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A BENEFIT-COST ANALYSIS OF TOTAL MAXIMUM DAILY LOAD IMPLEMENTATION[1]

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ABSTRACT: Total Maximum Daily Load (TMDL) implementation generates benefits and costs from water quality improvements, which are rarely quantified. This analysis examines a TMDL written to address bacteria and aquatic-life-use impairments on Abrams and Opequon Creeks in Virginia. Benefits were estimated using a contingent valuation survey of local residents. Costs were based on the number and type of best management practices (BMPs) necessary to achieve TMDL pollution reduction goals. BMPs were quantified using watershed-scale water quality simulation models (Generalized Watershed Loading Function and Hydrological Simulation Program-FORTRAN). Based on our projections, the costs to achieve TMDL induced pollution reduction goals outweigh the estimated benefits. Benefit-cost ratios ranged between 0.1 and 0.3.

(KEY TERMS: water quality economics; watershed management; best management practices; water policy; nonpoint source pollution; contingent valuation.)

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INTRODUCTION

According to the U.S. Environmental Protection Agency (USEPA), over 40% of the assessed waters in the United States (U.S.) (some 20,000 river or stream segments, lakes, and estuaries) are impaired, primarily from nonpoint source (NPS) pollution (USEPA, 2006a). The Clean Water Act (CWA) (33 U.S.C. §§ 1251-1387) classifies water bodies that do not meet water quality standards as "impaired," and requires development of a total maximum daily load (TMDL) plan to bring these waters into compliance with water quality standards. A TMDL specifies the maximum amount of a pollutant that a water body can receive without violating applicable water quality standards. Development of a TMDL involves conducting a watershed-scale study to identify the sources of the pollutant causing the impairment, quantifying the pollutant contribution from each source, and determining the pollutant reduction required from each source to meet applicable water quality standards.

For industrial sources and sewage treatment plants that discharge through a pipe and hence are classified as point sources, TMDL-induced pollutant reductions are implemented through National Pollution Discharge Elimination System (NPDES) permits

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(USEPA, 1997). For NPS (e.g., agricultural and residential lands, forests, and erodible streambanks), the USEPA guidance links the TMDL implementation with federal funding available to the States according to Section 319 of CWA (USEPA 1997, 2003). To receive funding, state governments are required to develop watershed-based plans to achieve TMDL pollutant reductions for NPS. However, flexibility is given in the watershed planning process such that states can proceed even though some of the information in the watershed plan is imperfect and may need to be modified over time.

Most states have developed guidance or regulations for TMDL implementation, which vary significantly in their requirements. For example, discussion draft of Maryland's TMDL Implementation Framework states only that "detailed [TMDL] implementation planning is often occurring among stakeholders who are most able to establish the plans at a local level," while the "state reserves the option of playing a more direct role in drafting and maintaining [implementation] plans for each TMDL" only "if federal regulations or other circumstances evolve" (MDE, 2006a,b). Similarly, in West Virginia, local watershed stakeholders and state agency personnel have organized into project teams and are responsible for TMDL implementation, with no specific requirements to the process suggested by the State (WVDEP, 2006). In contrast, state law in California mandates TMDL implementation plans to be a part of TMDL development process (California Water Code Section 13000 et. seq.).

In Virginia, state law also requires the State Water Control Board (VASWCB) to both develop TMDLs and implement plans to achieve fully supporting status for impaired waters (Virginia Water Quality Monitoring, Information and Restoration Act, section 62.1-44.19:7). A TMDL implementation plan (IP) is required to describe and quantify a suite of corrective actions [e.g., best management practices (BMP), ordinance changes] to be implemented within a watershed to achieve load reductions, specifies a time line and milestones for achieving water quality goals, outlines a monitoring plan to evaluate progress towards meeting the water quality goals, and describes the costs and benefits of improving water quality (VADCR and VADEQ, 2003). As of November 2007, 24 TMDL IPs have been finalized in Virginia, and 15 of them have been approved by the VASWCB (VADEQ, 2006a).

One possible explanation for the absent TMDL implementation in many states is the lack of incentives for TMDL implementation at the state and local levels. TMDLs often call for significant pollutant load reductions, which can be costly to achieve. On the other hand, benefits to local communities from achieving water quality standards, which is the ultimate goal of TMDL implementation, are usually difficult to quantify. For example, in Virginia, most of the completed TMDL IPs focus on installation costs for pollution reduction activities only (potentially neglecting significant maintenance costs) and contain only a descriptive analysis of the benefits anticipated from achieving TMDL pollutant allocations.

The objective of this study was to evaluate and compare monetary costs and benefits from TMDL implementation and the resulting water quality improvements. Benefits and costs are computed based on a TMDL IP for Abrams and Opequon Creeks in Virginia. Benefits are estimated using a contingent valuation (CV) survey to derive a willingness to pay for water quality improvements by watershed residents. Water quality models are used to evaluate implementation actions necessary to achieve pollutant load reductions required to meet the TMDL. Costs are estimated over a 10 year implementation period from information about similar actions throughout the region.

The next section describes the Opequon Creek watershed, TMDL development, and the TMDL IP. Sections "TMDL IP Costs" and " TMDL IP Benefits" provide details on estimation of costs and benefits from TMDL IP. In Discussion section, comparisons of the benefits and costs show that implementation costs to achieve TMDL pollutant load reduction goals in the Opequon watershed outweigh the estimated benefits.

OPEQUON WATERSHED AND TMDL IMPLEMENTATION

Opequon Creek begins in Frederick County, Virginia, flows east to Clarke County, Virginia, and then north through West Virginia to the Potomac River (Figure 1). The total area of Opequon Creek watershed is about 890 km^2, with the Virginia portion covering about 44% of the area. Current land use in Virginia portion of the watershed is 50% forest, 30% agriculture, and 20% is urban. The watershed is urbanizing rapidly with annual population growth rates in Clarke and Frederick Counties (2.5% and 3.6%, respectively) above the U.S. average (U.S. Census Bureau, 2006).

Opequon Creek is used by local residents for canoeing, kayaking, swimming, and wading. Residents from outside the watershed also come to enjoy the creek; however, their number is small in comparison with the local creek users. There are no significant water withdrawals from the creek. Opequon Creek

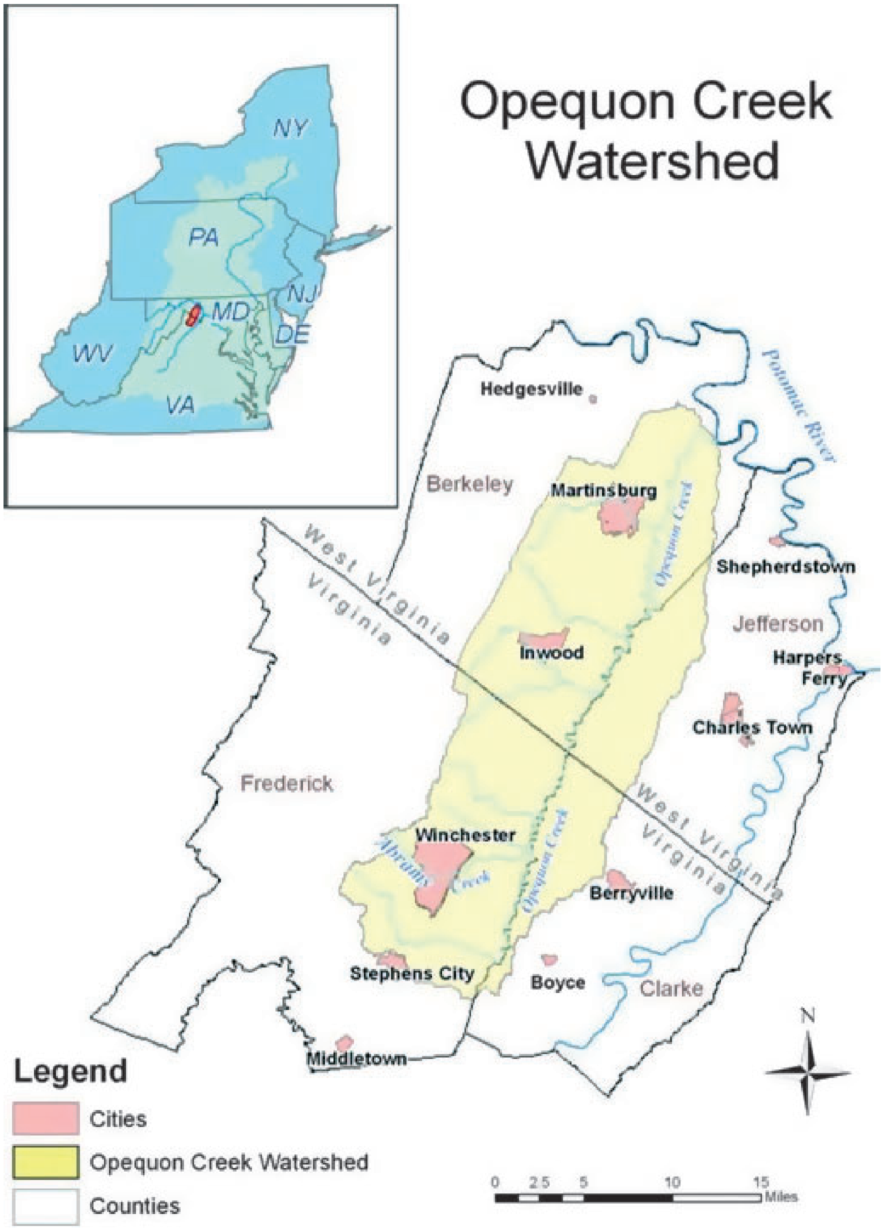

FIGURE 1. Map of the Opequon Creek Watershed.

and its tributaries have designated uses of recreation (e.g., swimming and boating) and aquatic life (e.g., propagation and growth of native fish and benthic macroinvertebrates) (VASWCB, 2006). The support of recreational designated use is determined by a set of chemical and bacteria water quality criteria. Virginia Department of Environmental Quality (VADEQ) monitoring showed violations of the bacteria criteria in Opequon Creek and its main tributary – Abrams Creek, and as a result both creeks were classified as impaired (Mostaghimi *et al.*, 2003a). In turn, aquatic life support is tested against general criterion, which states that "all state waters…shall be free from substances…which…are inimical or harmful to…aquatic life" (p. 7, VASWCB, 2006). The biological monitoring programs by VADEQ showed that Abrams Creek and the portion of Opequon Creek below the confluence with Abrams Creek (referred to as Lower Opequon Creek) did not support "healthy" population of benthic macro-invertebrates, and hence, violated the general criterion (Mostaghimi *et al.*, 2003b). As a result, Abrams Creek and the Lower Opequon Creek were also classified as impaired due to benthic impairment.

TMDL plans for Upper and Lower Opequon and for Abrams creek were developed and approved by VASWCB in 2005 (Mostaghimi *et al.*, 2003a,b). Sediment was identified as the most probable cause of

TABLE 1. Annual Sediment Loading and Allocation Scenarios for Abrams and Lower Opequon Creek Watersheds Under a 25% Build-Out Scenario.

Source	Abrams Creek		Lower Opequon Creek	
	Estimated Loading (ton/year)	% Reduction Required	Estimated Loading (ton/year)	% Reduction Required
Agriculture	1,269	10	13,162	15
Urban	1,419	25	4,018	15
Forestry	30	0	86	0
Channel erosion	319	55	2,275	35
Municipal separate storm sewer systems (MS4) areas	586	25	314	15
Point sources	478	0	1,039	0
Total	4,101	22	20,894	17

benthic impairment in Lower Opequon and Abrams Creeks. Sediment load reductions required to meet the general criterion were estimated using Generalized Watershed Loading Function (GWLF) model (Haith *et al.*, 1992). To account for the expected urban growth in the watershed, TMDL modeling scenarios were developed given 25% increase in commercial areas in two planning zones that are currently experiencing the highest growth (referred to as "25% built-out scenario" hereafter) (Table 1).

In addition, bacteria TMDL plans were developed for the Upper and Lower portions of Opequon creek along with Abrams creek. Bacteria load reductions required to meet state water quality bacteria criteria were estimated using the Hydrologic Simulation Program-Fortran (WinHSPF) computer model (Duda *et al.*, 2001). As VASWCB encourages iterative implementation of TMDLs to provide the opportunity for evaluation of the adequacy of the TMDL limits, two-stage TMDL plans were developed for both Opequon and Abrams creeks.

The Stage 1 TMDL plan focused on bacterial load reduction necessary to remove the "impaired" classification from the creeks, although minimal frequency of violations of bacteria water quality criteria would still remain. The Stage 2 TMDL plan sets a target of 0% violations of bacteria water quality criteria. This paper examines costs and benefits associated with water quality changes for a Stage 1 improvement (i.e., where in Opequon and Abrams creeks are no longer classified as impaired) (Table 2).

To develop a TMDL IP for the Opequon watershed, the following four groups were formed: a resource team, two working groups (agricultural and urban), and a steering committee. The resource team involved representatives from the VADEQ and VADCR, universities in Virginia and West Virginia, and a local watershed organization. The working groups included representatives of stakeholder organizations in the community (watershed organizations, local businesses, wastewater treatment facilities, universities, and federal agencies), community leaders, landowners, and local residents. Working group members were invited to participate at the initial TMDL IP public meeting through media, mailing, and e-mail campaigns. The steering committee consisted of self-selected members from the working groups.

Each working group identified a variety of potential implementation actions. Theses actions were summarized in a matrix format by the resource team. This matrix included the following: lead agency or

TABLE 2. Annual Loadings for Fecal Coliform Bacteria and Load Reductions for Stage 1 of Opequon Creek Watershed Bacteria TMDL.

Land Use Category	Abrams Creek		Upper Opequon Creek		Lower Opequon Creek	
	25% Build-Out Load ($\times 10^{12}$ cfu)	Required Reduction From Build-Out Load (%)	25% Build-Out Load ($\times 10^{12}$ cfu)	Required Reduction From Build-Out Load (%)	25% Build-Out Load ($\times 10^{12}$ cfu)	Required Reduction From Build-Out Load (%)
Cropland	7	0	93	80	205	50
Pasture	2,950	0	13,600	80	21,300	50
Residential	2,770	0	2,580	80	1,430	40
Loafing Lot	2,280	0	297	100	966	100
Forest	1,090	0	583	0	593	0
Non-MS4 Impervious Land Segments	333	60	7	80	7	70
Cattle in Streams	4	20	94	95	16	0
Wildlife in Streams	13	0	13	0	2	0
MS4 Impervious Land Segments	485	60	NA	NA	NA	NA
Point Sources	NA	NA	6	0	33	40

organization responsible for implementation; target locations and audiences; integration with other programs; bacteria and sediment pollution reduction efficiencies; cost per unit; technical assistance requirements; and the availability of cost-share, tax credit, or loans. Next, the matrix was presented to the steering committee who discussed the need for and likelihood of successful implementation for each action. The steering committee then used majority voting to prioritize the actions for inclusion into TMDL IP. Those actions approved for inclusion into TMDL IP were referred to as "high priority actions" (Table A1 in Appendix A). The extent of each of high priority actions required to achieve TMDL pollution load reductions were estimated by the resource team using GWLF and HSPF computer models. Model results were discussed and approved by the steering committee during the summer 2006. More details about Opequon TMDL IP can be found in a report issued by Opequon Creek IP Steering Committee *et al.* (2006).

TMDL IP COSTS

Costs were estimated for installation, maintenance, and personnel requirements of high priority actions identified within the TMDL IP. Installation costs can vary from location to location depending on site-specific factors (e.g., soil type) and specific BMP characteristics (e.g., the type of fence installed for stream protection). To account for installation cost uncertainty, the following three cost scenarios were considered: Low, Medium, and High. Maintenance and personnel cost were assumed to be the same across all three scenarios.

Installation cost data were collected from a NRCS cost information database (USDA, 2006a), a VADCR database of BMP costs (USDA, 2006b), other Virginia TMDL IPs, input from Opequon TMDL steering committee, and personal communications with field professionals. For each high priority action, three estimates of per unit BMP installation cost were estimated from the available sources: minimum, median, and maximum values for the Low, Medium, and High cost scenarios, respectively.

The data from the NRCS and VADCR databases were gathered primarily for Clarke and Frederick Counties. If fewer than 10 cost estimates were obtained for BMPs in the VADCR database, then a larger region (Virginia's Potomac-Shenandoah subbasin) was examined. To account for possible outliers, the largest and smallest cost estimates for each BMP were excluded from the analysis. All costs were adjusted for inflation (USBLS2006; USDA, 2007).

For riparian buffers, the per unit installation cost estimates found in NRCS database were adjusted upward to account for average opportunity cost of crop and pasture land (US$320 per hectare) in Clarke and Frederick Counties in 2003-2007 (Virginia Tech, 2006). In turn, per unit installation cost estimates for cover crops found in VADCR database were adjusted downward to account for nutrient benefits to agricultural producers from implementing this BMP. Small grain winter cover crops were assumed to be used to capture the nitrogen in soil, protect it from leaching, and make it available to the following crops (PSU, 2007). As a result, planting cover crops reduces the need for nitrogen fertilizer application in the following seasons. Nitrogen content of winter rye, one of the most popular small grain cover crop in the region, was estimated at 65.9 kg/ha (PSU, 2007). It was assumed that this nitrogen would be lost through leaching and runoff if cover crops were not planted. Given a cost of US$219.4/ton for urea (Collins and Basden, 2006), planting of cover crops and tilling them back into the soil saved US$26.9/ha in fertilizer costs.

Finally, the average costs of repair of failing septic systems found in VADCR database were used in the Low cost scenario. For Medium and High cost scenarios, average costs from USDA (2006b) for replacement of failing septic systems with conventional systems and with alternative waste systems were used, respectively.

Low, Medium, and High estimates of per unit implementation costs for pet waste education program, geese and duck waste clean-up, and bioretention were based on values reported in other Virginia TMDL IPs, existing literature sources, or personal communications with field professionals. It was assumed that bioretention would be implemented on marginal land owned by municipalities, such as buffer strips and drains along roads and parking lots, or would be integrated into lawn landscapes in residential areas. Hence, the land opportunity costs were ignored in this analysis.

Personnel requirements and costs for the TMDL IP were estimated based on the knowledge of the steering committee and experience of the resource team from similar projects (Table A2 in Appendix A). Costs associated with personnel were estimated to be US$50,000 per full-time equivalent per year. Maintenance costs and practice lifespan for the high priority actions are summarized in Table A3 of the Appendix A. Maintenance costs for pasture management BMP were adjusted downward by the land rent value (Dunford and Whittle, 1999) to account for annual economic benefits that agricultural producers could derive from this BMP implementation, specifically, from feed grains and hay sales.

TABLE 3. Installation, Maintenance, and Personnel Costs Over a 10-Year Period for Sediment and Stage 1 Bacteria TMDL Implementation in Opequon Creek Watershed.

	Installation Cost, Millions of 2006 U.S. Dollars			Maintenance Cost, Millions of 2006 U.S. Dollars	Personnel Cost, Millions of 2006 U.S. Dollars
	Low	Medium	High		
Grazing land protection	0.02	0.12	1.14	0.04	0.43
Stream protection	0.03	0.07	1.40	0.02	-
Riparian buffer zones	0.01	0.04	0.05	0.03	-
Pasture management	0.20	1.69	3.35	1.33	-
Loafing lot management	0.02	0.09	0.18	0.07	-
Small grains cover crop	0.12	0.37	0.84	-	-
Replacement/repair of failing septic systems	0.55	1.27	3.94	0.28	0.43
Pet waste education programs	0.004	0.01	0.01	0.04	0.22
Geese and duck waste clean-up (sweeper)	0.03	0.04	0.06	0.04	0.22
Rain garden	0.86	1.72	4.03	2.92	0.43
Erosion and sediment control inspector	-	-	-	-	0.43
Total	1.84	5.42	15.00	4.77	2.16

All costs (installation, maintenance and personnel) were estimated for a period of 10 years (Table 3). For implementation actions with shorter life spans, replacement costs were included. Discounting was used to convert future costs into their present (2006) dollar values using an interest rate of 2.74% [average of real treasury interest rates for 10-year maturities based on 2002-2006 U.S. budget assumptions (OMB, 2006)].

Cost totals for Low, Medium, and High cost scenarios are summarized in Table 4. Present value costs ranged from under US$9 million to almost US$22 million. For each scenario, the bioretention BMP accounted for the largest share of total costs (ranging from 34% in high to 48% in low cost scenarios). Other major contributors to total TMDL IP cost included pasture management BMP (17-24%) and repair and replacement of failing septic systems (14-21%). Inclusion of maintenance costs for implementation actions added significantly to the total costs of TMDL IP implementation (22-54%, depending on cost scenario). Thus, failure to account for maintenance costs would lead to a significant underestimation of the total TMDL IP costs.

TABLE 4. Present Value Costs for Low, Medium, and High Cost Scenarios of Stage 1 TMDL Implementation in Opequon Creek Watershed.

	Cost Scenario (millions of 2006 U.S. dollars)		
	Low	Medium	High
Present value of total costs for installation, maintenance, and personnel	8.76	12.34	21.92

TMDL IP BENEFITS

The benefits from TMDL were defined as water quality improvements to a level required to support aquatic life and recreational designated uses. To estimate the monetary value of these benefits, CV was used. Despite some controversy over the validity of its estimates (see Diamond and Hausman, 1994 and Hanemann, 1994), CV methods have become well refined over decades in practice (Champ *et al.*, 2003; Mitchell, 2002; Boyle, 2001). CV has been widely used in the economic valuation of water resources (see reviews in Johnston *et al.*, 2005; Duberstein and de Steiguer, 2003; Wilson and Carpenter, 1999). CV involves the use of surveys to elicit respondents' willingness-to-pay (WTP) for environmental improvements. An individual's WTP is equivalent to the enhanced well being that a respondent receives from providing specific environmental improvements (Kramer and Eisen-Hecht, 2002; Mitchell and Carson, 1989).

To properly develop the CV survey instrument, commonly accepted procedures were used. Background information was collected through meetings with the Opequon TMDL steering committee and a local watershed organization, through interviewing local citizens and watershed officials. Other CV water quality surveys were reviewed. Two focus groups were administered along with three pretests of draft survey instruments. The final version of the survey included questions about respondents' use and knowledge of Opequon watershed, their opinion of local environmental quality and improvements to Opequon watershed, and respondents' socio-economic characteristics. Three separate surveys were developed: one for each of the general publics in the

Virginia and West Virginia portions of the watershed and one for riparian landowners in Virginia. Watershed residents in West Virginia were included in the CV survey to reflect the downstream water quality improvements resulting from the TMDL IP in Virginia.

In the WTP questions, Opequon and Abrams Creek water quality improvements associated with TMDL IP implementation were described in terms of a watershed clean-up to improve the safety of swimming and wading (see Table B1 in Appendix B). Virginia respondents were asked how much they would be willing to pay annually over a five-year period for a hypothetical clean-up plan that would lead to such improvements. For West Virginia residents, a similar CV question was phrased using a one-time donation to a hypothetical fund (see Table B2 in Appendix B). Virginia and West Virginia respondents were asked to select their WTP value from a provided range of dollar values (i.e., a modified payment card).

Surveys were mailed to random samples of three sub-populations: 2,300 general public households within four zip code area in Clarke and Frederick counties, Virginia; 200 households of riparian landowners in Opequon Creek watershed in Virginia; and 2,500 households in four zip code areas in Berkley and Jefferson counties of West Virginia. Traditionally, survey sampling procedure focuses on a small sample of respondents and employs multiple rounds of mailing (Dillman, 2000). In the current study, an alternative sampling strategy was adopted which used a larger sample, with only one round of mailings to the general public with a follow-up reminder postcard. This approach was adopted to reduce the time needed for CV study and to meet the overall deadline for TMDL IP development.

Of the 230 Virginia general public returned surveys, 72% were supportive of the clean-up plan. Of the 63 riparian landowner returned surveys, 67% were supportive of the clean-up plan. To estimate WTP among both respondents and nonrespondents, empirical models of WTP as a function of explanatory variables were developed. A generic WTP model can be represented as

$$\mathrm{WTP}_i = \mathrm{WTP}_i(K_i, X_i, S_i), \tag{1}$$

where WTP_i is individual's i's maximum WTP for improved water, K_i represents variables concerning individual i's use and knowledge of the creek, X_i represents variables concerning individual i's attitudes and opinions of local environmental quality including aquatic ecosystems, and S_i represents socio-economic characteristics for individual i.

Grouped tobit models were used to estimate WTP models in Virginia and West Virginia (Benson, 2006). Grouped tobit models allowed us to statistically examine observations of the dependent variable that are both nonnegative and are grouped into responses at specific intervals (Cameron and Huppert, 1989; Greene, 2002; Rosenberger *et al.*, 2005). In this analysis, WTP responses were grouped based on response categories in the modified payment card used in the CV question. For the Virginia general public subsample, statistically significant coefficients were found for variables reflecting recreational use of the creek, concern about aquatic life; beliefs of local environment improvements in recent years; awareness of the TMDL; and respondent demographics (education, age, and household income) (Collins *et al.*, 2006).

The two Virginia subsamples (general public and riparian landowners) were compared and found to be explained by different WTP models (Benson, 2006). Among the general public sample in Virginia, the median WTP was US$48 per household annually. For riparian landowners, median annual WTP per household was about 30% higher at US$62 annually. In West Virginia, the median WTP per household for out-of-state clean-up of the Opequon was US$17 for a one-time payment.

To examine the aggregated benefits, household WTP estimates were aggregated for the entire population in the Virginia and West Virginia portions of the Opequon watershed based on U.S. census data for zip code areas. Because survey response rates were lower than expected, nonrespondent WTP was estimated using the grouped tobit model coefficients multiplied by imputed values from the survey and census statistics for age, income, and education. Nonrespondents were estimated to have a median WTP of US$24 annually in Virginia and a median WTP of US$11 in West Virginia in the form of a one-time donation for a clean-up. Because response rates for riparian landowners were higher than those for the general public, it was assumed that riparian landowner nonrespondents would have the same WTP as respondents to the survey.

Three different present value scenarios were constructed for the aggregated benefits. The scenarios differed by the discount rates assumed to reflect Virginia households' views on the five-year annual tax increase to fund the clean-up plan. Based on literature review, discount rates ranging from 4.25% to 29% were applied to compute the present value of five years worth of WTP (Benson, 2006). The present value estimates ranged from US$2.0 to US$2.75 million (Table 5). As indicated above, these estimates were only based on two specific benefits: improved aquatic life (game fish population) and the safety of swimming and wading.

TABLE 5. Aggregated Monetary Benefits From Improved Aquatic Life and the Safety of Swimming and Wading Within the Virginia Portion of the Opequon Creek Watershed as a Result of TMDL IP Implementation.

	Aggregated, Present Value Monetary Benefits (millions of 2006 U.S. dollars)		
Discount Rate Scenario	**Virginia**	**West Virginia**	**Total**
Low (4.25%)	2.46	0.29	2.75
Medium (11%)	2.17	0.29	2.46
High (29%)	1.71	0.29	2.00

DISCUSSION

Comparisons of the monetary costs and benefits from TMDL IP within the Virginia portion of the Opequon watershed show that present value costs exceed benefits. Total present value costs ranged from US$9 to US$22 million, while aggregated present values benefits ranged between US$2 and US$3 million. These estimates produced benefit-cost ratios between 0.1 and 0.3, much below a desired ratio of 1.0 or greater. Our findings of benefit-cost ratios less than 1.0 contrast with prior research on watershed improvements (e.g., Eisen-Hecht and Kramer, 2002; Subramanian, 2003; and Holmes *et al.*, 2004) but correspond to concerns expressed elsewhere about misbalances between costs and benefits of water quality policy actions (Freeman, 1982, 2002; Callen and Thomas, 2000; and Luken and Clark, 1991).

Both the benefit and cost estimates obtained in this analysis were regarded as reasonable. For Opequon creek watershed benefits, the median annual household WTP for water quality improvements ranged from US$24 to US$62. These monetary values were toward the lower end of ranges reported by Johnston *et al.* (2005) who found annual household WTP values ranging from US US$17.04 to US$248.87 (in 2006 US dollars) for water quality improvements in rivers and streams.

Cost estimates also were comparable to estimates reported by other TMDL IP in Virginia. For example, total cost for TMDL IP for bacteria and nitrate reductions in a portion of North River watershed of Virginia were estimated to be US$13.93 million in 2006 dollars (MapTech Inc., 2001). This estimate included only installation and personnel costs and involved a watershed area less than one-fourth of the size of the Opequon creek watershed. Similarly, a TMDL IP for bacteria reduction in the highly urbanized Four Mile Run watershed of Virginia, reported an *annual* budget of more than US$6 million in 2006 dollars for various programs required to restore water quality in the watershed (TMDL implementation being one such program) (Northern Virginia Regional Commission, 2004).

Similar to other environmental valuation studies [see a review by Wilson and Carpenter (1999)], monetary benefit estimations in our analysis focused on expected outcomes of water quality improvement (i.e., increased game fish population and recreational safety). These outcomes were deemed to be measurable and directly linked to designated uses. Other economic benefits associated with implementation of agricultural BMPs (pasture management and cover crops) also were considered in this analysis.

As with any cost-benefit analysis, there were assumptions and limitations. One important assumption was that monetary benefits were assessed only for local residents. Previous CV surveys to assess the monetary benefits from surface water quality improvements have been conducted primarily on local residents within the affected watershed (for examples, see Collins *et al.*, 2005; Holmes *et al.*, 2004; Brox *et al.*, 2003; Eisen-Hecht and Kramer, 2002; Farber and Griner, 2000; Loomis *et al.*, 2000; Hurley *et al.*, 1999). Some surveys have included recreational users (Duffield *et al.*, 1992; Desvouges *et al.*, 1987), while others have involved aggregation of state (Hite *et al.*, 2002) or national (Carson and Mitchell, 1993) populations. The limited number of CV studies that assess a distance decay function for their sample population beyond the affected watershed have found that economic valuation of water quality protection or improvements declines with distance from respondents' residences to the water resources in question (Pate and Loomis, 1997; Sutherland and Walsh, 1985).

Monetary benefits from Opequon water quality improvements are likely to be small outside the watershed. As a rough estimate, we projected the monetary benefits from the Opequon TMDL IP into the Potomac River watershed. Based on an observed distance decay of monetary values within the watershed (from riparian landowners to Virginia general public to West Virginia general public) and the fact that the Opequon TMDL IP will contribute only about 1% of the required cap load allocation reduction for sediment in the Potomac basin (Chesapeake Bay Program, 2006; USGS, 2003), the monetary benefits from the Opequon TMDL IP were projected to be under US$0.5 million in downstream counties along the Potomac River based on an average value of less than US$1.0 per household. Thus, these monetary values do not alter our benefit-cost calculations.

As a limitation, the TMDL IP will result in a variety of other beneficial outcomes both within the Opequon watershed and on a regional scale that were not estimated monetarily in this analysis. Examples include; (1) increased on-site property values from replacement of failing septic systems or installation of picturesque rain gardens, (2) nutrient load reductions, thereby contributing to restoration of the Chesapeake Bay; and (3) sequestration of carbon, improvement of riparian habitat, and reduction of flooding risks from restoration of riparian buffers. Estimation of monetary values for these benefits would require additional research such as a hedonic property analysis and a broader ecosystem valuation.

Another limitation is that this analysis evaluated *ex ante* estimates of costs and benefits (i.e., the estimates prior to actual TMDL IP implementation and water quality improvements). Harrington (2006) showed that *ex ante* and *ex post* cost and benefit estimates can diverge substantially. Hence, it is possible that an *ex post* benefit-cost ratio actually achieved for the Opequon watershed after implementation of the TMDL IP could be higher.

CONCLUSIONS

This analysis evaluated the costs and benefits of a TMDL IP developed to address bacteria and aquatic-life-use impairments in an Abrams and Opequon Creeks in Virginia. Water quality improvement benefits were estimated using a CV survey of the watershed residents. Costs were based on the number and types of BMPs necessary to achieve TMDL pollution reduction goals. The results showed that the present value costs of achieving TMDL pollution-reduction goals outweigh the present value benefits, with benefit-cost ratios ranging between 0.1 and 0.3.

In addition to aiding decision making within the Opequon watershed, this cost-benefit analysis provides useful information for understanding the TMDL IP process. While development of TMDL plans represents a legal and regulatory requirement for state environmental agencies, federal regulation and guidance for TMDL implementation is limited, especially for NPS portion of TMDL. The primary mechanism for achieving TMDL pollution reduction goals for NPS is federal funding of appropriate implementation measures, and the states are required to develop watershed based plans (an analog of TMDL IP) to apply for the funds. However, USEPA (2003) acknowledged that many states do not have enough information to prepare comprehensive plans, and hence states are offered some flexibility in developing their plans. As a result, TMDL IPs differ significantly among the states.

In addition to the lack of information alluded to by the USEPA, the benefit-cost ratio results reported in this study may potentially explain why some states do not require a detailed IP component of TMDLs. Detailed estimation of costs and benefits as a part of TMDL IP development may result in benefit-cost ratios less than 1.0, as was found in this analysis. These unfavorable benefit-cost ratios most likely would have negative influences on the level of participation and support of local communities and stakeholders for TMDL program.

State agencies have taken two basic approaches to TMDL assessment. First, the lack of specific state requirements for TMDL IPs allows agencies to avoid strict accounting of TMDL benefits and costs (e.g., in West Virginia). Second, benefits and costs can be assessed across all water quality improvement programs within the agency including TMDL implementation (e.g., in Maryland). This bundling approach allows for a joint accounting of costs and benefits, which may result in more favorable benefit-cost ratios for water quality improvement in general.

When estimated costs of water quality improvements are higher than estimated benefits, local residents can be unwilling to participate in TMDL implementation. This reluctance can be overcome by state and federal cost-share programs (e.g., funding associated with CWA Section 319, Environmental Quality Incentives Program, Conservation Reserve Enhancement Program, or Virginia SWCD Cost-Share Program). Thus, cost-share programs are particularly crucial for engaging local communities into successful TMDL implementation when local costs exceed local benefits of watershed improvements.

APPENDIX A. EXTENT, PERSONNEL REQUIREMENTS, AND PER UNIT IMPLEMENTATION AND MAINTENANCE COSTS FOR HIGH PRIORITY ACTIONS FOR OPEQUON TMDL IP

TABLE A1. Extent and Per Unit Implementation Costs for Opequon TMDL IP High Priority Actions.

BMPs for High Priority Actions	Unit	Units Required	Units Cost (2006 US$)			
			Low	Medium	High	Reference
Grazing Land Protection[1]	km	4.2	4,109	31,263	291,952	VADCR, 2006b, Clarke and Frederick Counties
Stream Protection (Fencing)[2]	km	2.2	6,400	15,693	329,925	VADCR, 2006b, Clarke and Frederick Counties
Riparian buffer zones (width?)[3]	km^2	0.2	56,709	218,824	261,799	USDA, 2006a, Clarke and Frederick Counties, adjusted for opportunity cost of land (Virginia Tech, 2006)
Pasture management[4]	km^2	73.4	2,908	24,927	49,419	USDA, 2006a, Clarke and Frederick Counties
Loafing lot management[5]	System	2.0	10,040	45,280	92,966	VADCR, 2006b, Virginia Potomac-Shanandoah subbasin
Small grains cover crops [6]	km^2	7.6	2,446	7,215	16,556	VADCR, 2006b, Virginia Potomac-Shanandoah subbasin, adjusted for saving in fertilizer costs due to reduction in nitrogen loss from soil
Replacement/repair of failing septic systems	System	249.0	2,382 (1)	5,548 (2)	17,134 (3)	VADCR, 2006b; Virginia Potomac-Shenandoah subbasin; (1) repair; (2) replacement; (3) replacement with alternative wastewater system
Pet waste education programs[7]	Program	1.0	3,750 (1)	8,750 (2)	10,000 (3)	(1) Engineering Concepts, Inc. (2006) and VADCR (2006a); (2) MapTech and New River-Highlands (2005); (3) Opequon Creek IP Steering Committee *et al*. (2006).
Geese and duck waste clean-up[8]	sweeper	1.0	15,000 (1)	23,750 (2)	32,500 (3)	(1) Opequon Creek IP Steering Committee *et al*. (2006); (2) average between (1) and (3); (3) Byron Smith, WVU, Facilities Management, personal communications, 12/07/2006
Rain garden	km^2 treated	0.8	1,235,525 (1)	2,471,050 (2)	5,799,945 (3)	(1) VADCR, 2006a; (2) medium for (1), (3), VADCR (2006a), and Engineering Concepts, Inc. (2006); (3) computed assuming treating 1 inch of runoff from treated acre would cost US\$187.2/m^3 (USEPA, 1999), adjusted for inflation.

[1] Establishing rotational grazing by constructing livestock water systems and fences (VADCR, date not found).

[2] Permanent fencing along all streams in a field and installing livestock crossings (VADCR, date not found).

[3] Planting trees and/or shrubs adjacent to streams to protects the waterway from the impacts of surrounding land use (USDA, 2004a, VADOF, 2006).

[4] Pasture and hay planting to provide forage for livestock and reduce soil erosion (USDA, 2004b).

[5] Livestock rotation from lot to lot to maintain vegetative cover and prevent excessive manure deposition (VADCR, date not found).

[6] Vegetative cover on cropland for protection from erosion and the reduction of nutrient losses to ground water (VADCR, date not found).

[7] Pet waste stations; signs, brochures, and public service announcements about the proper pet droppings disposal techniques (SMRC, 2006, VADCR, 2006a).

[8] Purchase and operation of a compact mini street sweeper.

TABLE A2. Technical Assistance Needs Associated With Implementation Actions to Meet Bacteria and Sediment TMDLs in Abrams and Upper and Lower Opequon Creeks Watersheds.

	Personnel Requirements (full-time equivalent/year)
Pet waste education program	0.5
Sweeper/vacuum technician	0.5
E&S inspection	1.0
Septic system technician	1.0
Stormwater BMP technician	1.0
Technical assistance with grazing land protection and stream protection practices	1.0

TABLE A3. Lifespan and Maintenance Costs for High Priority Implementation Actions Identified in Opequon Watershed TMDL IP

		Practice Lifespan		Annual Maintenance	
Implementation Action	**Unit**	**Lifespan, Years**	**Source**	**Unit Cost US$**	**Source**
Grazing land protection	km	10	VADCR, 2006b	1,639	Cost-share rate for stream protection (VADCR, 2006c)
Stream protection	km	5	VADCR, 2006b	1,639	Similar to grazing land protection
Establishment and enhancement of riparian buffer zones	km^2	10	Koehn, 1997	21,794	Based on Klapproth and Johnson (2002), adjusted for inflation.
Pasture management	km^2	10	USDA, 2006b	3,113	Warm season pasture maintenance budget (Virginia Tech, 2001), adjusted downward by the land rent value per pasture acre to account for profits from feed grains and hay sales (Shenandoah Valley weighted average from Dunford and Whittle, 1999; inflation-adjusted)
Loafing lot management	System	10	VADCR, 2006b	4,528	10% of median value of installation cost; professional judgment
Small grains cover crop	km^2	1	VADCR, 2006b	NA	NA
Replacement/repair of failing septic systems	System	More than 10	Beatty, 2005	196	Septic tank pump out, based on USDA (2006b), average for Potomac-Shanandoah subbasin, adjusted for inflation, the smallest and the highest values disregarded
Geese and duck waste clean-up	Sweeper	8	USEPA, 2005	5,000	Opequon Creek IP Steering Committee *et al.* (2006)
Pet Waste Education Program	Program	More than 10	Opequon Creek IP Steering Committee *et al.* (2006)	5,000	Opequon Creek IP Steering Committee *et al.* (2006)
Rain garden	km^2 treated	10	NVPDC and ESI, 1992 NVPDC, 2000	2,697	Average maintenance for two bioretention projects reported in Wossink and Hunt (2003), adjusted for inflation.

APPENDIX B. CV QUESTIONS UTILIZED IN THE VIRGINIA AND WEST VIRGINIA SURVEYS IN OPEQUON CREEK WATERSHED

TABLE B1. CV Question Utilized in the Virginia Survey.

Opequon and Abrams Creeks are currently polluted with dirt and sediment along with sewage and bacteria. Because of these pollutants, no swimming or wading is recommended in the Virginia portion of these Creeks.

Assume that you are asked to vote on a project that would provide the funding required to clean-up Opequon and Abrams Creeks. In approximately five years, this clean-up would make Opequon and Abrams Creeks safe for swimming and wading in the Virginia portion. This project would raise local taxes over a **five year period** to pay for the clean-up project. Would you support, oppose, or remain neutral about this project? *(Please check one)*

_____Support *(Please answer Question 10(b) and then skip to Question 12)*
_____Oppose
_____Remain neutral/ not participate

If you **support** the proposed project, what is the **highest** level of taxes that you would be willing to pay annually (per year) for five years to clean-up Opequon and Abrams Creeks? *(Please circle one)*

$0	$5	$10	$15	$20
$25	$30	$40	$50	$75
$100	$125	$150	$200	$300
$500	$1,000	Other, please specify $_______		

TABLE B1. Continued.

If you **oppose or remain neutral** about this clean-up project, which statement best reflects why you would **not** be willing to provide financial support for clean-up of Opequon and Abrams Creeks? *(Please check one)*

_____I support clean-up of Opequon and Abrams Creeks, but cannot afford higher taxes at this time.
_____I support the clean-up project, but I think someone else should pay for it.
_____I support the clean-up project, but I don't think taxes are the best way to pay for it.
_____I support the clean-up project, but I think it cannot be accomplished as described in Question 10(a).
_____I support improvement of Opequon and Abrams Creeks, but I think that dirt and sediment plus bacteria are not environmental problems in these creeks.
_____I think Opequon and Abrams Creeks are okay the way they are.
_____Other, please specify____________________

TABLE B2. CV Questions Utilized in the West Virginia Survey.

Opequon Creek in Virginia is currently polluted with dirt and sediment, as well as with sewage and bacteria. Clean-up on the West Virginia (WV) side would not solve pollution problems in Virginia (VA). Because of these pollutants, no swimming or wading is recommended in the VA portion of Opequon Creek.

Assume that in addition to cleaning up Opequon Creek in WV, you are asked to participate in cleaning up the VA portion of Opequon Creek by donating to an Opequon Creek Restoration Fund. Recall that as the creek flows from VA to WV, improving water quality on the VA side will result in cleaner water on the WV side (the amount of improvement is unknown). The money from this fund would be used to make water quality in Opequon Creek in VA safe for swimming and wading.

What is the **highest one-time donation** you would be willing to pay for clean-up of the Virginia portion of Opequon Creek? (*Please circle one*)

$0	$5	$10	$15	$20
$25	$30	$40	$50	$75
$100	$125	$150	$200	$300
$500	$1,000	Other, please specify $_______		

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