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Analysis

Pay for Performance: Optimizing public investments in agricultural best management practices in the Chesapeake Bay Watershed

John Talberth [a,*], Mindy Selman [b], Sara Walker [b], Erin Gray [b]

[a] Center for Sustainable Economy, 16869 SW 65th Avenue, Suite 493, Lake Oswego, OR 97035-7865, United States
[b] World Resources Institute, 10 G Street NE, Washington, DC 20001, United States

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ABSTRACT

Agricultural best management practices (BMPs) such as streamside buffer zones and cover crops are increasingly being used to reduce nutrient pollution into water bodies. Eutrophication from fertilizer runoff is the key driver behind growth of hypoxic "dead zones" where fish production comes to a standstill. Governments heavily subsidize BMPs, but do not generally allocate funds to maximize their environmental benefits. But with ever-increasing fiscal constraints, policy makers are searching for ways to enhance efficiency of BMP programs. Pay for performance presents an alternative platform based on nutrient reduction achieved. This paper compares a conventional subsidy approach with pay for performance for BMPs designed to reduce nutrient pollution into the Chesapeake Bay. We model four paired scenarios using a constrained optimization model. In the first pairing we held the level of nutrient reduction constant and compared cost effectiveness of the two subsidy allocation methods. In the second pairing we held the level of program investment constant and compared nutrient reduction outcomes. In both pairings, pay for performance was far superior — delivering identical nutrient reduction outcomes at less than half the cost in the first and delivering two to three times the amount of nutrient reduction for the same budget allocation in the second.

1. Introduction

Non-point source pollution (NPS) from agricultural operations is a leading cause of hypoxic marine "dead zones" worldwide. The extent of these dead zones has increased more than nine fold since 1969 and now encompasses more than 245,000 km^2 (Diaz and Rosenberg, 2008). Continued growth of these marine dead zones undermines global biodiversity conservation goals and poses a significant challenge to meeting the world's increasing demands for capture fisheries and aquaculture (Díaz et al., 2012; Chislock et al., 2013).

By 2050, global population is expected to be 50% larger than today and demand over twice the amount of grain as diets shift up the food chain and overall wealth increases (Tilman et al., 2002). Yield improvements through increased fertilizer applications will be an important strategy for meeting this demand. Recent modeling by FAO suggests that fertilizer consumption could increase from 166 million tonnes in 2005/2007 to 263 million tonnes in 2050 (Alexandratos and Bruinsma, 2012). This could be accompanied by a 2.7-fold increase in nitrogen and phosphorus driven eutrophication of terrestrial, freshwater, and near shore marine ecosystems along with "unprecedented ecosystem simplification, loss of ecosystem services, and species extinctions" (Tilman et al., 2001). Thus, one of the world's most urgent sustainability challenges is to dramatically improve the nutrient efficiency of agriculture so that as crop production increases, nutrient runoff into aquatic ecosystems can be leveled off or reduced (Cassman et al. 2002; Tilman et al., 2002).

Agricultural best management practices (BMPs) such as cover crops, precision conservation, forest buffers, vegetative filter strips and restored wetlands are critical for achieving this outcome. The United Nations Environmental Programme inventory identifies 290 such practices with examples drawn from 55 countries in North and South America, Europe, Africa and Asia.[1] There are many successes to report. For example Bausch and Delgado (2003) and Delgado and Bausch (2005) demonstrated that with remote sensing and precision conservation techniques nitrogen applications could be cut back by 50% in sprinkler irrigated systems. Vegetative filter strips typically remove 50% to 80% of nutrients (Grismer et al., 2006; Blanco-Canqui et al., 2004). In

* Corresponding author.
E-mail addresses: jtalberth@sustainable-economy.org (J. Talberth), msellman@wri.org (M. Selman), swalker@wri.org (S. Walker), egray@wri.org (E. Gray).

[1] United Nations Environmental Programme, Global Programme of Action for the Protection of the Marine Environment from Land Based Activities. Nutrient Management BMP Summary 2012. Available online at: http://www.gpa.unep.org/index.php/global-partnership-on-nutrient-management/unep-gef-global-nutrient-cycle-project/reports-publications-and-policy-toolbox.

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the Chesapeake Bay Watershed a 1 acre restored wetland can reduce nitrogen loads by 57% and phosphorous loads by 70% from a four-acre upland crop area (Scientific Technical and Advisory Committee (STAC), 2008).

Public subsidies are critical for scaling up use of these practices. But public support for BMPs is facing significant cutbacks. In recent years, the US Congress cut over $500 million from US Department of Agriculture (USDA) conservation programs that have been the dominant vehicle for subsidizing agricultural BMPs, and additional large cuts are expected. As such, policy reforms that improve cost-effectiveness must be a priority for continued progress in managing agricultural non-point source pollution. The issue of cost effectiveness is also a global concern. For example, in 2011 the European Cooperation in Science and Technology (e-COST) program concluded a five-year scientific evaluation of the suitability and cost-effectiveness of different options for reducing nutrient loss to surface and groundwaters at the river basin scale. Fourteen papers were produced by this evaluation and appear in a special issue (Issue 2, 2012) of the Journal of Environmental Quality. The search for cost effective nutrient reduction strategies for agricultural lands is also a growing concern in China (Jones and Zhong, 2013).

Typically, subsidies for approved agricultural BMPs in the US are provided on a first come, first serve basis to qualified landowners.[2] This has limited their efficiency and efficacy because they (a) are not directly targeted at nutrient pollution (i.e. as a nutrient tax would be) but for practices that often have unknown or highly uncertain nutrient reduction efficiencies; (b) are not targeted geographically to watersheds and land uses that could represent the greatest return for each dollar spent (Babcock et al., 1997; Wu and Boggess, 1999); (c) are subject to the vagaries of public budgeting (Isik, 2004), and; (d) reduce flexibility of polluters to adopt practices that may be more effective than the list of approved BMPs (Ribaudo and Caswell, 1999). In response, many have proposed an alternative approach — pay for performance. A pay for performance (PFP) subsidy approach would offer subsidies on the basis of actual nutrient reduction achieved and allow producers to adopt whatever practices they deem appropriate using their specialized knowledge. PFP subsidies are a form of payments for environmental services (PES), a policy tool that has garnered widespread international attention in part because it is based on the beneficiary-pays rather than the polluter-pays principle and thus attractive in settings where the providers of environmental quality outcomes are small scale producers, poor, or marginalized landholders (Engel et al., 2008). There is ample evidence that PFP approaches as well as other forms of spatially explicit targeting are more cost effective than practice based subsidies for pollution control because they increase producers' flexibility to choose cost-effective production and pollution abatement options (Davies and Mazurek, 1998; Searchinger et al., 2008; Sterner, 2003; Lankowski and Cattaneo, 2010; Shortle and Horan, 2001; Weinberg and Claassen, 2006). For example, Khanna et al., 2003 determined that a marginal value landowner payment scheme for Conservation Reserve Enhancement Program enrollment based on parcel specific modeling of sediment deposition could achieve sediment abatement goals at 39% lower costs than a conventional productivity-based rental scheme.

The purpose of this paper is to extend the PFP research by considering the benefits of transforming current subsidy programs for BMPs in the Chesapeake Bay Watershed to a PFP platform. We accomplish this by comparing business as usual (BAU) subsidy allocation patterns with results from a constrained optimization model that could inform the design of a PFP allocation system. The model allows users to maximize nutrient reduction across 93 sub-watersheds and 558 farming units with an annual budget constraint for subsidies or, alternatively, minimize costs for achieving a nutrient reduction goal set by the Chesapeake Bay-wide total daily maximum load (TMDL) limits developed by the Environmental Protection Agency (EPA) and affected states. Data for the model were derived from the Chesapeake Bay Watershed Model (CBWM)[3] as well as state-specific nutrient efficiency and cost data for 14 BMPs applicable to cropland, pastureland, and concentrated animal feedlot operations (CAFOs).

The remainder of this paper is organized as follows. In Section 2 we discuss the geographic and policy setting in more detail. In Section 3 we describe the modeling approach, datasets, and policy scenarios. Results are presented in Sections 4 and 5 and discussed in Section 6. In Section 7 we offer concluding thoughts and call attention to key design features that need attention when operationalizing a PFP-based subsidy allocation program.

2. Geographic and Policy Setting

The Chesapeake Bay is a large estuary with a surface area of over 11,500 km^2 located in the US mid-Atlantic coastal region. The Bay is almost 300 km long, with a relatively deep (20 to 30 m) and narrow (1 to 4 km) central channel confined by a sill at its ocean entrance (Kemp et al., 2005). An average of 2300 m^3 per second of freshwater flows into the Bay's 74.4 km^3 water volume, with the Susquehanna River at the northern tip of the Bay providing more than half of the flow (Schubel and Pritchard, 1986). The Chesapeake Bay Watershed is home to more than 17 million people. For over 200 years it provided a rich bounty of crabs, shellfish, and fish, and high quality recreational opportunities. However, as the region's population grew and land was converted from forests to farms and to urban development, the quality of the Bay's waters declined, along with its living resources (Kemp et al., 2005). Significant reductions in pollution discharges from sewage treatment plants, factories, and other point sources have been achieved in the CBW since the 1970s. But these reductions have not been enough to meet established water quality goals because point sources are only part of the problem. In particular, continued heavy nutrient and sediment runoff from non-point sources have contributed to low oxygen levels, algal blooms, decreased water clarity, loss of submerged aquatic vegetation, and declines in fish and shellfish populations (Chesapeake Bay Program, CBP, 2013). Non-point sources, especially agricultural non-point sources, are a major source of the nutrients and sediments degrading the Bay.

The history of efforts to restore the ecosystem of the Chesapeake Bay is emblematic of the failure to solve the agricultural non-point source (NPS) problem. The Bay has been a focal point of federal and state initiatives to reduce nutrient pollution from agriculture and other sources for decades. But little progress has been made. The limited progress has led the US Environmental Protection Agency (EPA) to establish a Total Maximum Daily Load (TMDL) for the Bay. The TMDL calls for reductions in nitrogen (25%), phosphorus (24%) and sediment (20%) entering the tidal waters of the Bay. The states were required to develop watershed implementation plans (WIPs) for achieving load reductions from agriculture and other sources. Although there are some exceptions, the WIP strategies for reducing non-point source nutrient loads largely call for continuing the traditional, voluntary adoption of pollution control practices with financial support from federal, and to a lesser degree, state subsidy programs for BMPs.

Existing subsidy programs have a poor record of improving water quality (Shortle et al. 2012). Despite years of conservation expenditures

[2] There are some exceptions, notably, for lands enrolled in the Conservation Reserve Program (CRP). CRP decision makers use an Environmental Benefits Index to help prioritize lands for enrollment based on provision of wildlife habitat, water quality, reduced erosion, likelihood of longevity, air quality, and cost (Farm Service Agency (FSA), 2012). However, the EPI is not a PFP approach targeted at a specific ecosystem service (i.e. nutrient reduction) as so we do not address it in detail here.

[3] The Chesapeake Bay Watershed Model is maintained by the Chesapeake Bay Program of the Environmental Protection Agency. The model is designed to simulate the Chesapeake Bay watershed, the river flows, and associated transport and fate of nutrients and sediment that contribute to Chesapeake Bay water quality degradation.

80% of cropland in the Bay watershed is in need of additional nutrient management measures (Conservation Effects Assessment Project (CEAP), 2011). One problem is that resources allocated to purchasing environmental improvements through current programs are poorly targeted (U.S. Government Accountability Office (GAO), 2007). A well-targeted program would direct resources to attaining specific, measurable water quality goals through the most efficient means possible — that is, through activities that realize these goals at lowest cost. Effective targeting would prioritize pollution hot spots (e.g., particular watersheds and possibly locations within them) and BMPs to achieve the proverbial "biggest bang for the buck" (Babcock et al., 1997). Current USDA programs are not designed to do this. Program goals include reaching as many farmers as possible, and treating them equally (Nickerson et al., 2010). PFP presents an alternative that may represent a more effective and efficient use of scarce public resources. The remainder of this paper tests that hypothesis.

3. Modeling Approach, Data, and Policy Scenarios

To test the merits of transitioning to a PFP platform for BMP subsidies we created a spreadsheet-based model capable of comparing the cost effectiveness of meeting TMDL nutrient (nitrogen and phosphorous) reduction goals under a business as usual (BAU) subsidy allocation program versus one based on PFP. We also used the model to compare the nutrient reduction achieved by BAU versus PFP for a given budget constraint. The modeling thus addressed two BAU scenarios and two PFP scenarios. The PFP scenarios employed an optimization macro built for Excel that selected BMPs based on their cost effectiveness in delivering nutrient reduction per acre.[4] Spatially explicit optimization models that maximize the benefits of conservation programs for a given budget constraint have proven their worth in a variety of complex policy settings and so are critical to apply here (See, e.g. Wu and Boggess, 1999; Wiest et al., 2014). The BAU scenarios were based on historical trends and targets set forth in watershed implementation plans. These targets were developed not for cost effectiveness, but to generally meet the goal of having a diverse mix of BMPs in use. Thus, they do not represent an optimization approach. Under each scenario the model output consisted of levels of implementation for 14 BMPs, nutrient reduction achieved, total costs, and total public costs. There were five steps involved with constructing the model and populating it with site-specific data from the region.

3.1. Farming Units and Existing Nutrient Loads

An initial step was to divide the watershed into 558 separate farming units that represented aggregations of six farm types within each of 93 subwatersheds or "segments" (Fig. 1). The 93 segments were delineated spatially by the CBWM. The six farm types represent the three major categories of agricultural operations in the watershed and for each of these, good actors and bad actors that reflect various levels of existing BMP implementation. The six farm types and associated variable names used in the modeling were:

1. Cropland using low-tillage techniques, no manure, and nutrient management plans (CropLotil);
2. Cropland using high-tillage techniques, manure, and no nutrient management plans (CropHitil);
3. Pastureland with nutrient management (PastureNM);
4. Pastureland with no nutrient management (PasturenoNM);
5. Concentrated animal feeding operations with manure storage in place (CAFOgood), and;
6. Concentrated animal feeding operations with no manure storage in place (CAFOpoor).

[4] The macro utilized was the open-source "OpenSolver" software. Details are provided at: http://opensolver.org/. Accessed 6/2/14.

The CBWM was queried for data on the acreage for each farming unit in each of the 93 subwatersheds. The acreage of these farming units represents approximately 60% of total agricultural acres in the CBWM. In addition, the CBWM provided data on existing loads for both total nitrogen (TN) and total phosphorous (TP). Load calculations are loads delivered to the Chesapeake Bay, not waters immediately surrounding each farming unit. This is important because due to geological and hydrological factors farming units far upstream have a lower impact than those immediately adjacent to the Chesapeake Bay or its major tributaries and thus influence the targeting of BMPs under our optimization model.

3.2. BMPs, Nutrient Efficiencies, and Costs of Implementation

The CBWM includes 35 agricultural BMPs. We chose to model only 14 that are most commonly implemented and those for which good cost data were available. In order to determine those that were most common, the team conducted surveys and phone interviews with state and federal BMP subsidy program managers. To make our modeling more efficient, we also aggregated variations on some BMPs into one generic category (i.e. various kinds of cover crops into one generic category) and then screened out BMPs for which reliable cost data were lacking. Not all BMPs in the final list are applicable to all farm types. For instance, streambank fencing is a BMP reserved for pastureland uses, while animal waste management systems are reserved for confined animal feeding operations. Furthermore, some of our farming units preclude the application of certain BMPs. For example, the CropLotil farming unit assumes that all acres that are currently under low tillage also have implemented nutrient management. Thus, the model restricted the selection of any new units of these BMPs for farming units of this farm type. Our final list of BMPs and the farm types to which they are applicable is presented in Table 1.

Table 1 also displays our assumptions with respect to maximum nutrient efficiencies. Nutrient efficiencies — often expressed as a percentage of total nitrogen (TN) or total phosphorous (TP) reduced per acre or unit of BMP implementation — vary considerably in our model and across the region in part because of the geographic and hydrological factors that affect delivered nutrient loads to the Chesapeake Bay and partly because they depend on what assumptions are used with respect to prior implementation of other BMPs before the subject BMP's efficiency is modeled. For example, a forest buffer implemented on lands that are already being managed under an approved nutrient management plan will have a lower nutrient efficiency than the same buffer put in place in the same subwatershed on lands not already covered by a nutrient management plan. This reflects the declining marginal efficiency of BMPs as they are implemented sequentially. To control for this, we used efficiency estimates from the CBWM that account for variations across geographies (Chesapeake Bay Program (CBP), 2013) but modified them to account for prior implementation of BMPs that involve land use changes (i.e. forest and grass buffers, wetlands) that take lands out of production and reduce residual loads from upland pastures or croplands. We also adjusted the BMP efficiencies to account for good and bad actors, the latter having no BMPs in place. For example, the phosphorous reduction efficiency for cover crops on low tillage agriculture is zero, but for high tillage it is 9%.

Table 2 displays mean cost assumptions for each BMP. For each BMP, we surveyed state level databases maintained by the USDA's Environmental Quality Improvement Program (e.g. Natural Resources Conservation Service (NRCS), 2011) and cost studies specific to particular watersheds or types of BMPs (e.g. Weiland et al., 2009). We also conducted personal interviews with state-level staff. We gathered three basic types of cost data: (1) implementation or capital costs, which represent up front investments in equipment or structures; (2) annual operating and maintenance costs, such as the planting of cover crops or repair of pasture fencing, and (3) land rental costs, which represent the opportunity costs of land taken out of production for forest and grass buffers or restored wetlands. Not all cost categories are applicable

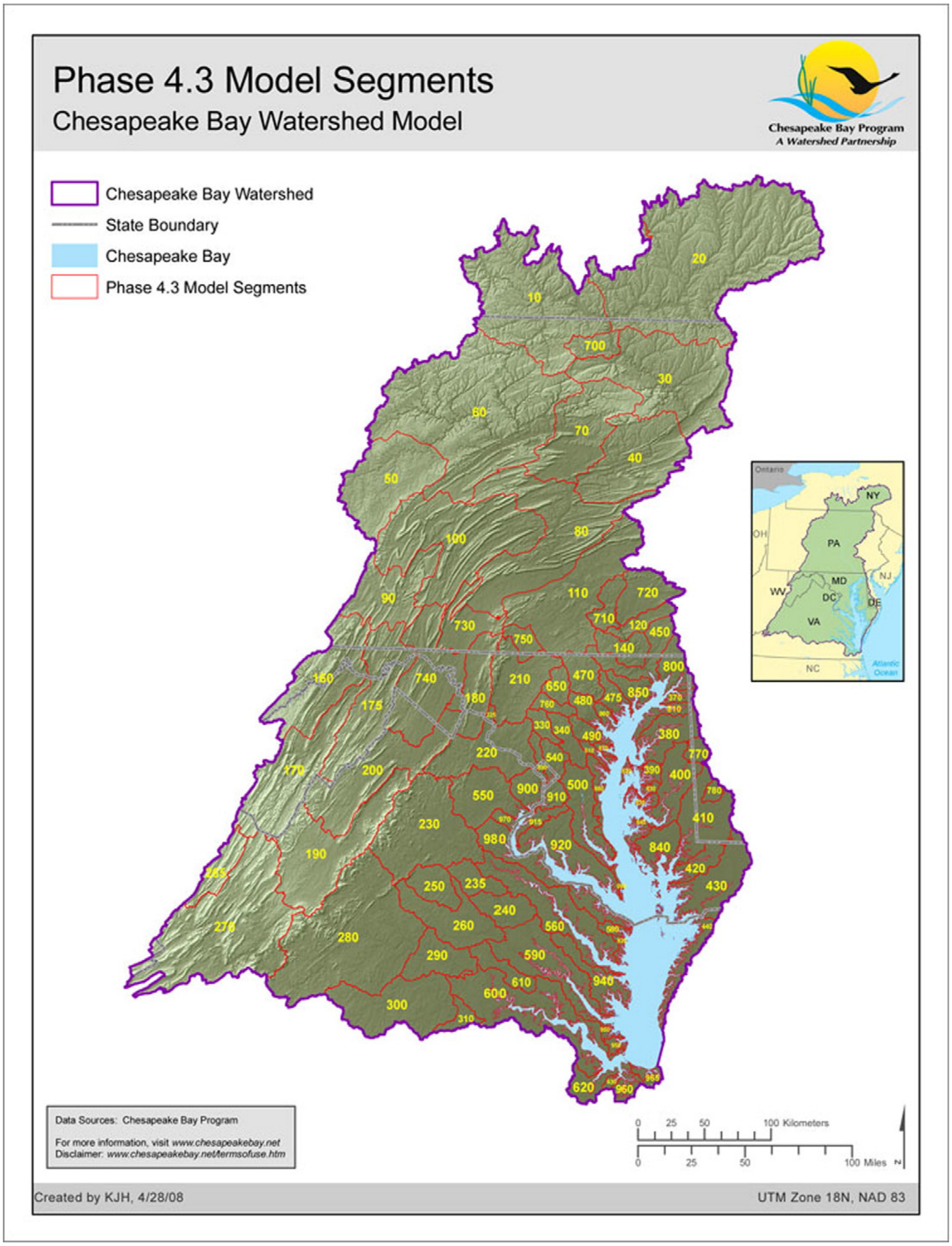

Fig. 1. 93 Subwatershed Segments of the Chesapeake Bay.

to each BMP. Costs varied from state to state (i.e. land rental costs vary significantly due to differences in land productivity) and so we incorporated this variation in the model by using state-specific values and by testing the sensitivity of the results to high and low cost inputs.

To convert these cost data into annual values, we followed the U.S. Environmental Protection Agency (EPA) "two stage discounting" procedure, which is generally used for water infrastructure investments (Environmental Protection Agency, EPA, 2010). The two stage discounting process involves three key steps: (1) annualizing capital costs over the expected life of a BMP; (2) adding annual operating and maintenance costs and land rental costs to this cost stream, and (3) discounting the resulting total cost stream back to the present. Annualized capital costs are adjusted to reflect the opportunity cost of capital (OCC), or the returns private farm owners could have received if the up-front capital expenditures on BMPs were invested. The consumption rate of interest is used to discount the total cost stream back to the present. EPA recommends a baseline rate of 7% for the opportunity cost of capital and 3% for the consumption rate of interest. We used this in our baseline model, but varied both to test the sensitivity of our results.

3.3. Levels of BMP Implementation

For each farming unit, we calculated the following with respect to BMP implementation: (a) the existing level of implementation based

Table 1
Modeled BMPs, Applicable Farming Units, and Maximum Nutrient Efficiencies From the CBWM.

BMP	Farming unit type (s)	Max TN reduction %	Max TP reduction %
Forest buffers	All crop/all pasture	65%	45%
Grass buffers	All crop/all pasture	46%	45%
Wetlands	All crop/all pasture	25%	50%
Nutrient management	CropHitil, PasturenoNM	9%	24%
Enhanced nutrient management	All crop	7%	0%
Conservation planning	All crop/all pasture	8%	22%
Cover crops	All crop	27%	9%
Conservation tillage	CropHitil	8%	22%
Pasture fencing	All pasture	73%	67%
Prescribed grazing	All pasture	11%	24%
Alternative watering facility	All pasture	5%	8%
Animal waste systems	CAFOpoor	75%	75%
Mortality composters	All CAFO	40%	10%
Barnyard runoff control	All CAFO	20%	20%

on data from the CBWM, and (b) a "what-if" scenario of watershed conditions if BMPs are carried out to the fullest extent possible. Data for the latter were based on the "Everything, Everywhere, by Everyone" or E3 study described as part of the overall Chesapeake Bay TMDL (Environmental Protection Agency (EPA), 2010). By subtracting existing levels of implementation from E3 we populated the model with the universe of available BMP units that could be chosen by the model under each of the four policy scenarios described below.

3.4. Policy Scenarios

With these data in hand, we compared business as usual versus pay for performance in the context of four paired policy scenarios. In the first pairing, we held the level of nutrient reduction constant at the TMDL target and compared business as usual trends for BMP implementation and award of cost share assistance (TMDL-BAU) versus a scenario where that TMDL pollution reduction goal was achieved in a least cost manner through PFP (TMDL-PFP). In the second pairing, we imposed a budget constraint on cost share assistance based on historical trends and compared the pollution reduction achieved by the business as usual approach (BUD-BAU) versus a pay for performance approach (BUD-PFP). Both PFP scenarios utilized the Excel-based constrained optimization macro *OpenSolver*. Details of the four scenarios follow.

3.4.1. TMDL-BAU

This scenario assumes full implementation of TMDL BMP targets for our scenario farms as set forth in state watershed implementation plans (WIP II). The scenario assumes that conservation dollars are allocated under a business as usual approach with 75% cost share assistance provided to all landowners who participate, regardless of performance, on a first come, first served basis. We assume that the 75% payments is sufficient (as it has been in the past) to spur participation taking into consideration all known costs, including transaction costs. The CBWM "WIP II" scenario run provides acreage or unit targets for each farming unit and BMP addressed in this analysis. To develop inputs into this scenario, we simply subtracted 2010 BMP implementation figures from TMDL targets for each BMP and manually input the remainder into the cost model. Thus for purposes of modeling, we assume that all TMDL implementation targets are met in the first year of our analysis but that the annualized costs of implementing these would extend over the life of each relevant practice. There were many segments where TMDL targets for certain BMPs have already been met — at least according to the latest CBWM model runs — so we only included those BMPs where the CBM indicates that there was room for further implementation.

3.4.2. TMDL-PFP

This scenario assumes a PFP platform for cost share assistance with the goal of achieving TMDL nutrient reduction targets in a least cost manner. We assume that PFP support is targeted both geographically and quantitatively among practices, meaning that dollars can be spent anywhere in the watershed and that payments are allocated for practices that provide the maximum nutrient reductions at the least cost. BMPs are implemented up to the point where the nitrogen reduction targets have been met. For each farm type, targets (in terms of pounds of TN reduced) were developed proportional to existing loads so that an overall goal of 20% nitrogen reduction across all farming units was met. We did not solve the optimization for TP, but rather assume that the TP reductions "piggyback" on TN reductions since BMPs reduce both pollutants simultaneously. *OpenSolver* was used to select the optimal BMP mix within each of the six farm types to identify the least cost portfolio of applicable BMPs that achieved TMDL nutrient pollution reduction targets at least cost.[5] In particular, for each of six farm types, the optimization was specified as:

$$Min(C*) = \sum_{s=1}^{93}\sum_{b=1}^{14} c_{sb}x_{sb} \tag{1}$$

subject to:

$$x, c, p \geq 0$$

$$\sum_{s=1}^{93}\sum_{b=1}^{14} p_{sb}x_{sb} \geq TMDL$$

$$\sum_{s=1}^{93}\sum_{b=1}^{14} x_{sb} \leq x^{*}_{sb} - x^{2010}_{sb}$$

where C^* is the overall cost of implementing a suite of relevant BMPs (b) at implementation level (x) within each of the 93 segments (s) subject to meeting an overall TMDL nutrient reduction goal for the farm type and the condition that the number of units of each BMP cannot exceed the available units, defined as the difference between the TMDL target for that segment (x^*) and the 2010 levels of implementation (x^{2010}). The amount of nutrient reduction associated with each relevant BMP implemented in each segment is the product of its implementation level (x) and its nutrient reduction efficiency, expressed in pounds (p).

For forest and grass buffers and wetlands, BMP implementation was further constrained to no more than 10% of the total land use acres within each segment to prevent the model from taking the majority of land out of production in any one farming unit. For simplicity, this constraint is not shown in Eq. (1).

3.4.3. BUD-BAU

This scenario attempts to reflect the business as usual allocation of a limited annual budget for conservation funding for BMPs that reduce TN and TP. The BUD-BAU scenario uses an annual budget constraint derived from an analysis of federal and state cost share program data dating back to 2008 (e.g., Virginia Department of Conservation and Recreation (VDCR), 2012). Within the Chesapeake Bay watershed, cost share assistance averages \$53.28 million per year based on these data. We then adjusted this figure downward to \$41.48 million to exclude the nutrient load from agricultural acres not included in our analysis (about 23%). The residual budget was allocated to BMPs in our model based on policy preferences revealed by recent cost share program expenditures. These data indicate strong preferences for animal waste management,

[5] We chose to optimize within as opposed to across all farming units because the portfolio of relevant BMPs is different and because policy makers want to ensure that the burden of nutrient reduction does not fall exclusively on one group.

Table 2
Mean BMP Implementation Costs ($2012).

BMP/units	Installation ($/unit)	Maintenance ($/unit/year)	Land rental ($/acre/year)	Total annualized ($/unit)
Forest buffers (acres)	$1663.57	$19.45	$52.38	$202.53
Grass buffers (acres)	$392.91	$22.51	$52.38	$127.06
Wetlands (acres)	$4882.79	$316.78	$52.38	$781.94
Nutrient management (acres)	–	$28.39	–	$28.39
Enhanced nutrient management (acres)	–	$58.91	–	$58.91
Conservation planning (acres)	–	$2.32	–	$2.32
Cover crops (acres)	–	$67.69	–	$67.69
Conservation tillage (acres)	–	$22.73	–	$22.73
Pasture fencing (acres)	$3920.10	$20.00	–	$315.94
Prescribed grazing (acres)	–	$44.04	–	$44.04
Alternative watering facility (acres)	$121.38	$1.74	–	$9.82
Animal waste management (au)	–	$111.11	–	$111.11
Mortality composters (au)	$1453,37	$2.67	–	$129.12
Barnyard runoff control (acres)	$17,197.09	$154.80	–	$1727.34

barnyard runoff control, and fencing along grass buffers to protect riparian zones. Taken together, these three BMPs represent over 80% of program expenditures. In declining order, the remaining 20% of the budget was allocated to conservation tillage, nutrient management, alternate watering facilities, prescribed grazing, riparian forest buffers, mortality composting, and cover crops. The selection of BMPs and their distribution across farm types and farming units for this scenario was completed by allocating the $48.41 million annual budget constraint to each BMP in proportion to these percentages and then using a simplified run of the optimization model to distribute implementation acres or units for each BMP to each farming unit.[6] Where BMPs are applied to more than one farm type, we simply assumed that the budget constraint for that BMP was divided equally between them.

3.4.4. BUD-PFP

This scenario optimizes the allocation of land-use specific budget constraints to achieve the maximum nutrient reduction possible through a PFP approach. To develop budget constraints relevant to each farm type, we allocated the $41.48 million annual figure to farm types in our model based on shares of total nutrient reduction anticipated by the CBWM WIP II scenario run for each. An alternate method would have optimized the budget allocation across farm types leaving the total ($41.48 million) intact, however, we wanted to mimic the actual policy context as closely as possible. Current policies allocate cost share by state and then by farm type and so we felt this approach was best.[7] As a result of this process, the budget constraints incorporated into the model were: CropLotil ($7.78 million), CropHitil ($15.97 million), PastureNM ($0.19 million), PasturenoNM ($6.58 million), CAFOgood ($0.21 million) and CAFOpoor ($10.75 million). The PFP approach was simulated using an optimization model which allocated BMP implementation within each farm type to maximize nutrient (TN) reduction subject to farm type-specific budget constraints from above in addition to the implementation constraints used under TMDL-PFP. For each farm type, the optimization was specified as:

$$Max(TN*) = \sum_{s=1}^{93}\sum_{b=1}^{14} p_{sb}x_{sb} \tag{2}$$

subject to:

$$x, c, p \geq 0$$

$$\sum_{s=1}^{93}\sum_{b=1}^{14} c_{sb}x_{sb} \leq BUD$$

$$\sum_{s=1}^{93}\sum_{b=1}^{14} x_{sb} \leq x^*_{sb} - x^{2010}_{sb}$$

where TN^* is the reduction of TN achieved by implementing a suite of relevant BMPs (b) at implementation level (x) with nutrient reduction efficiencies of (p) within each of the 93 segments (s) subject to a farm type-specific budget constraint (BUD) and the same implementation constraints described above for the TMDL-PFP scenario.

4. Results

Key results are summarized by Tables 3 through 7. Tables 3 through 6 describe the new acres or units implemented for each BMP, the quantity of annual TN and TP pollution reduced, total costs, public costs, and unit costs. Public costs represent the Chesapeake Bay-wide average cost share assistance for each BMP — a fairly uniform 75% for each state according to federal and state program managers consulted. Nutrient reductions achieved as a percentage from the 2010 baseline for each farm type across the four scenarios are reported in Table 7.

The results provide a compelling justification for further research on how to transition agricultural cost share support programs to a pay for performance (PFP) platform. First, consider the two TMDL scenarios. Under the TMDL-BAU scenario significant investments in all BMPs except alternative watering facilities are implemented to achieve TMDL segment-specific targets and cost share assistance is paid in a business as usual, first come first serve basis (Table 3). BMP implementation results in a 35% (39.24 million lbs) reduction in TN and 35% (2.91 million lbs) reduction in TP across all modeled farm types per year (Table 7). Total annualized costs are in the order of $420 million, of which $315 million would be borne by public agencies. How many years into the future these payments would need to be sustained to keep target BMPs on the landscape is an open question, but for many, contract terms could be up to 15 years or greater and so a considerable amount of this public support would probably be needed annually for quite some time. Unit costs would be $9.97 per pound per year for both TN and TP combined.

In contrast, under the TMDL-PFP scenario BMP portfolios are implemented through a PFP arrangement that seeks to achieve roughly the same level of nutrient pollution reduction achieved under TMDL-BAU but with maximum flexibility for use of cost share funds to support BMPs that are distributed quantitatively and geographically in a least cost manner. Under this scenario, the modeled BMP allocation achieves a 32% reduction (36.2 million lbs) in TN and 29% reduction (2.4

[6] Although we used an optimization model here, it was applied to a very small fraction of the total BMPs and so this scenario overall should not be thought of as an optimal allocation.

[7] For instance, implementation of EQUIP programs in Pennsylvania has different arrangements and funding formulae for crops vs. pastures vs. CAFOs.

Table 3
TMDL-BAU Results.

BMP	New units—year	TN reduced (lbs/year)	TP reduced (lbs/year)	Total costs	Public costs	Costs/lb
Pasture fencing (acres)	45,128	434,813	46,154	$12,934,462	$9,700,847	$26.89
Forest buffers (acres)	122,003	10,087,031	289,350	$32,816,913	$24,612,685	$3.16
Wetland restoration (acres)	31,937	1,791,972	90,590	$20,712,121	$15,534,091	$11.00
Grass buffers (acres)	114,905	6,003,819	259,715	$14,945,823	$11,209,367	$2.39
Conservation tillage (acres)	486,271	1,440,520	238,476	$11,827,216	$8,870,412	$7.04
Nutrient management (acres)	662,608	604,916	185,373	$21,800,311	$16,350,233	$27.59
Enhanced nutrient management (acres)	715,648	2,373,608	0	$40,932,272	$30,699,204	$17.24
Conservation planning (acres)	637,695	1,174,930	126,228	$2,751,336	$2,063,502	$2.11
Cover crops (acres)	454,492	4,612,374	306	$32,569,750	$24,427,313	$7.06
Alternative watering facility (acres)	0	0	0	$0	$0	–
Prescribed grazing (acres)	311,177	347,657	24,779	$14,106,523	$10,579,892	$37.88
Animal waste management (Aus)	1,700,820	9,051,486	1,444,156	$183,467,717	$137,600,788	$17.48
Mortality composting (Aus)	68,419	76,547	3064	$9,156,701	$6,867,526	$115.02
Barnyard runoff control (acres)	14,423	1,238,866	198,895	$22,067,722	$16,550,791	$15.35
	Totals:	39,238,537	2,907,085	$420,088,866	$315,066,649	$9.97

million lbs) in TP across all farm types per year (Table 7). Relative to TMDL-BAU, the selection of BMPs eliminates nutrient and enhanced nutrient management as choices, significantly reduces use of conservation tillage and animal waste management, and makes modest reductions in the use of wetland restoration, prescribed grazing, mortality composting, and barnyard runoff control (Table 4). Although we could expect that overall the number of new BMPs needed would decline as a logical outcome of getting more out of fewer units, there were four categories of BMPs that were favored by the model relative to their TMDL-BAU levels: pasture fencing, forest buffers, grass buffers, conservation planning and cover crops. Total annualized costs for the TMDL-PFP scenario were estimated at roughly $200 million, of which $150 million would be borne by public agencies. Unit costs were calculated to be $5.18 per pound per year for both TN and TP combined. Thus, through a PFP arrangement, TMDL nutrient reduction targets could be met at less than half the cost relative to a business as usual cost share approach.

Similar PFP benefits are demonstrated by the budget constraint scenarios. Under BUD-BAU, cost share support is allocated to practices that represent current policy preferences and is capped at $41.48 million per year. As with the TMDL scenarios, these funds are applied to a mix of practices that have to be supported into an indefinite number of years in the future to ensure that nutrient reduction accomplishments are sustained. The BMP portfolio under this scenario includes investments in ten of the fourteen practices included in our model. Tables 5 and 7 suggest that the annual nutrient reduction achieved by this scenario would represent a 9% reduction (10 million lbs) for TN and roughly 3% (0.9 million lbs) reduction for TP each year relative to current base loads. These are far below the nutrient reduction goals set by the TMDL for all segments (20%). Total units costs would be $5.02 for both TN and TP combined.

In contrast, under the BUD-PFP scenario, the overall $41.48 million annual budget constraint is allocated to BMPs under a PFP arrangement and not constrained or guided by existing policy preferences. Relative to BUD-BAU, this scenario eliminates enhanced nutrient management and alternative watering facilities as practices, significantly curtails use of conservation tillage, prescribed grazing and animal waste management, and reduces the use of grass buffers, mortality composting, and barnyard runoff control somewhat. In contrast, the scenario drastically scales up use of forest buffers, conservation planning, and cover crops. Tables 6 and 7 suggest that the annual nutrient reduction achieved by this scenario would be over 21% (24 million lbs) for TN and over 16% (1.4 million lbs) reduction for TP each year relative to current base loads. The overall goal of TN reduction envisioned by the TMDL (20%) would be exceeded. Total units costs would be $2.18 for both TN and TP combined. Thus, through a PFP arrangement, our analysis suggests that annual TN nutrient reduction could be more than doubled at less than half the cost relative to a business as usual cost share approach.

5. Sensitivity Analysis

Key factors that would affect the results are BMP costs, discount rates, the opportunity costs of capital (OCC) and BMP nutrient reduction efficiencies. Modeling alternative efficiencies was not possible because of our limited access to the CBWM and because that model produces point estimates not ranges for location-specific efficiencies. But varying the other parameters is within our reach. As a preliminary matter, we note that increases in the discount rate decrease overall costs because of the time preference effect, and increases in the opportunity costs of capital (OCC) increase overall costs because gains from alternative investments are that much higher. For example, the annualized costs for pasture fencing in Delaware increase from $240.25 to $257.15 as OCC increases from 7% to 8% and to $281.00 if we also lower the discount rate from 3% to 2%. We also have a range of costs for each practice. We thus created two

Table 4
TMDL-PFP Results.

BMP	New units—year	TN reduced (lbs/year)	TP reduced (lbs/year)	Total costs	Public costs	Costs/lb
Pasture fencing (acres)	45,295	833,720	46,325	$9,070,977	$6,803,233	$10.31
Forest buffers (acres)	128,879	9,470,598	319,653	$33,026,904	$24,770,178	$3.37
Wetland restoration (acres)	4089	64,248	6006	$3,139,721	$2,354,791	$44.69
Grass buffers (acres)	125,451	6,625,504	285,971	$15,746,478	$11,809,858	$2.28
Conservation tillage (acres)	61,126	308,959	28,655	$1,240,159	$930,119	$3.67
Nutrient management (acres)	0	0	0	$0	$0	–
Enhanced nutrient management (acres)	0	0	0	$0	$0	–
Conservation planning (acres)	651,062	3,013,792	312,754	$4,390,259	$3,292,694	$1.32
Cover crops (acres)	483,909	6,748,404	11,491	$30,986,185	$23,239,638	$4.58
Alternative watering facility (acres)	0	0	0	$0	$0	–
Prescribed grazing (acres)	238,656	474,791	32,319	$5,689,950	$4,267,463	$11.22
Animal waste management (Aus)	658,604	6,669,382	1,062,149	$71,043,776	$53,282,832	$9.19
Mortality composting (Aus)	55,891	111,164	4662	$7,105,125	$5,328,844	$61.34
Barnyard runoff control (acres)	11,857	1,896,750	299,044	$18,559,471	$13,919,603	$8.45
	Totals:	36,217,313	2,409,029	$199,999,004	$149,999,253	$5.18

Table 5
BUD-BAU Results.

BMP	New units—year	TN reduced (lbs/year)	TP reduced (lbs/year)	Total costs	Public costs	Costs/lb
Pasture fencing (acres)	0	0	0	$0	$0	–
Forest buffers (acres)	6145	1,283,875	47,426	$1,106,250	$829,688	$0.83
Wetland restoration (acres)	0	0	0	$0	$0	–
Grass buffers (acres)	101,139	3,433,269	165,131	$11,062,503	$8,296,877	$3.07
Conservation tillage (acres)	128,441	759,107	81,522	$2,765,626	$2,074,219	$3.29
Nutrient management (acres)	0	0	0	$0	$0	–
Enhanced nutrient management (acres)	24,177	261,728	0	$2,765,626	$2,074,219	$10.57
Conservation planning (acres)	0	0	0	$0	$0	–
Cover crops (acres)	7285	262,070	2555	$553,125	$414,844	$2.09
Alternative watering facility (acres)	250,468	247,324	16,326	$1,659,375	$1,244,532	$6.29
Prescribed grazing (acres)	25,700	43,277	3958	$1,106,250	$829,688	$23.42
Animal waste management (Aus)	153,831	1,317,715	222,427	$16,593,755	$12,445,316	$10.77
Mortality composting (Aus)	4351	15,745	629	$553,125	$414,844	$33.78
Barnyard runoff control (acres)	10,807	2,473,324	384,366	$17,146,880	$12,860,160	$6.00
	Totals:	10,097,435	924,338	$55,312,516	$41,484,387	$5.02

Table 6
BUD-PFP Results.

BMP	New units—year	TN reduced (lbs/year)	TP reduced (lbs/year)	Total costs	Public costs	Costs/lb
Pasture fencing (acres)	0	0	0	$0	$0	–
Forest buffers (acres)	57,359	7,517,872	207,184	$13,914,710	$10,436,032	$1.80
Wetland restoration (acres)	0	0	0	$0	$0	–
Grass buffers (acres)	98,112	6,861,303	270,566	$12,060,875	$9,045,656	$1.69
Conservation tillage (acres)	1259	12,189	3777	$25,544	$19,158	$1.60
Nutrient management (acres)	0	0	0	$0	$0	–
Enhanced nutrient management (acres)	0	0	0	$0	$0	–
Conservation planning (acres)	2,432,483	3,750,690	397,246	$4,959,873	$3,719,905	$1.20
Cover crops (acres)	218,195	2,751,864	6748	$9,697,916	$7,273,437	$3.52
Alternative watering facility (acres)	0	0	0	$0	$0	–
Prescribed grazing (acres)	2570	4687	107	$39,923	$29,942	$8.33
Animal waste management (Aus)	48,385	735,072	123,837	$5,219,346	$3,914,510	$6.08
Mortality composting (Aus)	1673	13,876	550	$212,691	$159,518	$14.74
Barnyard runoff control (acres)	5809	2,335,153	364,428	$9,181,637	$6,886,228	$3.40
	Totals:	23,982,706	1,374,442	$55,312,516	$41,484,387	$2.18

additional models based on a package of (1) low practice costs, a discount rate of 4%, and an OCC of 6%, and (2) high practice costs, a discount rate of 2%, and an OCC of 8%.

Results are reported in Table 8 for the low, baseline, and high cost models. For the TMDL analyses, results are comparable across all scenarios in terms of cost reduction potential. The PFP approach is modeled to reduce costs by 52% to 57% over BAU. For the BUD analyses, the results were somewhat surprising. While the overall nutrient reduction achieved by PFP predictably fell with higher costs and rose with lower costs, nutrient reduction gains relative to BAU under the high (350%) and low cost (252%) models were substantially higher than those achieved by the baseline model (130%). This demonstrates the complex, non-linear nature of modeling different cost assumptions, but nonetheless seems to corroborate our findings and imply that our baseline results may in fact be quite conservative.

6. Discussion — What are the Tradeoffs?

While our results demonstrate that at PFP platform may be substantially more cost effective and efficient than a BAU subsidy allocation program, the results must be put into perspective in relation to other program objectives. In other words, what are the tradeoffs? Two tradeoffs may be particularly important to consider: equity and ecosystem services. With respect to equity, subsidies are often targeted at farmers with limited financial resources and those below a certain gross income threshold.[8] In addition, subsidies are now allocated to equitably distribute the burden of conservation across watersheds. For example, Conservation Reserve Enhancement Program targets are often set on a watershed basis rather than regions (Yang et al., 2003). Allocating subsidies in accordance with PFP may subvert these objectives. As an illustration, in the TMDL-BAU model for the CropHiTil land use, cover crop subsidies were allocated to farms along 79 of the model's 93 watershed segments for a total of 486,271 acres. In the TMDL-PFP approach, only 5 watershed segments were selected with a total affected acreage of 61,126. Given the dramatic shift in the pattern of subsidies it is likely that both financial and geographic equity objectives would not be achieved under PFP.

Ecosystem service provision represents another key objective of agricultural BMP cost share programs, especially those that convert farm or pastureland to forest or grass riparian buffers and wetlands. The ecosystem service values from these land use conversions are substantial. In a New Jersey study, Costanza et al., 2006 found a mean ecosystem service value of $3852 for riparian buffers in 2012 dollars. To the extent that switching from a BAU to PFP platform stimulates more or less of these land use changes, significant economic impacts could result and complicate our findings. As an example, consider the number of acres enrolled in forest buffers, grass buffers, and wetland buffers in our modeling. Under the TMDL-BAU scenario, our model projects 268,845 additional acres protected with these BMPs. Under the TMDL-PFP scenario, the total is projected to be 258,419. Ecosystem service values on the 10,426 buffer acres not enrolled under PFP could be substantial — $40.16 million per year if we use the Costanza et al., 2006 figure — and thus reduce the cost advantages reported in Table 8. But it is important to note that a PFP platform may increase or decrease buffers depending on relative cost and efficiencies as compared with other BMPs. In our modeling, for example, the number of forest and grass buffers with PFP increased slightly relative to BAU, but the number of wetland acres was lowered significantly and thus the latter effect dominated. A complete analysis of ecosystem service effects for this analysis was not possible due to the lack of location specific ecosystem service

[8] For example, the US Environmental Quality Incentives Program (EQUIP) offers higher cost share percentages for historically underserved producers and bars assistance to farms with gross incomes above $900,000 per year.

Table 7
Nutrient Reduction From Baseline (2010) Levels Across Farming Units and Scenarios.

Farming unit	TMDL-BAU		TMDL-PFP		BUD-BAU		BUD-PFP	
	TN%	TP%	TN%	TP%	TN%	TP%	TN%	TP%
CropLotil	−19.06%	−3.40%	−18.58%	−4.49%	−0.67%	−0.00%	−8.87%	−4.28%
CropHitil	−57.48%	−48.13%	−52.91%	−42.87%	−8.79%	−10.31%	−53.51%	−45.12%
PastureNM	−10.83%	−14.43%	−10.54%	−15.31%	−2.62%	−3.17%	−5.16%	−9.64%
PasturenoNM	−22.80%	−24.72%	−23.02%	−17.25%	−13.48%	−0.66%	−12.16%	−9.62%
CAFOgood	−11.61%	−11.07%	−11.61%	−11.95%	−29.91%	−30.70%	−2.22%	−2.40%
CAFOpoor	−61.80%	−61.64%	−51.53%	−50.86%	−20.01%	−20.02%	−18.52%	−18.39%
All	−35.03%	−34.70%	−32.33%	−28.75%	−9.01%	−2.77%	−21.41%	−16.40%

values for these BMPs but this is certainly an issue to address in future modeling and in PFP program design.

7. Summary and Concluding Thoughts

The pervasive and growing problem of hypoxic dead zones coupled with increasing fiscal constraints on agricultural subsidy programs for BMPs provides the motivation to investigate ways to make such programs more cost effective while simultaneously boosting their environmental payoff in terms of nutrient pollution abatment. As suggested by this modeling exercise, switching from a traditional “first-come-first-serve” to a pay for performance (PFP) subsidy allocation platform may fit this bill. In two constrained optimization settings, we demonstrated that a PFP approach to allocation of public cost share support for BMPs in the Chesapeake Bay Watershed has the potential to achieve nearly identical nutrient reduction goals at less than half the cost or, alternatively, double or triple the nutrient reduction with the same amount of funding through existing state and federal funding sources. While the case for PFP suggested here looks promising, the institutional design of PFP needs careful attention to ensure that these benefits are fully realized and that other program objectives are not subverted.

For example, despite its characterization in theory, PFP cannot be thought of in practice as a system whereby farmers cash in nutrient reduction tokens ex post facto after implementing BMPs. There is simply no way to design a program as such. Instead, presumed reductions would need to be made ex ante, and funding streams could be targeted in order of diminishing returns until exhausted. But to do this accurately, the ever-shifting landscape of BMPs being implemented must be closely monitored since prior implementation of any given BMP in any given location affects the nutrient reduction potential of subsequent BMPs and thus the performance payment. Investing in state of the art monitoring systems to accomplish this would reduce PFP's overall economic advantage, but probably not by much since the magnitude of cost savings suggested here could run hundreds of millions each year and decent monitoring systems just a fraction of that.

As another example, in agricultural BMP programs and other environmental policies transaction costs are always a difficult dilemma (Bohlen et al., 2009; McCann et al., 2005). Regardless of whether or not a cost share program manager identifies and prioritizes a list of BMPs for implementation, farmers may face significant transaction costs in adopting new practices. This may confound the efficiency of PFP if it is biased towards participants that are familiar with BMP programs or enjoy economies of scale irrespective of the priority of the lands they manage in the BMP implementation que. In the past, programs like those managed by the Natural Resource Conservation Service have doubled (or more) land rental payments to compensate for these transaction costs, and such a mechanism should probably be continued for PFP as well.

Table 8
Sensitivity Analysis.

Objective/scenario	Low cost (r = 4%, OCC = 6%)	Baseline (r = 3%, OCC = 7%)	High cost (r = 2%, OCC = 8%)
Cost to meet target ($2012 mil.)			
TMDL-BAU	$341.12	$420.09	$626.91
TMDL-PFP	$148.15	$200.00	$301.03
Difference	$192.97	$220.09	$325.88
% diff from BAU	−57%	−52%	−52%
TN + TP reduction (million lbs.)			
BUD-BAU	12.78	11.02	5.32
BUD-PFP	32.28	25.36	21.85
Difference	19.50	14.34	16.53
% diff from BAU	252%	130%	311%

Another issue is the harmonization of PFP with other policy objectives. As we noted above, equity and ecosystem service provision are two important goals for subsidy programs that may conflict with a PFP platform. It may be more important for the burden of nutrient reduction to be shared equitably among all producers regardless of the inefficiencies involved. Likewise, expanding the presence of forest, grass, and wetland buffers on the landscape may be a worthy economic investment even if they have a lower bang for the buck in terms of nutrient reduction because of the ecosystem service benefit streams they generate in perpetuity. In the context of PFP, one way to deal with these other program objectives is through constraints that, say, require a minimum contribution from each subwatershed for priority BMPs or to redefine performance goals to include other ecosystem services in addition to nutrient reduction.

Despite these complexities, the magnitude of cost savings and increase in overall program efficacy suggested by this research warrants a more in depth examination of these and other PFP design options.

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