Units**	**Year**	**Location**	**Reference**
1	Bioswale	NA	NA	$42,000	NA	impervious acre treated	2011	Maryland	*16*
2	Bioswale (900 sf)	NA	NA	$10,000	NA	½ impervious acre treated	2005	Chesapeake Bay Program	*27*
3	Bioinfiltration swale	$24,546	$100,488	$57,818	NA	BMP	1999	Unknown	*20*
4	Bioinfiltration swale	$182	$2,005	$752	NA	m^3 of WQV	1999	Unknown	*20*
5	Bioinfiltration swale (retrofit)	$182	$2,005	$968	NA	m^3 of design storm treated	2009	California	*4*
6	Swale	$267	$827	$470	NA	m^3 of design storm treated	2009	Unknown	*4*
7	Dry and wet swale (10 ft bottom width, 3:1 side slopes, 1 ft ponding depth)	NA	NA	$1,500	NA	acre treated	1992	Unknown	*28*

Notes:

[1] Includes pre-construction costs of $12,000 for site discovery, planning, design, surveys, permitting, etc.

[5,6] To convert from $/m³ to $/acre-ft multiply by 1233.6.

NA = not applicable

Dry swale (bioswale, bioinfiltration swale)

		O&M Cost ($)								
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Fraction of Construction Cost**	**Units**	**Year**	**Location**	**Reference**
1	Bioswale	NA	NA	$900	NA	NA	annually	2011	Maryland	*16*
2	Bioswale	NA	NA	$200	NA	NA	annually	2005	Chesapeake Bay Program	*27*
3	Bioinfiltration swale	NA	NA	NA	$2,236	NA	annually	2004	Unknown	*20*
4	Bioinfiltration swale (retrofit)	NA	NA	NA	$95	NA	annually per m^3 of design storm treated	2009	California	*4*

Notes:

[3] This includes equipment and materials only. It is estimated that 246 labor hours is required annually.

[4] To convert from $\$/m^3$ to $/acre-ft multiply by 1233.6.

NA = not applicable

Extended detention basin (dry pond, detention pond, extended detention pond)

No.	BMP Type Listed in Reference	Construction Cost ($) Min	Max	Avg	Actual	Units	Year	Location	Reference
1	Dry extended detention pond (new)	NA	NA	$39,000	NA	impervious acre treated	2011	Maryland	*16*
2	Dry extended detention pond (retrofit)	NA	NA	$67,500	NA	impervious acre treated	2011	Maryland	*16*
3	Retention & detention basin	$0.50	$1		NA	ft^3 of WQV	1997	20 cities average	*1*
4	Detention basins	NA	NA	$7.47V^{0.78}$	NA	BMP	1997	NA	*1*
5	Dry detention basin	NA	NA	$41,541	1064.5x + 39592	BMP	2010	Unknown	*20*
6	Dry pond	NA	NA	$97.338 * WQV^{-0.3843}$	NA	WQV	2006	Unknown	*20*
7	Extended detention basin	$91,035	$356,300	$172,737	NA	BMP	1999	Unknown	*20*
8	Extended detention basin	$303	$1,307	$590	NA	m^3 of WQV	1999	Unknown	*20*
9	Extended detention basin (retrofit)	$390	$1,683	$760	NA	m^3 of design storm treated	2009	California	*4*
10	Pond (retrofit)	$38	$367	$113	NA	m^3 of design storm treated	2009	Unknown	*4*
11	Detention basin	NA	NA	$2.195 * 10^4V^{0.69}$	NA	BMP	1999	Unknown	*30*
12	Extended dry detention pond	NA	NA	$168.39 * V^{0.69}$	NA	BMP	1995	Unknown	*28*
13	Dry detention basin	NA	NA	$\beta_0(WQV)^{\beta 1}$	NA	ft^3 of WQV	2005	USEPA rainfall zone 1	*19*

Notes:

[1] Includes pre-construction costs of $9,000 for site discovery, planning, design, surveys, permitting, etc.

[2] Includes pre-construction costs of $22,500 for site discovery, planning, design, surveys, permitting, etc.

[4] Where V = total basin volume (ft^3).

[5] Where x = impervious drainage area (acres).

[9,10] To convert from $/$m^3$ to $/acre-ft multiply by 1233.6.

[11] V = volume of storage (ml).

[12] V = volume of storage (m^3).

[13] Where WQV = water quality volume (ft^3) and Table 2.2 in reference provides β values.

NA = not applicable

Extended detention basin (dry pond, detention pond, extended detention pond)

		O&M Cost ($)								
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Fraction of Construction Cost**	**Units**	**Year**	**Location**	**Reference**
1	Dry extended detention pond (new)	NA	NA	$1,200	NA	NA	annually	2011	Maryland	*16*
2	Dry extended detention pond (retrofit)	NA	NA	$1,200	NA	NA	annually	2011	Maryland	*16*
3	Detention basin	NA	NA	NA	NA	<1%	annually	1999	Unknown	*1*
4	Dry pond (treating 20 acres)	NA	NA	$600.50	NA	NA	annually per acre	2009	New Castle Co, Delaware	*31*
5	Extended detention basin	NA	NA	NA	$958	NA	annually	2004	Unknown	*20*
6	Extended detention basin (retrofit)	NA	NA	$107	NA	NA	annually per m^3 of design storm treated	2009	California	*4*
7	Detention basin	NA	NA	NA	NA	1.8-2.7%	annually	Unknown	Unknown	*19*

Notes:

[5] This includes equipment and materials only. It is estimated that 188 labor hours is required annually.

[6] To convert from $/m^3 to $/acre-ft multiply by 1233.6.

NA = not applicable

Sand filter (Austin filter, Delaware filter, storm filter, media filter)

No.	BMP Type Listed in Reference	Construction Cost ($) Min	Max	Avg	Actual	Units	Year	Location	Reference
1	Above ground sand filter	NA	NA	$49,000	NA	impervious acre treated	2011	Maryland	*16*
2	Below ground sand filter	NA	NA	$56,000	NA	impervious acre treated	2011	Maryland	*16*
3	Sand filter	$3	$6	NA	NA	ft^3 of WQV	1997	20 cities average	*1*
4	Sand filter (treating 5 acre commercial area with 65% impervious cover)	$35,000	$70,000	NA	NA	BMP	1997	20 cities average	*1*
5	Delaware sand filter	NA	NA	$23,500	NA	BMP	1994	Alexandria, VA	*1*
6	Filtration device (installed at two stormwater inlets)	NA	NA	$8,000	NA	½ impervious acre treated	2005	Chesapeake Bay Program	*27*
7	Surface sand filter	NA	NA	$30,000	NA	½ impervious acre treated	2005	Chesapeake Bay Program	*27*
8	Sand filter	NA	NA	$389 * WQV^{-0.3951}$	NA	WQV	2006	Unknown	*20*
9	Austin sand filter	$203,484	$314,346	$242,799	NA	BMP	1999	Unknown	*20*
10	Austin sand filter	$746	$2,118	$1,447	NA	m^3 of WQV	1999	Unknown	*20*
11	Storm filter (retrofit)	NA	NA	$2,024	NA	m^3 of design storm treated	2009	California	*4*
12	Delaware sand filter (retrofit)	NA	NA	$2,462	NA	m^3 of design storm treated	2009	California	*4*
13	Austin sand filter (retrofit)	$746	$2,118	$1,863	NA	m^3 of design storm treated	2009	California	*4*
14	Structural sand filter (retrofit)	$601	$827	$752	NA	m^3 of design storm treated	2009	Unknown	*4*
15	Underground sand filter (retrofit)	$1,052	$2,818	$2,442	NA	m^3 of design storm treated	2009	Unknown	*4*
16	Sand filter	NA	NA	K_1A	NA	BMP	1999	Unknown	*30*
17	Austin surface sand filter	$3,400	$16,000	NA	NA	impervious acre treated	1994	Unknown	*28*
18	Delaware underground sand filter	$10,000	$14,000	NA	NA	impervious acre treated	1994	Unknown	*28*
19	Austin sand filter	NA	NA	$18,500	NA	impervious acre treated	1997	Unknown	*29*
20	Sand filter (Austin, Delaware, undefined)	NA	NA	$\beta_0(WQV)^{\beta 1}$	NA	ft^3 of WQV	2005	USEPA rainfall zone 1	*19*

Notes:

[1] Includes pre-construction costs of $14,000 for site discovery, planning, design, surveys, permitting, etc.

[2] Includes pre-construction costs of $16,000 for site discovery, planning, design, surveys, permitting, etc.

[3] Range in cost is due to different filter types. Perimeter sand filters are moderate cost and surface/underground filters are most expensive.

[4] Range in cost is due to different filter types. Perimeter sand filters are dmoderate cost and surface/underground filters are most expensive.

[11,12,13,14,15] To convert from $/$m^3$ to $/acre-ft multiply by 1233.6.

[16] Where A = impervious surface (ha) and K_1 = 27,700 to 55,300 (a constant).

[20] Where WQV = water quality volume (ft^3) and Table 2.2 in reference provides β values.

NA = not applicable

Sand filter (Austin filter, Delaware filter, storm filter, media filter)

		O&M Cost ($)								
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Fraction of Construction Cost**	**Units**	**Year**	**Location**	**Reference**
1	Above ground sand filter	NA	NA	$1,400	NA	NA	annually	2011	Maryland	*16*
2	Below ground sand filter	NA	NA	$1,600	NA	NA	annually	2011	Maryland	*16*
3	Sand filter	NA	NA	NA	NA	11-13%	annually	1999	Unknown	*1*
4	Filtration device (installed at two stormwater inlets)	$500	$1,200	NA	NA	NA	annually	2005	Chesapeake Bay Program	*27*
5	Surface sand filter (treats ½ impervious acre)	NA	NA	$1,683	NA	NA	annually	2005	Chesapeake Bay Program	*27*
6	Sand filter	NA	NA	NA	$872	NA	annually	2004	Unknown	*20*
7	Storm filter (retrofit)	NA	NA	$263	NA	NA	annually per m^3 of design storm treated	2009	California	*4*
8	Delaware sand filter (retrofit)	NA	NA	$100	NA	NA	annually per m^3 of design storm treated	2009	California	*4*
9	Austin sand filter (retrofit)	NA	NA	$100	NA	NA	annually per m^3 of design storm treated	2009	California	*4*
10	Austin sand filter	NA	NA	NA	NA	5%	annually	1992	Unknown	*29*
11	Sand filter	NA	NA	NA	NA	0.9-9.5%	annually	Unknown	Unknown	*19*

Notes:
[4] O&M costs alternate each year from $500 to $1200.
[5] Intermittant top layer replacement required every 3 years estimated at $2500 and concrete repairs required every 5 years estimated at $1500.
[6] This includes equipment and materials only. It is estimated that 152 labor hours is required annually.
[7,8,9] To convert from $/m^3 to $/acre-ft multiply by 1233.6.
NA = not applicable

Grass channel (grass swale, vegetated open channel)

No.	BMP Type Listed in Reference	Construction Cost ($) Min	Max	Avg	Actual	Units	Year	Location	Reference
1	Vegetated open channel	NA	NA	$24,000	NA	impervious acre treated	2011	Maryland	*16*
2	Grass swale	NA	NA	$0.50	NA	ft^2	1997	20 cities average	*1*
3	Grass swale (treats 5 acre commercial site with 35% impervious cover)	NA	NA	$3,500	NA	BMP	1997	20 cities average	*1*
4	Grass channel	NA	NA	$0.25	NA	ft^2	1991	Unknown	*1*
5	Water quality swale/grass swale (900 sf)	NA	NA	$6,000	NA	½ impervious acre treated	2005	Chesapeake Bay Program	*27*
6	Swale	NA	NA	$12,483	NA	BMP	2010	Unknown	*20*
7	Grass swale	NA	NA	21.779 * ln(A) - 42.543	NA	WQV	2006	Unknown	*20*
8	Grass swale	NA	NA	K_2L	NA	BMP	1999	Unknown	*30*
9	Grass swale	$5	$15	NA	NA	ft	1992	Unknown	*28*
10	Vegetated swale	$4.9	$9	NA	NA	ft	1987	Unknown	*29*
11	Vegetated swale	$8.5	$50	NA	NA	ft	1991	Unknown	*29*
12	Grassed swale	$8.0	$24	$16	NA	ft	2005	USEPA rainfall zone 1	*23*

Notes:

[1] Includes pre-construction costs of $4,000 for site discovery, planning, design, surveys, permitting, etc.

[3] Base capital cost for typical application. Total capital cost can typically be determined by increasing by 30%.

[7] Where A = watershed area (acres).

[8] L = length of swale (m) and K_2 ranges from 16.4 to 45.9 (a constant)

[12] Minimum cost for top width of 10 ft, maximum cost for top width of 20 ft, average cost for top width of 15 ft.

NA = not applicable

Grass channel (grass swale, vegetated open channel)

No.	BMP Type Listed in Reference	O&M Cost ($) Min	Max	Avg	Actual	Fraction of Construction Cost	Units	Year	Location	Reference
1	Vegetated open channel	NA	NA	$600	NA	NA	annually	2011	Maryland	*16*
2	Swale	NA	NA	NA	NA	5-7%	annually	1999	May be dated.	*1*
3	Biofiltration (treats 10 acres)	NA	NA	$145.70	NA	NA	annually per acre	2009	New Castle Co, Delaware	*31*
4	Water quality swales/grass swale (swale size = 900 ft^2)	NA	NA	$200	NA	NA	annually	2005	Chesapeake Bay Program	*27*
5	Vegetated swale (1.5 ft deep channel)	NA	NA	$1.9	NA	NA	annually per foot	1991	Unknown	*29*
6	Swales	NA	NA	NA	NA	4-178%	annually	Unknown	Unknown	*19*

Notes:
NA = not applicable

Infiltration practices (infiltration trench, infiltration basin)

		Construction Cost ($)							
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Units**	**Year**	**Location**	**Reference**
1	Infiltration practices (new - without sand and vegetation)	NA	NA	$58,450	NA	impervious acre treated	2011	Maryland	*16*
2	Infiltration practices (new - with sand)	NA	NA	$61,250	NA	impervious acre treated	2011	Maryland	*16*
3	Infiltration trench (100-ft long)	NA	NA	$4	NA	ft^3 of WQV	1997	20 cities average	*1*
4	Infiltration basin (0.25-acre)	NA	NA	$1	NA	ft^3 of WQV	1997	20 cities average	*1*
5	Infiltration trench (treats 5 acre commercial site with 65% impervious cover)	NA	NA	$45,000	NA	BMP	1997	20 cities average	*1*
6	Infiltration basin (treats 5 acre commercial site with 65% imperivous cover)	NA	NA	$15,000	NA	BMP	1997	20 cities average	*1*
7	Infiltration trench	2V	4V	2.5V	NA	BMP	1997	Unknown	*1*
8	Infiltration basin (0.25-acre basin [15,000 ft^3])	NA	NA	1.3V	NA	BMP	1991	Unknown	*1*
9	Infiltration basin (1-acre basin [76,300 ft^3])	NA	NA	0.8V	NA	BMP	1991	Unknown	*1*
10	Infiltration basin	NA	NA	$13.2V^{0.69}$	NA	BMP	1987	Unknown	*1*
11	Infiltration trench (treats 1/2 impervious acre)	NA	NA	$10,000	NA	½ impervious acre treated	2005	Chesapeake Bay Program	*27*
12	Filtration basin	NA	NA	$107,650	30959x + 46156	BMP	2010	Unknown	*20*
13	Infiltration trench	NA	NA	$44.108 * WQV^{-0.1991}$	NA	WQV	2006	Unknown	*20*
14	Infiltration basin	$138,512	$171,707	$155,110	NA	BMP	1999	Unknown	*20*
15	Infiltration basin	$340	$397	$369	NA	m^3 of WQV	1999	Unknown	*20*
16	Infiltration basin (retrofit)	$340	$397	$475	NA	m^3 of design storm treated	2009	California	*4*
17	Infiltration trench (retrofit)	$691	$775	$944	NA	m^3 of design storm treated	2009	California	*4*
18	Infiltration basin (retrofit)	$376	$864	$564	NA	m^3 of design storm treated	2009	Unknown	*4*
19	French drain/dry well (retrofit)	$395	$507	$451	NA	m^3 of design storm treated	2009	Unknown	*4*
20	Infiltration trenches	NA	NA	$1482.864 * V^{0.63}$	NA	BMP	1999	Unknown	*30*
21	Infiltration basins	NA	NA	$178.967 * V^{0.69}$	NA	BMP	1999	Unknown	*30*
22	Infiltration basin	NA	NA	$13.9(V/0.02832)^{0.69}$	NA	BMP	1995	Unknown	*28*
23	Infiltration trench	NA	NA	$1317.1V^{0.63}$	NA	BMP	1995	Unknown	*28*
24	Infiltration trench (6 ft deep x 4 ft wide - 2,400 ft^3 volume)	$8,000	$19,000	NA	NA	BMP	1999	Unknown	*29*
25	Infiltration trench (3 ft deep x 4 ft wide - 1,200 ft^3 volume)	$3,000	$8,500	NA	NA	BMP	1999	Unknown	*29*
26	Infiltration trench	NA	NA	$\beta_0(WQV)^{\beta 1}$	NA	ft^3 of WQV	2005	USEPA rainfall zone 1	*19*

Notes:

[1] Includes pre-construction costs of $7,000 for site discovery, planning, design, surveys, permitting, etc.

[2] Includes pre-construction costs of $17,500 for site discovery, planning, design, surveys, permitting, etc.

[5,6] Base capital cost for typical application. Total capital cost can typically be determined by increasing by 30%.

[7,8,9,10] Where V = total trenh or basin volume (ft^3).

[12] Where x = impervious drainage area (acres).

[16,17,18,19] To convert from $/$m^3$ to $/acre-ft multiply by 1233.6.

[20, 21] V = volume of voids (m^3)

[22] V = voume of water (m^3)

[26] Where WQV = water quality volume (ft^3) and Table 2.2 in reference provides β values.

NA = not applicable

Infiltration practices (infiltration trench, infiltration basin)

No.	BMP Type Listed in Reference	O&M Cost ($) Min	Max	Avg	Actual	Fraction of Construction Cost	Units	Year	Location	Reference
1	Infiltration practices (new - without sand or vegetation)	NA	NA	$835	NA	NA	annually	2011	Maryland	*16*
2	Infiltration practices (new - with sand and vegetation)	NA	NA	$875		NA	annually	2011	Maryland	*16*
3	Infiltration trench	NA	NA	NA	NA	5-20%	annually	1999	Unknown	*1*
4	Infiltration basin	NA	NA	NA	NA	1-10%	annually	1999	Unknown	*1*
5	Infiltration trench (treats 1 acre)	NA	NA	$1,085	NA	NA	annually per acre	2009	New Castle Co, Delaware	*31*
6	Infiltration basin (treats 20 acres)	NA	NA	$600.50	NA	NA	annually per acre	2009	New Castle Co, Delaware	*31*
7	Infiltration trench (treats ½ impervious acre)	NA	NA	$650	NA	NA	annually	2005	Chesapeake Bay Program	*27*
8	Infiltration basin	NA	NA	NA	$3,126	NA	$3126 for equipment/materials + 238 labor hours annually	2004	Unknown	*20*
9	Infiltration trench	NA	NA	NA	$723	NA	$723 for equipment/materials + 98 labor hours annually	2004	Unknown	*20*
10	Infiltration basin (retrofit)	NA	NA	NA	$104	NA	annually per m^3 of design storm treated	2009	California	*4*
11	Infiltration trench (retrofit)	NA	NA	NA	$91	NA	annually per m^3 of design storm treated	2009	California	*4*
12	Infiltration basin	NA	NA	NA	NA	1-3%	annually	2006	Unknown	*21*
13	Infiltration trench	$325	$700	NA	NA	NA	annually	1999	Unknown	*29*
14	Infiltration trench	NA	NA	NA	NA	5.1-12.6%	annually	Unknown	Unknown	*19*
15	Infiltration basin	NA	NA	NA	NA	2.8-4.9%	annually	Unknown	Unknown	*19*

Notes:

[8] This includes equipment and materials only. It is estimated that 238 labor hours is required annually.

[9] This includes equipment and materials only. It is estimated that 98 labor hours is required annually.

NA = not applicable

Manufactured Hydrodynamic BMP

No.	BMP Type Listed in Reference	Construction Cost ($)				Units	Year	Location	Reference
		Min	Max	Avg	Actual				
1	Hydrodynamic structure (new)	NA	NA	$42,000	NA	impervious acre treated	2011	Maryland	*16*
2	Catch basin controls (hydrodynamic separator)	NA	NA	$20,000	NA	½ impervious acre treated	2005	Chesapeake Bay Program	*27*
3	Hydrodynamic (CDS units [2]) (retrofit)	$224	$353	$340	NA	m^3 of design storm treated	2009	California	*4*
4	Stormceptor™	$7,600	$33,560	NA	NA	unit	1996	Unknown	*28*
5	Downstream Defender™	NA	NA	$1,250	NA	cfs	1996	Unknown	*28*
6	Vortech™	$1,500	$3,500	NA	NA	cfs	1997	Unknown	*28*
7	CDS hydrodynamic separator	$2,300	$7,200	NA	NA	cfs	1999	Unknown	*29*
8	Downstream Defender	$10,000	$35,000	NA	NA	pre-cast unit	1999	Unknown	*29*
9	Stormceptor	$7,600	$33,560	NA	NA	units treating 900 to 7200 gallons	1999	Unknown	*29*
10	Vortech	$10,000	$40,000	NA	NA	units treating 1.6 to 25 cfs	1999	Unknown	*29*

Notes:

[1] Includes pre-construction costs of $7,000 for site discovery, planning, design, surveys, permitting, etc.

[2] Based on installing catch basin controls on two stormwater inlets.

[3] To convert from $\$/m^3$ to $/acre-ft multiply by 1233.6.

[4,5,6] Installation costs run about 25-35% of the unit costs of structures.

[7,8] Includes installation costs.

[9] Installation cost per unit is $9,000.

[10] Does not include shipping or installation.

NA = not applicable

Manufactured Hydrodynamic BMP

		O&M Cost ($)								
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Fraction of Construction Cost**	**Units**	**Year**	**Location**	**Reference**
1	Hydrodynamic structure (new)	NA	NA	$3,500	NA	NA	annually	2011	Maryland	*16*
2	Catch basin controls (hydrodynamic separator)	NA	NA	$1,000	NA	NA	annually	2005	Chesapeake Bay Program	*27*
3	Hydrodynamic (retrofit - two CDS units)	NA	NA	$127	NA	NA	annually per m^3 of design storm treat	2009	California	*4*
4	Hydrodynamic separator	NA	$1,000	NA	NA	NA	annually	1999	Unknown	*29*

Notes:
[3] To convert from $/m^3 to $/acre-ft multiply by 1233.6.
[4] Maximum of $1000 per year, dependent on company contracted to clean the unit, travel distances, and ferquency of cleaning.
NA = not applicable

Permeable pavement (porous pavement)

		Construction Cost ($)							
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Units**	**Year**	**Location**	**Reference**
1	Permeable pavement (new - without sand and vegetation)	NA	NA	$239,580	NA	impervious acre treated	2011	Maryland	*16*
2	Permeable pavement (new - with sand and vegetation)	NA	NA	$335,412	NA	impervious acre treated	2012	Maryland	*16*
3	Porous pavement	NA	NA	50000A	NA	BMP	1991	Unknown	*1*
4	Porous pavement	NA	NA	80000A	NA	BMP	1987	Unknown	*1*
5	Permeable/porous pavement (0.05 acre pavement to treat ½ impervious acre)	NA	NA	$12,000	NA	BMP	2005	Chesapeake Bay Program	*27*

Notes:

[1] Includes pre-construction costs of $21,780 for site discovery, planning, design, surveys, permitting, etc.

[2] Includes pre-construction costs of $30,492 for site discovery, planning, design, surveys, permitting, etc.

[4,5] Where A = surface area of pavement (acres)

NA = not applicable

Permeable pavement (porous pavement)

		O&M Cost ($)								
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Fraction of Construction Cost**	**Units**	**Year**	**Location**	**Reference**
1	Permeable pavement (new - without sand or vegetation)	NA	NA	$2,178	NA	NA	annually	2011	Maryland	16
2	Permeable pavement (new - with sand and vegetation)	NA	NA	$3,050	NA	NA	annually	2011	Maryland	16

Notes:
NA = not applicable

Retention basin (wet pond)

		Construction Cost ($)							
No.	**BMP Type Listed in Reference**	**Min**	**Max**	**Avg**	**Actual**	**Units**	**Year**	**Location**	**Reference**
1	Wet pond & wetland (new)	NA	NA	$24,115	NA	impervious acre treated	2011	Maryland	*16*
2	Wet pond & wetland (retrofit)	NA	NA	$63,998	NA	impervious acre treated	2011	Maryland	*16*
3	Retention & detention basin	$0.50	$1		NA	ft^3 of WQV	1997	20 cities average	*1*
4	Retention basin (treating 50-acre residential site with 35% impervious cover)	NA	NA	$100,000	NA	BMP	1997	20 cities average	*1*
5	Retention basin and wetland	NA	NA	$18.5V^{0.70}$	NA	BMP	1997	NA	*1*
6	Wet pond	NA	NA	$230.16 * WQV^{-0.4282}$	NA	WQV	2006	Unknown	*20*
7	Wet basin	NA	NA	$448,412	NA	BMP	1999	Unknown	*20*
8	Wet basin	NA	NA	$1,731	NA	m^3 of WQV	1999	Unknown	*20*
9	Wet basin (retrofit)	NA	NA	$2,229	NA	m^3 of design storm treated	2009	California	*4*
10	Ponds (retrofit)	$38	$367	$113	NA	m^3 of design storm treated	2009	Unknown	*4*
11	Retention basin	NA	NA	$2.247 * 10^4V^{0.75}$	NA	BMP	1999	Unknown	*30*
12	Wet detention pond	$0.50	$1	NA	NA	ft^3 of WQV	1998	Unknown	*29*
13	Wet basin	NA	NA	$\beta_0(WQV)^{\beta 1}$	NA	ft^3 of WQV	2005	USEPA rainfall zone 1	*19*

Notes:

[1] Includes pre-construction costs of $5,565 for site discovery, planning, design, surveys, permitting, etc.

[2] Includes pre-construction costs of $21,333 for site discovery, planning, design, surveys, permitting, etc.

[4] Base capital cost for typical application. Total capital cost can typically be determined by increasing by 30%.

[5] Where V = total basin volume (ft^3).

[9,10] To convert from $/$m^3$ to $/acre-ft multiply by 1233.6.

[11] Where V = volume of storage (ml).

[13] Where WQV = water quality volume (ft^3) and Table 2.2 in reference provides β values.

Retention basin (wet pond)

No.	BMP Type Listed in Reference	O&M Cost ($) Min	Max	Avg	Actual	Fraction of Construction Cost	Units	Year	Location	Reference
1	Wet pond & wetland (new)	NA	NA	$742	NA	NA	annually	2011	Maryland	*16*
2	Wet pond & wetland (retrofit)	NA	NA	$742	NA	NA	annually	2011	Maryland	*16*
3	Retention basin & constructed wetland	NA	NA	NA	NA	3-6%	annually	1999	Unknown	*1*
4	Wet pond (treats 40 acres)	NA	NA	$441.50	NA	NA	annually per acre	2009	New Castle Co, Delaware	*31*
5	Wet basin	NA	NA	NA	$2,148	NA	annually	2004	Unknown	*20*
6	Wet basin (retrofit)	NA	NA	NA	$582	NA	annually per m^3 of design storm treated	2009	California	*4*
7	Wet detention pond	NA	NA	NA	NA	3-5%	annually	1992	Unknown	*29*
8	Wet basin	NA	NA	NA	NA	1.9-10.2%	annually	Unknown	Unknown	*19*

Notes:

[5] This includes equipment and materials only. It is estimated that 485 labor hours is required annually.

[6] To convert from $/$m^3$ to $/acre-ft multiply by 1233.6.

NA = not applicable

Vegetated filter strip

No.	BMP Type Listed in Reference	Construction Cost ($)				Units	Year	Location	Reference
		Min	Max	Avg	Actual				
1	Filter strip	$0.00	$1.30	NA	NA	ft^2	1997	20 cities average	*1*
2	Filter strip (treating 5 acre commercial site with 35% impervious cover)	$0	$9,000	NA	NA	BMP	1997	20 cities average	*1*
3	Filter strip (no existing vegetation; seed)	NA	NA	$13,800	NA	acre	1991	Unknown	*1*
4	Filter strip (no existing vegetation; sod)	NA	NA	$29,000	NA	acre	1991	Unknown	*1*
5	Environmentally sensitive landscaping (½ acre area)	NA	NA	$5,000	NA	½ acre	2005	Chesapeake Bay Program	*27*
6	Bioinfiltration strip	$384	$1,237	$963	NA	m^3 of design storm treated	2009	California	*4*
7	Filter strip (hydroseeding)	NA	NA	$2,000	NA	acre	1995	Unknown	*28*

Notes:
[1] Based on cost per square foot, and assuming 6 inches of storage in the filter strip. The lowest cost assumes the filter uses existing vegetation and the highest assumes sod was used to establish the filter strip.
[2] Base capital cost for typical application. Total capital cost can typically be determined by increasing by 30%.
[6] To convert from $/m^3 to $/acre-ft multiply by 1233.6.
NA = not applicable

Vegetated filter strip

No.	BMP Type Listed in Reference	O&M Cost ($) Min	Max	Avg	Actual	Fraction of Construction Cost	Units	Year	Location	Reference
1	Vegetated filter strip	NA	NA	$320	NA	NA	annually per acre	1999	Unknown	*1*
2	Filter strip (treats 1 acre)	NA	NA	$1,127	NA	NA	annually per acre	2009	New Castle Co, Delaware	*31*
3	Environmentally sensitive landscaping (½ acre size)	NA	NA	$400	NA	NA	annually per 1/2 acre	2005	Chesapeake Bay Program	*27*
4	Bioinfiltration strip (retrofit)	NA	NA	NA	$95	NA	annually per m^3 of design storm treated	2009	California	*20*

Notes:
[4] To convert from $/m^3 to $/acre-ft multiply by 1233.6.
NA = not applicable

Appendix B
Detailed Cost Estimates of Select BMPs

BMP ID:	①
PPMS:	56184
Structure No:	14-11
Pond Name:	Basin 2
BMP Type:	Extended Detention Basin
Project No:	0095-016-111, C501
Project Title:	Rt 652 (Ruther Glen Rd) - From 0.443 miles S or Rt 207 to 0.369 miles N of Rt 207 (Carmel Church)
Description:	Relocation of Rt 652 at Rt 207
Functional Class:	(652) Rural Collector Rolling Undivided - 40 mph Des Speed (Urban Std GS-7 Used)
Date Installed:	10/2/2008
County:	Caroline
HUC:	YO49
Impervious Area Treated (acres):	2.44
BMP Treatment Volume (2 x WQV) (ft^3):	8414.34
Annual Phosphorus Removal (lbs) - 35% Efficiency:	1.85
Annual Phosphorus Removal (lbs) - 15% Efficiency:	0.79

Item	Units	Quantity	Item No	Unit Cost	Total Cost
SWM drainage structure (SWM-1)	ft	6	27550	$1,098.33	$6,589.98
Excavation (SWM basin)	yd^3	233	27545	$14.85	$3,460.05
Fill (not a pay item)	yd^3	771	NA	NA	NA
Concrete pipe (watertight 15 in)	ft	47	01152	$62.31	$2,928.57
End sections (ES-1, 15 in)	each	1	06151	$770.05	$770.05
Erosion control stone (Class I, EC-1, CL.2)	ton	12	09152	$54.47	$653.64
Concrete (Class A3)	yd^3	5.2	00525	$722.54	$3,757.21
Gabions	yd^3	14	09155	$173.56	$2,429.84

Notes:
Unit costs for construction materials obtained from VDOT Transport database.
Costs include materials and labor.
NA = not applicable

Component	Cost (2008)	Cost (2014)
Design, Permitting, & Pre-Construction Cost[a]		
Total	$6,588.59	$7,487.90
Construction Cost[b]		
Total	$20,589.34	$23,399.69
Per Cubic Foot of WQV Treated	$2.45	$2.78
O&M Cost[c]		
Annual	$205.89	NA
Total (20 year design life)	$4,117.87	$3,481.28
ROW Cost[d]		
Per BMP Footprint (0.27 acres)	$21,189.31	$24,081.55
BMP Cost (excluding ROW)		
Total	$31,295.79	$34,368.87
Per Cubic Foot of WQV Treated	$3.72	$4.08
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$16,887.62	$18,545.89
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$39,404.44	$43,273.74
BMP Cost (including ROW)		
Total	$52,485.10	$58,450.43
Per Cubic Foot of WQV Treated	$6.24	$6.95
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$28,321.64	$31,540.61
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$66,083.84	$73,594.75

Notes:

[a] Design, permitting, & pre-construction cost estimated at 32% of construction cost (*18*).

[b] Unit costs for construction materials obtained from VDOT Transport database.

[c] Annual O&M cost estimated at 1% of construction cost (*1*).

[d] ROW cost based on estimated BMP footprint and parcel cost from VDOT ROW and Utility Management System database.

O&M = operation and maintenance
NA = not applicable
ROW = right-of-way
WQV = water quality volume

BMP ID:	②
PPMS:	56184
Structure No:	11-8
Pond Name:	Basin 3
BMP Type:	Extended Detention Basin
Project No:	0095-016-111, C501
Project Title:	Rt 652 (Ruther Glen Rd) - From: 0.443 miles S or Rt 207 To: 0.369 miles N of Rt 207 (Carmel Church)
Description:	Relocation of Rt 652 at Rt 207
Functional Class:	(652) Rural Collector Rolling Undivided - 40 mph Des Speed (Urban Std GS-7 Used)
Date Installed:	10/2/2008
County:	Caroline
HUC:	YO49
Impervious Area Treated (acres):	2.56
BMP Treatment Volume (2 x WQV) (ft^3):	8828.16
Annual Phosphorus Removal (lbs) - 35% Efficiency:	1.94
Annual Phosphorus Removal (lbs) - 15% Efficiency:	0.83

Construction Cost of BMP ②

Item	Units	Quantity	Item No	Unit Cost	Total Cost
SWM drainage structure (SWM-1)	ft	6	27550	$1,098.33	$6,589.98
Excavation (SWM basin)	yd^3	460	27545	$14.85	$6,831.00
Fill (not a pay item)	yd^3	515	NA	NA	NA
Fill (borrow)	yd^3	738	00140	$19.92	$14,700.96
Concrete pipe (watertight 15 in)	ft	58	01152	$62.31	$3,613.98
End sections (ES-1, 15 in)	each	1	06151	$770.05	$770.05
Erosion control stone (Class I, EC-1, CL.1)	ton	13	09150	$111.61	$1,450.93
Erosion control stone (Class I, EC-1, CL.3)	ton	3	Unknown[a]	$83.04	$249.12
Concrete (Class A3)	yd^3	6.4	00525	$722.54	$4,624.26
Gabions	yd^3	14.7	09155	$173.56	$2,551.33

Notes:

[a] Unit cost could not be located in Transport database. Unit cost is an average of CL.1 & CL.2 stone costs.

Unit costs for construction materials obtained from VDOT Transport database.

Costs include materials and labor.

NA = not applicable

Component	Cost (2008)	Cost (2014)
Design, Permitting, & Pre-Construction Cost[a]		
Total	$13,242.11	$15,049.60
Construction Cost[b]		
Total	$41,381.61	$47,030.01
Per Cubic Foot of WQV Treated	$4.69	$5.33
O&M Cost[c]		
Annual	$413.82	NA
Total (20 year design life)	$8,276.32	$6,996.88
ROW Cost[d]		
Per BMP Footprint (0.39 acres)	$31,405.18	$35,691.84
BMP Cost (excluding ROW)		
Total	$62,900.04	$69,076.49
Per Cubic Foot of WQV Treated	$7.12	$7.82
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$32,350.66	$35,527.32
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$75,484.88	$82,897.09
Total Present Cost (including ROW)		
Total	$94,305.22	$104,768.33
Per Cubic Foot of WQV Treated	$10.68	$11.87
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$48,502.93	$53,884.30
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$113,173.51	$125,730.04

Notes:

[a] Design, permitting, & pre-construction cost estimated at 32% of construction cost (*18*).

[b] Unit costs for construction materials obtained from VDOT Transport database.

[c] Annual O&M cost estimated at 1% of construction cost (*1*).

[d] ROW cost based on estimated BMP footprint and parcel cost from VDOT ROW and Utility Management System database.

O&M = operation and maintenance
NA = not applicable
ROW = right-of-way
WQV = water quality volume

BMP ID:	③
PPMS:	56184
Structure No:	16-4
Pond Name:	Basin 1
BMP Type:	Extended Detention Basin
Project No:	0095-016-111, C501
Project Title:	Rt 652 (Ruther Glen Rd) - From 0.443 miles S of Rt 207 to 0.369 miles N of Rt 207 (Carmel Church)
Description:	Relocation of Rt 652 at Rt 207
Functional Class:	(652) Rural Collector Rolling Undivided - 40 mph Des Speed (Urban Std GS-7 Used)
Date Installed:	10/2/2008
County:	Caroline
HUC:	YO49
Impervious Area Treated (acres):	8.01
BMP Treatment Volume (2 x WQV) (ft^3):	27622.49
Annual Phosphorus Removal (lbs) - 35% Efficiency:	6.08
Annual Phosphorus Removal (lbs) - 15% Efficiency:	2.61

Item	Units	Quantity	Item No	Unit Cost	Total Cost
SWM drainage structure (SWM-1)	ft	6	27550	$1,098.33	$6,589.98
Excavation (SWM basin)	yd^3	2208	27545	$14.85	$32,788.80
Fill (not a pay item)	yd^3	188	NA	NA	NA
Concrete pipe (watertight 18 in)	ft	51	1182	$72.81	$3,713.31
End sections (ES-1, 18 in)	each	1	6181	$866.54	$866.54
Erosion control stone (Class I, EC-1, CL.1)	ton	12	9150	$111.61	$1,339.32
Erosion control stone (Class I, EC-1, CL.2)	ton	6	9152	$54.47	$326.82
Erosion control stone (Class I, EC-1, CL.3)	ton	8	Unknown[a]	$83.04	$664.32
Concrete (Class A3)	yd^3	6.6	525	$722.54	$4,768.76
Gabions	yd^3	24	9155	$173.56	$4,165.44

Notes:

[a] Unit cost could not be located in Transport database. Unit cost is an average of CL.1 & CL.2 stone costs.

Unit costs for construction materials obtained from VDOT Transport database.

Costs include materials and labor.

NA = not applicable

Component	Cost (2008)	Cost (2014)
Design, Permitting, & Pre-Construction Cost[a]		
Total	$17,671.45	$20,083.53
Construction Cost[b]		
Total	$55,223.29	$62,761.02
Per Cubic Foot of WQV Treated	$2.00	$2.27
O&M Cost[c]		
Annual	$552.23	NA
Total (20 year design life)	$11,044.66	$9,337.26
ROW Cost[d]		
Per BMP Footprint (0.33 acres)	$26,464.83	$30,077.16
BMP Cost (excluding ROW)		
Total	$83,939.41	$92,181.80
Per Cubic Foot of WQV Treated	$3.04	$3.34
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$13,797.67	$15,152.52
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$32,194.55	$35,355.88
BMP Cost (including ROW)		
Total	$110,404.24	$122,258.96
Per Cubic Foot of WQV Treated	$4.00	$4.43
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$18,147.86	$20,096.50
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$42,345.01	$46,891.83

Notes:

[a] Design, permitting, & pre-construction cost estimated at 32% of construction cost (*18*).

[b] Unit costs for construction materials obtained from VDOT Transport database.

[c] Annual O&M cost estimated at 1% of construction cost (*1*).

[d] ROW cost based on estimated BMP footprint and parcel cost from VDOT ROW and Utility Management System database.

O&M = operation and maintenance
NA = not applicable
ROW = right-of-way
WQV = water quality volume

BMP ID:	④
PPMS:	70043
Structure No:	6-11
Pond Name:	Basin 7A
BMP Type:	Extended Detention Basin
Project No:	0066-076-113, C501
Project Title:	I-66 Impovements - From 1.554 km W of SB Rt 29 Baseline to 3.716 km E of SB Rt 29 Baseline
Description:	I-66 HOV widening
Functional Class:	Rural Principal Arterial - Freeway - Level 100 km/h Min Des Speed
Date Installed:	4/12/2006 (Assumed)
County:	Prince William
HUC:	PL34
Impervious Area Treated (acres):	4.27
BMP Treatment Volume (2 x WQV) (ft^3):	14725.10
Annual Phosphorus Removal (lbs) - 35% Efficiency:	3.24
Annual Phosphorus Removal (lbs) - 15% Efficiency:	1.39

Item	Units	Quantity	Item No	Unit Cost	Total Cost
Excavation (SWM basin)	m^3	74	27545	$12.64	$935.36
Fill (not a pay item)	m^3	2523	NA	NA	NA
Concrete pipe (600 mm)	m	34	01242	$204.83	$6,964.22
Concrete cradle (class 20 miscellaneous)	m^3	2.93	00525	$1,016.17	$2,977.38
Cable barricade	each	1	13480	$461.80	$461.80
Aggregate (No. 25/26, depth @ 150 mm)	metric ton	385.5	00505	$19.71	$7,598.21
Impervious clay liner & cut-off wall	m^3	26.49	27544	$60.00	$1,589.40
Excavation (siltation control)	m^3	387.2	27430	$9.00	$3,484.80
Excavation (temporary sediment basin)	m^3	196.1	27580	$31.14	$6,106.55
Riser structure SWM-I	m	2.42	27550	$3,032.77	$7,339.30

Notes:

Material and cost data provided by VDOT in metric units.

Unit costs for construction materials obtained from VDOT Transport database.

Costs include materials and labor.

NA = not applicable

Component	Cost (2006)	Cost (2014)
Design, Permitting, & Pre-Construction Cost[a]		
Total	$11,986.25	$15,265.14
Construction Cost[b]		
Total	$37,457.02	$47,703.55
Per Cubic Foot of WQV Treated	$2.54	$3.24
O&M Cost[c]		
Annual	$374.57	NA
Total (20 year design life)	$7,491.40	$7,097.08
ROW Cost[d]		
Per BMP Footprint (0.35 acres)	$27,739.00	$35,327.13
BMP Cost (excluding ROW)		
Total	$56,934.67	$70,065.77
Per Cubic Foot of WQV Treated	$3.87	$4.76
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$17,555.82	$21,604.80
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$40,963.58	$50,411.20
BMP Cost (including ROW)		
Total	$84,673.67	$105,392.89
Per Cubic Foot of WQV Treated	$5.75	$7.16
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$26,109.15	$32,497.93
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$60,921.35	$75,828.50

Notes:

[a] Design, permitting, & pre-construction cost estimated at 32% of construction cost (*18*).

[b] Unit costs for construction materials obtained from VDOT Transport database.

[c] Annual O&M cost estimated at 1% of construction cost (*1*).

[d] ROW cost based on estimated BMP footprint and parcel cost from VDOT ROW and Utility Management System database.

O&M = operation and maintenance
NA = not applicable
ROW = right-of-way
WQV = water quality volume

BMP ID:	⑤
PPMS:	70043
Structure No:	4-9
Pond Name:	Basin 4A
BMP Type:	Extended Detention Basin
Project No:	0066-076-113, C501
Project Title:	I-66 Impovements - From 1.554 km W of SB Rt 29 Baseline to 3.716 km E of SB Rt 29 Baseline
Description:	I-66 HOV widening
Functional Class:	Rural Principal Arterial - Freeway - Level 100 km/h Min Des Speed
Date Installed:	4/12/2006
County:	Prince William
HUC:	PL43
Impervious Area Treated (acres):	7.33
BMP Treatment Volume (2 x WQV Treated) (ft^3):	25277.51
Annual Phosphorus Removal (lbs) - 35% Efficiency:	5.57
Annual Phosphorus Removal (lbs) - 15% Efficiency:	2.39

Item	Units	Quantity	Item No	Unit Cost	Total Cost
Excavation (SWM basin)	m^3	3322	27545	$12.64	$41,990.08
Fill (not a pay item)	m^3	1599	NA	NA	NA
Concrete pipe (600 mm)	m	22.5	01242	$204.83	$4,608.68
Concrete cradle (class 20 miscellaneous)	m^3	3.41	00525	$1,016.17	$3,465.14
End section (ES-1, 600 mm)	each	1	06241	$754.35	$754.35
Cable barricade	each	1	13480	$461.80	$461.80
Aggregate (No. 25/26, depth @ 150 mm)	metric ton	238.9	00505	$19.71	$4,708.72
Erosion control stone (Class I, EC-1)	metric ton	7.4	09150	$43.05	$318.57
Dry rip-rap (Class I @ 600 mm depth)	metric ton	550	26271	$50.00	$27,500.00
Impervious clay liner & cut-off wall	m^3	29.83	27544	$60.00	$1,789.80
Excavation (siltation control)	m^3	654.6	27430	$9.00	$5,891.40
Excavation (temporary sediment basin)	m^3	682.6	27580	$31.14	$21,256.16
Riser structure SWM-I	m	2.13	27550	$3,032.77	$6,459.80

Notes:
Material and cost data provided by VDOT in metric units.
Unit costs for construction materials obtained from VDOT Transport database.
Costs include materials and labor.
NA = not applicable

Component	Cost (2006)	Cost (2014)
Design, Permitting, & Pre-Construction Cost[a]		
Total	$38,145.44	$48,580.29
Construction Cost[b]		
Total	$119,204.50	$151,813.40
Per CF of WQV Treated	$4.72	$6.01
O&M Cost[c]		
Annual	$1,192.04	NA
Total (20 year design life)	$23,840.90	$22,586.00
ROW Cost[d]		
Per BMP Footprint (0.78 acres)	$45,535.66	$57,992.14
BMP Cost (excluding ROW)		
Total	$181,190.84	$222,979.68
Per Cubic Foot of WQV Treated	$7.17	$8.82
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$32,546.51	$40,052.86
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$75,941.87	$93,456.67
BMP Cost (including ROW)		
Total	$226,726.50	$280,971.82
Per Cubic Foot of WQV Treated	$8.97	$11.12
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$40,725.88	$50,469.73
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$95,027.06	$117,762.71

Notes:

[a] Design, permitting, & pre-construction cost estimated at 32% of construction cost (*18*).

[b] Unit costs for construction materials obtained from VDOT Transport database.

[c] Annual O&M cost estimated at 1% of construction cost (*1*).

[d] ROW cost based on estimated BMP footprint and parcel cost from VDOT ROW and Utility Management System database.

O&M = operation and maintenance
NA = not applicable
ROW = right-of-way
WQV = water quality volume

BMP ID:	⑥
PPMS:	70043
Structure No:	11-5
Pond Name:	Basin 11A
BMP Type:	Extended Detention Basin
Project No:	0066-076-113, C501
Project Title:	I-66 Impovements - From 1.554 km W of SB Rt 29 Baseline to 3.716 km E of SB Rt 29 Baseline
Description:	I-66 HOV widening
Functional Class:	Rural Principal Arterial - Freeway - Level 100 km/h Min Des Speed
Date Installed:	4/12/2006 (Assumed)
County:	Prince William
HUC:	PL34
Impervious Area Treated (acres):	7.42
BMP Treatment Volume (2 x WQV) (ft^3):	25587.87
Annual Phosphorus Removal (lbs) - 35% Efficiency:	5.64
Annual Phosphorus Removal (lbs) - 15% Efficiency:	2.42

Item	Units	Quantity	Item No	Unit Cost	Total Cost
Excavation (SWM basin)	m^3	686	27545	$12.64	$8,671.04
Fill (not a pay item)	m^3	6219	NA	NA	NA
Concrete pipe (450 mm)	m	11.5	01182	$120.00	$1,380.00
Concrete cradle (class 20 miscellaneous)	m^3	2.94	00525	$1,016.17	$2,987.54
End section (ES-1, 450 mm)	each	1	06181	$938.84	$938.84
Cable barricade	each	1	13480	$461.80	$461.80
Aggregate (No. 25/26, depth @ 150 mm)	metric ton	127.7	00505	$19.71	$2,516.97
Erosion control stone (Class I, EC-1)	metric ton	3.9	09150	$43.05	$167.90
Impervious clay liner & cut-off wall	m^3	29.47	27544	$60.00	$1,768.20
Excavation (siltation control)	m^3	374.46	27430	$9.00	$3,370.14
Pond clay liner	m^3	1141.4	27580	$75.00	$85,605.00
Riser structure SWM-I	m	1.72	27550	$3,032.77	$5,216.36

Notes:
Material and cost data provided by VDOT in metric units.
Unit costs for construction materials obtained from VDOT Transport database.
Costs include materials and labor.
NA = not applicable

Component	Cost (2006)	Cost (2014)
Design, Permitting, & Pre-Construction Cost[a]		
Total	$36,186.81	$46,085.87
Construction Cost[b]		
Total	$113,083.79	$144,018.34
Per Cubic Foot of WQV Treated	$4.42	$5.63
O&M Cost[c]		
Annual	$1,130.84	NA
Total (20 year design life)	$22,616.76	$21,426.29
ROW Cost[d]		
Per BMP Footprint (0.62 acres)	$48,752.37	$62,088.79
BMP Cost (excluding ROW)		
Total	$171,887.36	$211,530.50
Per Cubic Foot of WQV Treated	$6.72	$8.27
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$30,500.87	$37,535.42
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$71,168.70	$87,582.65
BMP Cost (including ROW)		
Total	$220,639.72	$273,619.28
Per Cubic Foot of WQV Treated	$8.62	$10.69
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$39,151.83	$48,552.88
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$91,354.26	$113,290.06

Notes:

[a] Design, permitting, & pre-construction cost estimated at 32% of construction cost (*18*).

[b] Unit costs for construction materials obtained from VDOT Transport database.

[c] Annual O&M cost estimated at 1% of construction cost (*1*).

[d] ROW cost based on estimated BMP footprint and parcel cost from VDOT ROW and Utility Management System database.

O&M = operation and maintenance
NA = not applicable
ROW = right-of-way
WQV = water quality volume

BMP ID:	⑦
PPMS:	70043
Structure No:	13-16
Pond Name:	Basin 13A
BMP Type:	Extended Detention Basin
Project No:	0066-076-113, C501
Project Title:	I-66 Impovements - From 1.554 km W of SB Rt 29 Baseline to 3.716 km E of SB Rt 29 Baseline
Description:	I-66 HOV widening
Functional Class:	Rural Principal Arterial - Freeway - Level 100 km/h Min Des Speed
Date Installed:	4/12/2006 (Assumed)
County:	Prince William
HUC:	PL43
Impervious Area Treated (acres):	15.15
BMP Treatment Volume (2 x WQV) (ft^3):	52244.78
Annual Phosphorus Removal (lbs) - 35% Efficiency:	11.51
Annual Phosphorus Removal (lbs) - 15% Efficiency:	4.93

Item	Units	Quantity	Item No	Unit Cost	Total Cost
Excavation (SWM basin)	m^3	2605	27545	$12.64	$32,927.20
Fill (not a pay item)	m^3	1622	NA	NA	NA
Concrete pipe (750 mm)	m	25.5	01302	$225.41	$5,747.96
Concrete cradle (Class 20 miscellaneous)	m^3	3.71	00525	$1,016.17	$3,769.99
End section (ES-1, 750 mm)	each	1	06301	$1,088.17	$1,088.17
Cable barricade (CR-1)	each	1	13480	$461.80	$461.80
Aggregate (No. 25/26, depth @ 150 mm)	metric ton	387.6	00505	$19.71	$7,639.60
Erosion control stone (Class I, EC-1)	metric ton	10.9	09150	$43.05	$469.25
Dry rip-rap (Class I @ 600 mm depth)	metric ton	585	26271	$50.00	$29,250.00
Impervious clay liner & cut-off wall	m^3	27.46	27544	$60.00	$1,647.60
Excavation (siltation control)	m^3	1060.29	27430	$9.00	$9,542.61
Excavation (temporary sediment basin)	m^3	1011	27580	$31.14	$31,482.54
Pond clay liner	m^3	850.02	27544	$75.00	$63,751.50
Riser structure SWM-I	m	2.02	27550	$3,032.77	$6,126.20

Notes:
Material and cost data provided by VDOT in metric units.
Unit costs for construction materials obtained from VDOT Transport database.
Costs include materials and labor.
NA = not applicable

Component	Cost (2006)	Cost (2014)
Design, Permitting, & Pre-Construction Cost[a]		
Total	$62,049.41	$79,023.29
Construction Cost[b]		
Total	$193,904.40	$246,947.78
Per Cubic Foot of WQV Treated	$3.71	$4.73
O&M Cost[c]		
Annual	$1,939.04	NA
Total (20 year design life)	$38,780.88	$36,739.59
ROW Cost[d]		
Per BMP Footprint (0.45 acres)	$42,255.32	$53,814.44
BMP Cost (excluding ROW)		
Total	$294,734.69	$362,710.66
Per Cubic Foot of WQV Treated	$5.64	$6.94
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$25,614.79	$31,522.45
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$59,767.85	$73,552.37
BMP Cost (including ROW)		
Total	$336,990.01	$416,525.10
Per Cubic Foot of WQV Treated	$6.45	$7.97
Per Pound of Annual Phosphorus Removal - 35% Efficiency	$29,287.12	$36,199.35
Per Pound of Annual Phosphorus Removal - 15% Efficiency	$68,336.60	$84,465.15

Notes:

[a] Design, permitting, & pre-construction cost estimated at 32% of construction cost (*18*).

[b] Unit costs for construction materials obtained from VDOT Transport database.

[c] Annual O&M cost estimated at 1% of construction cost (*1*).

[d] ROW cost based on estimated BMP footprint and parcel cost from VDOT ROW and Utility Management System database.

O&M = operation and maintenance
NA = not applicable
ROW = right-of-way
WQV = water quality volume

BMP ID:	⑧
PPMS:	63724
Structure No:	9-8
Pond Name:	SWM Basin 9A
BMP Type:	Sand Filter
Project No:	0066-076-113, C506
Project Title:	I-66 Reconstruction of Interchange - Phase I - University Blvd - From Wellington Rd to Rt 29
Description:	0.922 mi grade, drain, asphalt, pavement, signs, signals, and br.
Functional Class:	Urban Minor Arterial - Level 50 MPH Min Des Speed
Date Installed:	3/1/2004
County:	Prince William
HUC:	PL43
Impervious Area Treated (acres):	4.4
BMP Treatment Volume (1 x WQV) (ft^3):	7586.70
Annual Phosphorus Removal (lbs) - 65% Removal Efficiency:	6.21
Annual Phosphorus Removal (lbs) - 60% Removal Efficiency:	5.73

Item	Units	Quantity	Item No	Unit Cost	Total Cost
Excavation (SWM basin)	yd^3	1614	27545	$9.72	$15,688.08
Fill (not a pay item)	yd^3	72	NA	NA	NA
Concrete pipe (24 in)	ft	107	01242	$50.22	$5,373.54
Concrete pipe w/ rubber gaskets (24 in)	ft	50	02090	$70.00	$3,500.00
End walls (concrete Class A3 miscellaneous)	yd^3	1.6	00525	$657.84	$1,052.54
Concrete cradle (concrete Class A3 miscellaneous)	yd^3	8.4	00525	$657.84	$5,525.86
Cable barricade	each	1	13480	$473.06	$473.06
Aggregate (No. 25/26, depth @ 6 in)	ton	106	00505	$17.30	$1,833.80
Erosion control stone (Class I, EC-1)	ton	5.5	09150	$43.40	$238.70
Dry rip-rap (Class I @ 12 in depth)	ton	49	26271	$40.00	$1,960.00
Excavation (siltation control)	yd^3	360	27430	$6.25	$2,250.00
Poly pipe (4" Sch 40 perforated)	ft	144	02090	$10.00	$1,440.00
Poly pipe (4" Sch 40 non-perforated)	ft	172	02090	$10.00	$1,720.00
Concrete sand (ASTM 33)	ton	78.2	10250	$30.00	$2,346.00
Sand filter bedding material (Aggregate 25/26)	ton	69.2	00506	$25.00	$1,730.00
Filter fabric under sand layer	yd^3	106.7	27500	$4.00	$426.80
Low permeability liner	yd^3	131.3	27543	$35.00	$4,595.50
Riser structure (Class A3 concrete)	yd^3	3.7	00525	$657.84	$2,434.01
Riser structure (SWM-1)	ft	6.5	27550	$572.31	$3,720.02
SWM basin as-built survey	lump sum	1	27548	$10,000.00	$10,000.00

Notes:
Unit costs for construction materials obtained from VDOT Transport database.
Costs include materials and labor.
NA = not applicable

Component	Cost (2004)	Cost (2014)
Design, Permitting, & Pre-Construction Cost[a]		
Total	$21,218.53	$29,889.55
Construction Cost[b]		
Total	$66,307.90	$93,404.84
Per Cubic Foot of WQV Treated	$8.74	$12.31
O&M Cost[c]		
Annual	$7,956.95	NA
Total (20 year design life)	$159,138.97	$166,755.37
ROW Cost[d]		
Per BMP Footprint (0.32 acres)	$35,353.78	$49,801.21
BMP Cost (excluding ROW)		
Total	$246,665.40	$290,049.76
Per Cubic Foot of WQV Treated	$32.51	$38.23
Per Pound of Annual Phosphorus Removal - 65% Efficiency	$39,745.00	$46,735.48
Per Pound of Annual Phosphorus Removal - 60% Efficiency	$43,057.08	$50,630.11
BMP Cost (including ROW)		
Total	$282,019.18	$339,850.97
Per Cubic Foot of WQV Treated	$37.17	$44.80
Per Pound of Annual Phosphorus Removal - 65% Efficiency	$45,441.52	$54,759.91
Per Pound of Annual Phosphorus Removal - 60% Efficiency	$49,228.32	$59,323.24

Notes:

[a] Design, permitting, & pre-construction cost estimated at 32% of construction cost (*18*).

[b] Unit costs for construction materials obtained from VDOT Transport database.

[c] Annual O&M cost estimated at 12% of construction cost (*1*).

[d] ROW cost based on estimated BMP footprint and parcel cost from VDOT ROW and Utility Management

O&M = operation and maintenance
NA = not applicable
ROW = right-of-way
WQV = water quality volume

BMP ID:	⑨
PPMS:	63724
Structure No:	4C-2
Pond Name:	SWM Basin 4A
BMP Type:	Extended Detention Enhanced Basin
Project No:	0066-076-113, C506
Project Title:	I-66 Reconstruction of Interchange - Phase I - University Blvd - From Wellington Rd to Rt 29
Description:	0.922 mi grade, drain, asphalt, pavement, signs, signals, and br.
Functional Class:	Urban Minor Arterial - Level 50 MPH Min Des Speed
Date Installed:	10/28/2005
County:	Prince William
HUC:	PL34
Impervious Area Treated (acres):	9.2
BMP Treatment Volume (2 x WQV) (ft^3):	31726.20
Annual Phosphorus Removal (lbs) - 50% Removal Efficiency:	9.98
Annual Phosphorus Removal (lbs) - 31% Removal Efficiency:	6.19

Construction Cost of BMP ⑨

Item	Units	Quantity	Item No	Unit Cost	Total Cost
Excavation (SWM basin)	yd^3	8837	27545	$9.72	$85,895.64
Fill (not a pay item)	yd^3	98	NA	NA	NA
Concrete pipe (12 in)	ft	11	01122	$40.09	$440.96
Concrete pipe (18 in)	ft	168	01152	$33.67	$5,656.56
Concrete pipe w/ rubber gaskets (18 in)	ft	50	02090	$57.00	$2,850.00
Ductile iron pipe (12 in)	ft	11	02090	$25.00	$275.00
End walls (concrete Class A3 miscellaneous)	yd^3	0.4	00525	$657.84	$263.14
Concrete cradle (concrete Class A3 miscellaneous)	yd^3	6.5	00525	$657.84	$4,275.96
Cable barricade	each	1	13480	$473.06	$473.06
Aggregate (No. 25/26, depth @ 6 in)	ton	204	00505	$17.30	$3,529.20
Erosion control stone (Class I, EC-1)	ton	4.5	09150	$43.40	$195.30
Dry rip-rap (Class I @ 12 in depth)	ton	74	26271	$40.00	$2,960.00
Excavation (siltation control)	yd^3	650	27430	$6.25	$4,062.50
Topsoil (4" Class B)	acre	0.6	27024	$7,500.00	$4,500.00
Low permeability liner	yd^3	1802.9	27543	$35.00	$63,101.50
Riser structure (Class A3 concrete)	yd^3	5.2	00525	$657.84	$3,420.77
Riser structure (SWM-1)	ft	9.6	27550	$572.31	$5,494.18
Wetland planting	lump sum	1	27548	$15,000.00	$15,000.00
SWM basin as-built survey	lump sum	1	27548	$10,000.00	$10,000.00

Notes:

Unit costs for construction materials obtained from VDOT Transport database.

Costs include materials and labor.

NA = not applicable

Component	Cost (2005)	Cost (2014)
Design, Permitting, & Pre-Construction Cost[a]		
Total	$67,966.00	$88,069.13
Construction Cost[b]		
Total	$212,393.76	$275,216.03
Per Cubic Foot of WQV Treated	$6.69	$8.67
O&M Cost[c]		
Annual	$9,557.72	NA
Total (20 year design life)	$191,154.38	$184,253.38
ROW Cost[d]		
Per BMP Footprint (1.29 acres)	$154,771.04	$200,549.55
BMP Cost (excluding ROW)		
Total	$471,514.14	$547,538.54
Per Cubic Foot of WQV Treated	$14.86	$17.26
Per Pound of Annual Phosphorus Removal - 50% Efficiency	$47,236.44	$54,852.59
Per Pound of Annual Phosphorus Removal - 31% Efficiency	$76,187.81	$88,471.92
BMP Cost (including ROW)		
Total	$626,285.18	$748,088.08
Per Cubic Foot of WQV Treated	$19.74	$23.58
Per Pound of Annual Phosphorus Removal - 50% Efficiency	$62,741.45	$74,943.71
Per Pound of Annual Phosphrous Removal - 31% Efficiency	$101,195.89	$120,876.95

Notes:

[a] Design, permitting, & pre-construction cost estimated at 32% of construction cost (*18*).

[b] Unit costs for construction materials obtained from VDOT Transport database.

[c] Annual O&M cost estimated at 4.5% of construction cost (*1*).

[d] ROW cost based on estimated BMP footprint and parcel cost from VDOT ROW and Utility Management

O&M = operation and maintenance
NA = not applicable
ROW = right-of-way
WQV = water quality volume