Costs and Cost Efficiencies for Some Nutrient Reduction Practices in Maryland

For: NOAA Chesapeake Bay Office and Maryland Department of Natural Resources

By: Robert Wieland*, Doug Parker**, Will Gans**, and Andrew Martin**

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*   Main Street Economics, LLC
** University of Maryland, Department of Agricultural and Resource Economics

Executive Summary

This report develops cost estimates and cost efficiencies for a number of nutrient mitigation[1] best management practices (BMPs) employed to restore the ecological health of the Chesapeake Bay and its tributaries. Cost estimates are based on either or both *constructed costs*, using input prices and information about the production process, and *program costs*, using actual payment histories from programs that aim to expand BMP implementation. Cost efficiencies are then calculated using these estimated costs in tandem with technical efficiencies defined in research undertaken by the Chesapeake Bay Program (CBP) and the Mid-Atlantic Water Program (University of Maryland).

Costs are assessed for 12 BMPs (under 8 headings) and, for most of these, cost efficiencies are developed. These cost efficiencies relate the costs of implementing and maintaining the BMP to the amount of nutrients they keep out of the bay. In order to know the amount of nutrients kept out of the bay by the BMP, it is necessary to know the amount of nutrients that would have reached the bay in the absence of the practice. The report uses the Chesapeake Bay Model's (version 5.1) edge of stream loads as the basis for estimating those nutrient loads. The discussion is simplified by focusing the cost efficiency calculations on nitrogen (N) reduction: but, calculating similar efficiencies for phosphorous and suspended solids is also practicable.

The three BMPs for which cost efficiencies are not estimated are off-stream watering (and two subsidiary BMPs), conservation planning and conservation tillage. It was possible to cost a general scenario for off-stream watering and the associated BMPs, but it was unclear what the nutrient loads are in the absence of the practices. Conservation planning posed a problem for costing any general scenario, since that BMP's reduction efficiencies are based on an undefined rate of implementation for a number of different conservation practices. Conservation tillage is estimated to have a negative cost and, under this condition, the cost efficiency measure used in the report ($/lb) is less useful.

Cost Efficiency Findings

The estimate of costs for cover crops is straight-forward. This is an annual practice with well-defined requirements for implementation. Costs varied by cover crop seed and planting practices. Because cover crop reduction efficiencies are calculated over a range of implementation practices and conditions, 44 different combinations of practice costs and per pound N reduction efficiencies (cost efficiencies) can be estimated. This range of cost efficiencies provides a basis for optimizing purchases of nitrogen reductions by cover crops and this is taken up in the discussion chapter (Chapter 3).

The estimate of costs for off-stream watering is more complicated, as there are a nearly infinite number of permutations of the practice. A well-specified scenario is developed, based on specific animal stocking rates, field lay-out, and stream crossings. The cost of this scenario is

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[1] Throughout this report, the terms nutrient mitigation and nutrient reduction are used interchangeably.

estimated at a size of 50 acres for each of three BMP practices (i.e., off-stream watering without fencing, with fencing and with a hardened stream crossing). As noted above, cost efficiencies are not estimated for these BMPs.

Riparian Buffers also offer a challenge with respect to accurate costing of implementing and maintaining the BMP. Cost estimates from the literature and costs gathered under the study are reported, but these costs are highly variable, depending on the specific practices required. Since most riparian buffers are implemented as a result of incentives provided by various public sector programs, the costs paid under those programs are used as an approximation of practice costs for both forested and grassed riparian buffers. The report provides an example of cost efficiencies for riparian buffers applied on a specific upland land-use and over a range of geological types. But it is noted that these efficiencies will change, depending on which specific land-uses are upland from the practice.

Wetland restoration and creation costs are also estimated using publicly funded program costs, although it is noted that these are much lower than the costs reported by a firm that undertakes wetland restoration. An innovative, non-linear equation (Jordan et al., 2007) is used for calculating the nutrient removal efficiencies of wetlands depending on their size, relative to the area that drains into them. Cost efficiencies are estimated for a drainage area of 100 acres and ten different wetland sizes, but for a single upland land-use. Other upland land-uses will generate different cost efficiencies, and these can be calculated using the appropriate loading rates and the reduction efficiencies shown in the example.

Conservation planning is an amalgam of different practices that carry different implementation costs and which (presumably) have different nutrient mitigation efficiencies. However, a single, pooled efficiency is provided for this suite of practices. The contribution of each practice to this pooled efficiency is unknown, so estimating costs of implementing those practices is not sufficient to generate an appropriate cost for the BMP.

Forest harvest BMPs are practices undertaken on forestland to mitigate increases in nutrient loads that result when harvests take place. This BMP includes a range of practices implemented in uncertain combinations, similar to conservation planning, above. However, in the case of forest harvest practices, literature values were available from field research on the cost of implementing the BMP over a range of sites in Virginia (Aust et al. 1996). Those costs were used to estimate cost efficiencies for the practice.

Conservation tillage provides an example of the much sought-after win-win BMP in which benefits exceed costs for the implementer while also providing benefit for the nutrient mitigation objective. Since adopting conservation tillage provides net monetary benefits for the implementer, the practice has a negative cost. Reduction efficiencies are reported for a range of land-uses, but cost efficiencies are confounded by this negative cost and are not reported.

Stormwater management BMPs present considerable challenges for accounting costs of implementing and maintaining the BMP. The report uses recently revised guidelines promulgated by Maryland Department of the Environment (MDE) to develop scenarios for three different stormwater BMPs (dry detention basins, extended dry detention basins and wet ponds).

These scenarios are driven by expectations about the amount of impervious surface to be mitigated by the BMPs and runoff expectations as modeled by MDE's Stormwater Manual. A set of costs are developed using averages of county-specific cost schedules and cost efficiencies are calculated for stormwater BMPs on three different sized sites.

Using the cost efficiencies

The BMP costs and cost efficiencies developed in the report reveal significant variance, both across BMPs but also with respect to any single BMP. These numerous cost efficiencies need an organizing principal to be generally useful. Since practices with higher cost efficiencies (i.e., a smaller ratio of $/lb) provide greater nutrient reduction per dollar spent, the report suggests a hypothetical rank ordering of cost efficiencies with respect to individual BMPs. By rank ordering cost efficiencies from highest to lowest, a supply curve for nutrient mitigation can be approximated for some BMPs.

The cover crop BMP is used as an example of how one might enhance nutrient mitigation by changing the thing being bought. Current programs generally pay a fixed price for BMP implementation, independent of the actual number of pounds of nutrient mitigation that might result from the BMP. With the more precise specification of nutrient mitigation outcomes available for cover crops, it is possible to suggest a framework for pricing actual reductions. The current cover crop program pursues some of these efficiency gains by offering premiums for more efficient practices, but this approach does not achieve the level of reductions that could be obtained using the expected load reduction efficiencies and the price mechanism.

In addition to the efficiency gain possible from more precise valuation of a well-researched, short-term nutrient mitigation practice, the report points out that valuation of longer-term BMPs (such as riparian buffers) can be used to evaluate how those are purchased. Considering a more realistic time frame for riparian forest buffers, it can be shown that the prices of permanent easements are in the range of the current value of periodic payments made over the long term (60 years). If one strips away the time value of money, paying for permanent easements on forested buffers is clearly cheaper than paying current incentive costs over the long term. Including the time value of money, it is less clear that permanent easements are cheaper.

The report concludes with suggestions for future research.

Table of Contents

List of Tables

List of Figures

List of Abbreviated Terms

A: Acres
BMP: Best Management Practice
CREP: Conservation Reserve Enhancement Program
CBP: Chesapeake Bay Program
CP: Coastal Plain
CP#: Conservation Practice #
Edge of stream loads: Chesapeake Bay Program Watershed Model Phase 5.1 Edge of Stream Loads
ED: Extended Detention
EQIP: Environmental Quality Incentives Program
FSA: Farm Service Agency
FY: Fiscal Year
MDA: Maryland Department of Agriculture
MDE: Maryland Department of the Environment
N: Nitrogen
NRCS: Natural Resources Conservation Service
NM: Nutrient Management
PY: Program Year
TN: Total Nitrogen
TP: Total Phosphorus
TSS: Total Suspended Solids
USDA: United States Department of Agriculture

1. Project Goals and Approach

This report describes cost estimates and cost efficiencies for a number of practices designed to reduce nonpoint source pollution with special reference to Maryland. It incorporates findings from a review of the nutrient mitigation efficiencies recently completed for a number of Best Management Practices (BMPs)[2] in the Chesapeake Bay drainage. Those mitigation efficiencies were established through a review of the science literature undertaken in 2007 and 2008, and through a broad-based vetting process involving a number of Chesapeake Bay Program committees and sub-committees.

The review of BMP technical efficiencies provided definitions of the nutrient mitigation practices that were generally sufficient to establish estimates of average or representative implementation costs. Those costs were compiled under the current project and applied to each BMP as described in the following chapter. By costing the practices required to achieve nutrient pollution mitigation and then pairing those cost estimates with the technical efficiencies, *cost efficiencies* were derived for a sub-set of practices.

Because the technical efficiencies for nutrient mitigation practices are given in percentage terms, cost efficiencies measured in dollars per pound of nutrient reduction ($/lb) require information about the nutrient loads available to be reduced when any given BMP is applied. For those measures, the project used Program Watershed Model Phase 5.1 edge of stream loads (hereafter referred to as edge of stream loads). With those load estimates, it was possible to show mitigation efficiencies in $/lb, depending on the land-use on which any given BMP was applied. For convenience, the report focuses on nitrogen (N)[3] throughout its discussion of reduction efficiencies.

The cost and cost efficiency estimates developed in this study are vulnerable to several sources of error. Important among these are: measurement errors in the pricing of inputs for implementing BMPs, imprecision in the technical efficiencies, and inaccuracies in the loading rates.

Input prices were obtained from USDA and MDA time series, when available, and from commercial suppliers when official data series were not available. Costs are reported in 2007 dollars and, when non-2007 prices are used, they are converted using the producer price index for major agricultural commodities to 2007-dollar values. But even with this adjustment for changes in general price levels, the prices of inputs can vary, making our estimates time-limited. Costs were averaged across the entire state in order to generate a single practice cost. In some cases, significant information may be lost in that averaging.

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[2] This review was captured in a series of monographs supported by the Mid-Atlantic Water Program (UMD) and compiled by Tom Simpson and Sarah Weammert, posted at: www.mawaterquality.org/bmp_reports.htm

[3] Nitrogen is often, though not always, a limiting factor for biological processes leading to eutrophication (see Kemp et al. 2005). In cases where phosphorous is the limiting factor, phosphorous loadings and mitigation efficiencies could be paired with the BMP cost estimates to establish cost efficiencies with respect to that nutrient.

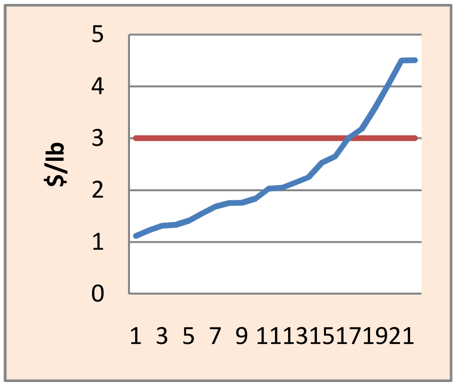
The technical efficiencies for BMPs are taken as reported in the Simpson and Weammert review. For some BMPs, implementation practices vary considerably even though there is only a single, general technical efficiency estimate. These cases are pointed out in the following chapter. While there appears to be scope for refining the technical efficiencies of BMPs with respect to the variable conditions surrounding their implementation, a critical assessment of the technical efficiencies was not part of this project. But clearly, cost efficiency estimates will change if implementation practices have divergent costs, while the technical estimate of the nutrient load reduction stays constant.

With respect to the load estimates, $/lb cost efficiencies are sensitive to changes in the nutrient loads available to be mitigated. The significance of this factor becomes apparent in the distinction between coastal plain and non-coastal plain regions of the state used throughout the report. The edge of stream load estimates show the non-coastal plain to have considerably greater nutrient export, which improves the cost efficiency of a given BMP applied on those acres relative to the coastal plain. There is little doubt that more precise estimates of nutrient loads could be obtained for any specific acres where BMPs are implemented. But, the Chesapeake Bay model's estimates provide a more broad-based measure of nutrient loads and, for that reason, better serve the purpose of the current project.

This potential error notwithstanding, the costs and cost efficiencies compiled here provide useful information about resource costs and nutrient load mitigation. The study uses a consistent approach across BMPs to establish costs and returns denominated in pounds of nitrogen mitigated. While the set of BMPs examined was limited to a sub-set of those supported through public budgets and certified by the Chesapeake Bay Program (CBP), the methods are replicable and alternative practices can be measured in the same manner as those treated in this report.

In addition to generating cost efficiency estimates, the study addresses some of the ways in which these measures can be used to improve the application of resources for optimal nutrient load mitigation. A condition that becomes clear in the second chapter this report is that there are more cost efficiencies for many of these BMPs than can be displayed conveniently in two dimensional tables. While it is not difficult to build datasets that will compile this information, the bigger question is how to make use of it all.

Since there is a range of different cost efficiencies, even for a single BMP, it is possible to imagine rank-ordering those cost efficiencies from lowest cost to highest cost and displaying them in a graph of $/lb over quantity of nutrient mitigated. This would approximate an upward-sloping supply curve for nutrient mitigation for that BMP. Picking a price on the $/lb axis and drawing a line parallel to the horizontal axis until it intersects the supply curve tells us which reductions are likely to be supplied (i.e., those cost efficiencies below the price line) and which ones are not, at the selected price. The accompanying graph shows this for 22 different cost efficiencies from the cover crop data.



Competitive markets for goods and services force the sort of rank-ordering imagined above. However, in order for this to happen someone needs to offer a price for the desired good or service – in this case, nutrient mitigation. As discussed in Chapter 3, this is not what happens under existing programs supporting the implementation of BMPs. Under existing programs, farmers are reimbursed for implementing practices, generally at some fixed rate per acre or per unit of implementation. While some programs, such as Maryland's cover crop program, seek greater nutrient reductions with incentives that motivate implementation practices with greater cost efficiency, such programs can only go so far before they become overly complicated.

Chapter 3 provides an example of how pricing the desired service – nutrient mitigation by cover crops – could change nutrient mitigation outcomes. By using the technical efficiencies, nutrient loading rates and cost estimates as if they accurately capture what is happening on specific acres on which cover crop practices are implemented, it is indicated that greater nutrient reductions could be achieved at a lower total cost by basing payments on those expected nutrient load reductions. In practice, such a shift in the allocation of public funds would require confidence in the technical efficiencies for the BMPs over a range of relevant conditions. Consideration of such a change draws attention to this important and unfinished component of the problem.

Appended to the report is a description of the datasets constructed under the project to estimate costs and cost efficiencies. With this appendix and an accompanying dataset, an up-to-date costing of practices could be maintained. Such updated estimates of costs and cost efficiencies could be useful for allocating resources to reduce nutrient loads into the Chesapeake Bay and its tributaries.

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2. BMP Descriptions, Costs and Cost Efficiencies

2.1. Cover Crop Practices

Winter cover crops can significantly reduce nutrient and sediment export from cropland that would otherwise lie fallow and without cover in the winter. Technical efficiencies are reported in Simpson and Weammert (2007) by planting period for the three major small grain winter cover crops (wheat, barley and rye) across the three major planting practices. These efficiencies are then factored across two major geological possibilities – coastal plain/piedmont crystalline/karst and Mesozoic lowlands/valley and ridge silisiciclastic (hereafter, coastal plain and non-coastal plain). In total, this results in 44 different cover crop reduction efficiencies that vary by seed type, planting method, planting time, and geology.

Costing cover crop practices entails summing the unit costs of variable and fixed production factors associated with each practice. These include seed, land preparation and planting costs. Since cover crops are typically planted on land that would have otherwise lain fallow, the opportunity cost of the land used in this practice is considered zero.

In the fall of 2008, the cost of cover crop grain seed was an important factor in the total costs of cover crop practices, accounting for more than half of total costs in some scenarios, and never less than forty percent. In 2008, there was a significant margin between the cost of purchased seed and retained seed, with the latter being much lower in cost. That margin is less evident in 2007 prices although seed prices remained a significant share of total costs. For consistency, the current study uses 2007 production costs, including, to the extent available[4], seed prices.

The fixed costs of planting equipment and the variable costs associated with its use are also major cost factors for establishing cover crops. Survey averages of custom farming rates give an approximation of unit equipment and labor costs, assuming that equipment owners doing custom farming have captured all their overhead and variable costs in their unit prices. Although a survey of custom farming rates (Dill 2009) has been completed, the current study uses custom rates from a Farm Service Agency/Pennsylvania Department of Agriculture survey of Pennsylvania custom farmers. The latter rates are more relevant to the implementation data (2007 planting year) presented below. Any analysis using 2008 (FY 2009) planting data (not yet available) should use the Maryland 2008 custom rates.

Estimates of cover crop planting costs take into account seed costs for the three principal winter cover cereal grains, and several planting methods, including: no-till drill, conventional drill, broadcast with light disking, aerial broadcast, and broadcasting with stalk-chop. This set of agricultural practices maps closely, but not perfectly to the set of technical efficiencies. The cost estimates for these practices assume no difference in cost between early planting and normal or late planting, which collapses that aspect of the pollution mitigation efficiencies with respect to costs. And, since a single technical efficiency is given for "other" planting methods (i.e., not

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[4] State level grain seed prices are apparently not tracked by either USDA or MDA from any readily or consistently accessible source. Seed prices used in this study were obtained from seed sellers.

drilled or flown on), this category must include broadcasting with light disking and broadcasting with stalk chopping. Additionally, there is no cost difference between aerial seeding into crops or stubble, while the technical efficiencies distinguish between these two practices.

Table 2.1.1 reports the complete range of technical efficiencies given in Simpson and Weammert, along with cost estimates for each practice. Costs of "other" planting in this table use the lower cost, "broadcast with light disking". Given time and resource limitations, we do not attempt to capture cost differences across regions. Those differences may be significant.

Table 2.1.1: Cover Crop Nitrogen Efficiencies and Costs

#	% Efficiency CP	% Efficiency Non-CP	Description	Cost ($/A)
1	45	34	drilled rye early	31.4
2	41	31	drilled rye normal	31.4
3	38	29	other rye early	31.6
4	38	29	drilled barley early	32.0
5	35	27	other rye normal	31.6
6	32	25	other barley early	32.2
7	31	24	aerial rye on soy early	34.8
8	31	24	drilled wheat early	33.4
9	29	22	drilled wheat normal	33.4
10	29	22	drilled barley normal	32.0
11	27	20	aerial barley on soy normal	35.5
12	27	20	other wheat early	33.6
13	24	19	other barley normal	32.2
14	24	18	other wheat normal	33.6
15	22	17	aerial wheat on soy early	37.3
16	19	15	drilled rye late	31.4
17	18	14	aerial rye on corn early	34.8
18	16	12	other rye late	31.6
19	15	12	aerial barley on corn early	35.5
20	13	10	drilled wheat late	33.4
21	13	10	aerial wheat on corn early	37.3
22	11	9	other wheat late	33.7

Source: Simpson and Weammert 2007 & project data

The practices in Table 2.1.1 are rank ordered from highest to lowest with respect to technical efficiency. Dividing a practice's per acre cost by its mitigation efficiency gives the dollar cost of each practice's percentage mitigation efficiency. The cost per unit of nitrogen mitigated will depend on the amount of nitrogen that the acre would have exported to the Chesapeake Bay in the absence of the practice. This depends in turn on the land-use for the acre.

There are six different land-uses (grouping together similar cropping systems) relevant to the cover crop practice. These land-uses have precise definitions in the Bay Model's accounting and are given the following titles: high-till without manure, high-till with manure, low-till with manure, nutrient management without manure, nutrient management with manure, and low-till nutrient management. Table 2.1.2 reports the nutrient and sediment export averages for each of these land-uses from the edge of stream loads estimates. Export estimates are provided as total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS) and, for nitrogen only, per acre averages. We can use these export estimates in combination with the technical efficiencies to develop a matrix of unit nitrogen mitigation cost efficiencies by cover crop practice and by land-use.

Table 2.1.2: Chesapeake Bay Model Nutrient and Sediment Export Estimates by Land-Use

Land-Use	TN (lbs)	TP (lbs)	TSS (short tons)	Acres	Avg. N (lb/A)
Coastal Plain					
High-till w/o manure	534,530	260,830	7,813	22,029	24.27
High-till w/ manure	6,712,100	483,118	37,078	197,600	33.97
Low-till w/ manure	7,136,850	467,469	26,490	257,417	27.72
NM high-till w/o manure	97,989	1,648	3,762	12,966	7.56
NM high-till w/ manure	2,782,779	312,004	27,889	100,602	27.66
NM low-till	4,628,055	555,025	32,167	189,270	24.45
Non-Coastal Plain					
High-till w/o manure	493,036	142,009	7,935	5,958	82.75
High-till w/ manure	5,939,019	311,900	98,334	70,307	84.47
Low-till w/ manure	9,607,063	439,497	101,219	126,682	75.84
NM high-till w/o manure	84,106	1,370	5,333	4,070	20.67
NM high-till w/ manure	2,993,597	98,222	59,457	45,827	65.32
NM low-till	5,571,781	176,611	71,478	99,099	56.22

Source: Chesapeake Bay Program Watershed Model Phase 5.1 Edge of Stream Loads

The following two tables report the cost efficiencies for nitrogen mitigation for the two different geological regions across land-uses and cover crop implementation practices. To get this measure we factor the nitrogen export coefficients (lbs/acre) for each land-use by the nitrogen mitigation efficiencies for each cover crop practice. We divide the resulting estimate of unit nitrogen reduction into the practice's cost estimate to get a cost in dollars per pound of nitrogen mitigation by practice, land-use and geology. Tables 2.1.3 and 2.1.4 report these unit reduction cost estimates for the six relevant land-uses in each region.

Practices in both tables are rank ordered by cost efficiency, which remains the same over all land-uses within each region but changes slightly between the two regions. It is clear from these tables that the variation in the nutrient export values for the six land-uses has a significant effect on cost efficiency. However, cost efficiencies also vary significantly within any given land-use, across planting practices and seed type. Comparing Table 2.1.3 and Table 2.1.4 reveals considerable differences in $/lb cost efficiency across the two geological regions as well.

Table 2.1.3: Cover Crop Nitrogen Mitigation Costs ($/lb), Coastal Plain

Land-Use	**High-till w/o manure**	**High-till w/ manure**	**Low-till w/ manure**	**NM high-till w/o manure**	**NM high-till w/ manure**	**NM low-till**
Estimated Export (lbs/A)	24.27	33.97	27.72	7.56	27.66	24.45
Cover Crop Practice	($/lb)	($/lb)	($/lb)	($/lb)	($/lb)	($/lb)
drilled rye early	2.90	2.07	2.54	9.32	2.55	2.88
drilled rye normal	3.17	2.27	2.78	10.18	2.78	3.15
other rye early	3.43	2.45	3.00	11.02	3.01	3.40
drilled barley early	3.48	2.49	3.05	11.18	3.05	3.46
other rye normal	3.75	2.68	3.28	12.03	3.29	3.72
other barley early	4.12	2.94	3.60	13.22	3.61	4.09
drilled wheat early	4.41	3.15	3.86	14.17	3.87	4.38
aerial rye early	4.59	3.28	4.02	14.74	4.03	4.55
drilled barley normal	4.61	3.30	4.04	14.82	4.05	4.58
drilled wheat normal	4.81	3.44	4.21	15.45	4.22	4.78
other wheat early	5.20	3.71	4.55	16.69	4.56	5.16
other barley normal	5.46	3.90	4.78	17.52	4.79	5.41
aerial barley normal	5.50	3.93	4.82	17.68	4.83	5.46
other wheat normal	5.69	4.06	4.98	18.27	4.99	5.65
drilled rye late	6.77	4.84	5.93	21.75	5.94	6.72
aerial wheat early	7.01	5.01	6.13	22.51	6.15	6.96
other rye late	7.98	5.70	6.98	25.61	7.00	7.92
aerial rye on corn early	8.00	5.72	7.00	25.69	7.02	7.94
aerial barley on corn early	9.63	6.88	8.43	30.93	8.45	9.56
drilled wheat late	10.27	7.34	8.99	32.98	9.01	10.19
other wheat planted late	12.13	8.66	10.61	38.94	10.64	12.04
aerial wheat on corn early	12.28	8.77	10.75	39.43	10.77	12.19

Source: Chesapeake Bay Program Watershed Model Phase 5.1 Edge of Stream Loads, Simpson and Weammert 2007 & project data

Table 2.1.4 reports the same unit costs as Table 2.1.3 except that both the technical efficiencies and the nitrogen loading rates are apposite to the non-coastal plain regions of Maryland. It is important to note that although the technical efficiencies are somewhat lower for cover crop practices in the non-coastal regions (see Table 2.1.1), higher nitrogen export levels generally reduce the $/lb nitrogen mitigation cost.

Table 2.1.4: Cover Crop Nitrogen Mitigation Costs ($/lb), Non-Coastal Plain

Land-Use	High-till w/o manure	High-till w/ manure	Low-till w/ manure	NM high-till w/o manure	NM high-till w/ manure	NM low-till
Estimated Export (lbs/A)	82.75	84.47	75.84	20.67	65.32	56.22
Cover Crop Practice	($/lb)	($/lb)	($/lb)	($/lb)	($/lb)	($/lb)
drilled rye early	1.12	1.09	1.22	4.47	1.41	1.64
drilled rye normal	1.22	1.20	1.34	4.90	1.55	1.80
other rye early	1.31	1.29	1.43	5.26	1.67	1.93
drilled barley early	1.33	1.31	1.46	5.34	1.69	1.96
other rye normal	1.41	1.38	1.54	5.65	1.79	2.08
other barley early	1.56	1.52	1.70	6.23	1.97	2.29
drilled wheat early	1.68	1.65	1.84	6.73	2.13	2.48
aerial rye early	1.75	1.71	1.91	7.01	2.22	2.58
drilled barley normal	1.76	1.72	1.92	7.04	2.23	2.59
drilled wheat normal	1.83	1.80	2.00	7.35	2.32	2.70
other wheat early	2.03	1.99	2.21	8.12	2.57	2.98
other barley normal	2.05	2.00	2.23	8.19	2.59	3.01
aerial barley normal	2.15	2.10	2.34	8.60	2.72	3.16
other wheat normal	2.25	2.21	2.46	9.02	2.85	3.32
drilled rye late	2.53	2.48	2.76	10.13	3.20	3.72
aerial wheat early	2.65	2.59	2.89	10.60	3.35	3.90
aerial rye on corn early	3.00	2.94	3.27	12.01	3.80	4.41
other rye late	3.18	3.11	3.47	12.72	4.02	4.68
aerial barley on corn early	3.58	3.51	3.90	14.33	4.53	5.27
drilled wheat late	4.04	3.95	4.40	16.16	5.11	5.94
aerial wheat on corn early	4.50	4.41	4.91	18.02	5.70	6.63
other wheat planted late	4.50	4.41	4.92	18.04	5.71	6.63

Source: Chesapeake Bay Program Watershed Model Phase 5.1 Edge of Stream Loads, Simpson and Weammert 2007, & project data

If cover crops are viewed as a production process for nitrogen mitigation, then the two preceding tables, in conjunction with Table 2.1.2, provide the basis for optimizing nitrogen mitigation across available acres. That is, these tables identify the acres on which one would choose to plant cover crops to obtain the most nitrogen mitigation possible for a specific budget. However, the current program which motivates cover crop planting pursues the purchase of nitrogen mitigation more generally, as explained below.

The most recent year for which cover crop planting and payment records are available is fiscal year 2008, which was planted in the fall of 2007. In that year, Maryland's cover crop program targeted the generally better reduction efficiency inherent in earlier planting by offering $50/A for cover crops planted before October 1st, $40/A for planting before October 15th, and $30/A for planting November 5th. Instead of considering the practice cost to be an average of incurred implementation costs, we can view the cost as the price paid for participation. Interestingly, the prices paid under the cover crop program were not very different from our estimated per acre costs, with a clear bonus for earlier planting.

Table 2.1.5: Maryland Cover Crop Plantings and Efficiencies (FY2008)

		Acres Planted	Total Load Reduction (lbs N)	Unit Load Reduction (lbs N/A)	Reduction Efficiency ($/lb N)
Coastal Plain	*Early Planting*				
	Rye	6,884	63,711	9.26	5.40
	Barley	17,939	130,859	7.29	6.85
	Wheat	57,249	349,912	6.11	8.18
	Normal Planting				
	Rye	1,639	14,916	9.10	4.39
	Barley	3,221	19,670	6.11	6.55
	Wheat	15,355	94,460	6.15	6.56
	Late Planting				
	Rye	2,037	8,349	4.10	7.32
	Barley*				
	Wheat	7,610	22,588	2.97	10.11
Non-Coastal Plain	*Early Planting*				
	Rye	4,254	80,048	18.83	2.66
	Barley	6,467	96,547	14.93	3.35
	Wheat	8,848	115,367	13.04	3.83
	Normal Planting				
	Rye	1,863	30,680	16.47	2.43
	Barley	1,983	22,774	11.48	3.48
	Wheat	5,467	66,597	12.18	3.28
	Late Planting				
	Rye	1,489	12,452	8.36	3.59
	Barley*				
	Wheat	2,574	14,265	5.54	5.41

Source: MDA 2008 Cover Crop Data and Bay Model 5.1 coefficients
* No technical efficiency given for late planting of barley

In Table 2.1.5, we report FY2008 cover crop planting and efficiency information by crop type, time of planting, and geographic location. MDA cover crop data provides acres by planting method, crop type, planting period and county. Coastal plain and non-coastal plain acres are approximated by dividing Maryland's counties into those that border the Chesapeake Bay (or are on the Eastern Shore), and those that do not border the Bay as coastal plain and non-coastal plain, respectively. In an intermediate step (not shown) we estimated nitrogen reduction amounts using the efficiencies from Simpson and Weammert and the load data by land-use and geographic region from the edge of stream loads. Since we do not know which land-use cover crop plantings were applied to, we apportion any given planting across the relevant land-uses in proportion to their relative share of total acres.

The cost efficiencies reported in Table 2.1.5 are based on the loads estimated to be reduced, factored by costs of $50, $40, or $30/A. By the Unit Load Reduction (lbs N/A) column, it is clear that the more expensive, early-planted acres buy down more nitrogen per acre than the normal and late plantings. It is also shown that per acre reduction efficiencies are much higher on the non-coastal plain, where higher loads are available to be exported[5].

While a direct mapping from Table 2.1.5 to Tables 2.1.3 and 2.1.4 is not possible, a casual perusal of the $/lb reduction efficiencies shows that, in general, the program-based cost efficiencies are lower (i.e., it takes more dollars per pound of mitigation) than a large share of those estimated using constructed costs for the practices. These two different ways of assessing cover crop costs and cost efficiencies will be explored further in Chapter 3.

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USDA/FSA/Pennsylvania Dept. of Agriculture. 2008. 2008 Machinery Custom Rates.

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[5] It is noteworthy that the FY2009 cover crop program has become more directed than the one assessed here. Once data for fall 2008 plantings are available, a similar, if more complicated, analysis could be done for that program year.

2.2. Off-stream Watering with Fencing and without Fencing Practices

Off-stream Watering with Fencing Practices incorporates both alternative watering and installation of fencing that excludes narrow strips of land along streams from pastures and livestock. The implementation of stream fencing should substantially limit livestock access to streams but allows for the use of limited hardened crossing areas where necessary to accommodate access to additional pastures or for livestock watering.

Fenced areas may be planted with trees or grass, but are typically not wide enough to provide the full benefits of buffers. When a fencing system is installed, the excluded land is not considered a buffer unless specific buffer installation criteria are met, as outlined by the Natural Resources Conservation Service (NRCS). In situations where installation criteria are met, farmers are eligible to receive credit for off-stream watering with fencing and a riparian buffer on pastureland. Buffers are reported as a separate practice. While stream protection may provide some buffer-like function when vegetated at a specified width, it is buffering a very low loading land-use and the major benefit is from keeping cows out of creeks and off of stream banks. Simpson and Weammert recommend developing effectiveness estimates for buffers implemented on pastureland. Fencing, or stream protection, is a pasture management practice.

Off-stream watering BMPs are best understood by disaggregation into their respective parts: the watering, the animal exclusion, and the stream crossing. Off-stream watering is designed to prevent animals from fouling the waters by relocating their source of hydration away from the streamside. Local geography will play a large role in the distance and cost required to achieve these goals, as will explicit animal exclusion measures (fencing or stream crossings).

The nutrient reduction efficiency of off-stream watering BMPs is difficult to characterize due to the wide range of conditions that impact both the “before” and “after” implementation loading rates. In the Simpson and Weammert review of this BMP it was recommended that the reduction efficiencies be reduced by 50 percent. While reduction efficiencies were lowered they were not reduced by the recommended amount. The new nutrient and sediment mitigation rates for this BMP are shown in Table 2.2.1.

Table 2.2.1: Off-Stream Fencing Nutrient and Sediment Reduction Efficiencies (%)

	TN	TP	TSS
Off-stream watering with fencing	25	30	40
Off-stream watering without fencing	15	22	30

Source: Simpson and Weammert (2007)

Water requirements

According to the NRCS Maryland Conservation Practice Standard (Code 614), there are two purposes for a watering facility: 1) to meet daily water requirements, and 2) to improve animal distribution. The design criteria for this practice advises locating the watering facility away from sensitive areas, and fencing *as necessary*, located as far away from streams *as practical.* The guide also gives an indication of materials requirements for the construction of fencing and watering facilities. The water requirements for different types of animals are given in Table 2.2.2. For convenience, we will use dairy cows in the costing scenario developed below. Dairy cows are a common grazing animal in the state and using them provides a higher-end estimate with respect to water requirements.

Table 2.2.2: Animal Water Requirements

Animal Type	Gallons / Head / Day
Beef Cattle	12
Dairy Cattle	15
Horses	12
Sheep	2
Swine (Hogs)	4
Goats	1.5
Poultry (Chickens)	35 (per 1000)

Herd size

An animal-land requirement is the primary assumption underlying the costs of this management practice. Fundamentally, the cost of facilities installed will vary according to the volume of water needed (number of animals) and the distance that water must be carried or pumped (farm size). For the purposes of this study, we assume a constant animal density (head per acre) and specify our costs in terms of pasture size (acreage).

Animal density recommendations vary widely. Buchanan-Smith (undated) recommends 1.6 hectares of land per cow-calf pair, approximately 4 acres per pair. Elferink and Nonhebela (2006) examine land requirements for meat production and find a range of 25-45 square meters per kg of beef production, a much smaller land requirement. Zobell and others (1999) describe several different classes of cattle, and their average weights. Market beef enterprise cattle start as calves between 700-900 pounds and grow to between 1100-1200 pounds before slaughter. Dairy, feeder, and cow-calf combinations weigh less.

In conversations with Chesapeake Bay Foundation staff[6], it was indicated that the animal density for Maryland is closer to 5 animals per acre, or 0.2 acres per head. Therefore, pasture acreage times 5 is our assumed stocking rate. Multiplying the stocking rate by 15 gallons per day yields the water requirements. Animals may not get nourishment solely from pasture, and there may be ‘excess’ pasture for the given number of animals relative to our benchmark. But, for the purposes of cost estimation, we assume water requirements to be determined from the simple expression:

$$Water = (Pasture\_acres)\left(\frac{5head}{1acre}\right)\left(\frac{15gallons}{head}\right)$$

Farm geometry

Our scenario assumes that one-fifth of the herd requires fencing (or that one-fifth of the land borders the stream). Importantly, we assume that the watering facility is four-fifths of the acreage distance away from the stream. For clarity, this template area is shown below (Figure 2.2.1). It is identical to the 4x1 geometry adopted by Simpson and Weammert in their report on buffers, 4 acres of off-stream land for every acre fronting the stream, and with it we can specify and cost three descriptive scenarios for off-stream watering.

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[6] Conversation with R. Schnabel, Chesapeake Bay Foundation, 3/27/09.

Scenario 1 – Off-Stream Watering without Fencing

This scenario is designed to illustrate the costs of providing off-stream watering when fencing is not required. Using the farm layout shown in figure 2.2.1, and Simpson and Weammert's recommended geometry (W = 5, H = 1), we can calculate a water requirement of A*75 gallons per day carried over a distance of $5*\sqrt{A/5}$ where A is the pasture acreage. Alternatively, farm specific estimates for watering facility cost can be developed by using the farm's actual number of acres, A, and animals, N, with the appropriate water recommendation level, or by using site-specific distance estimates, or both. This example is hypothetical and merely used for illustrating standard costs.

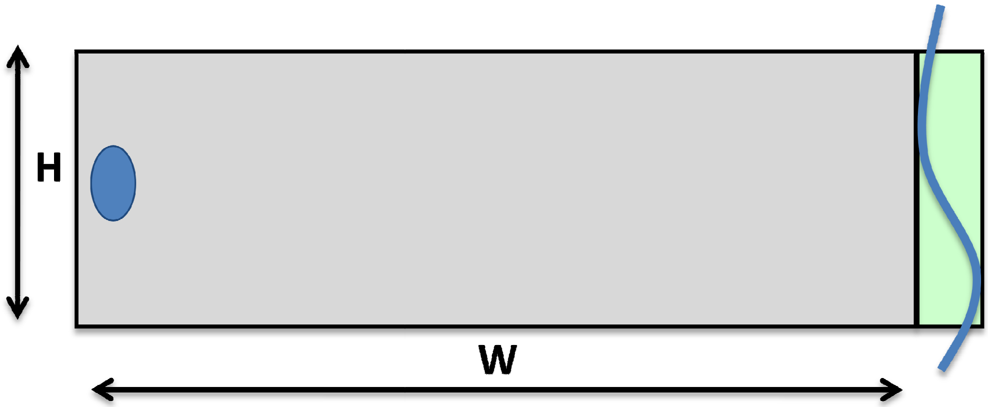

Figure 2.2.1: Off-Stream Watering without Fencing (Scenario 1)

Scenario 2 – Off-Stream Watering with Fencing

Scenario 2 is designed to illustrate the case when fencing is required. Using the geometry shown in figure 2.2.2, and the same relative areas as in scenario 1 and Simpson and Weammert, the water requirement of A*75 gallons per day carried over a distance of $5*\sqrt{A/5}$ (where A is the pasture acreage) is paired with fencing construction of length $\sqrt{A/5}$.

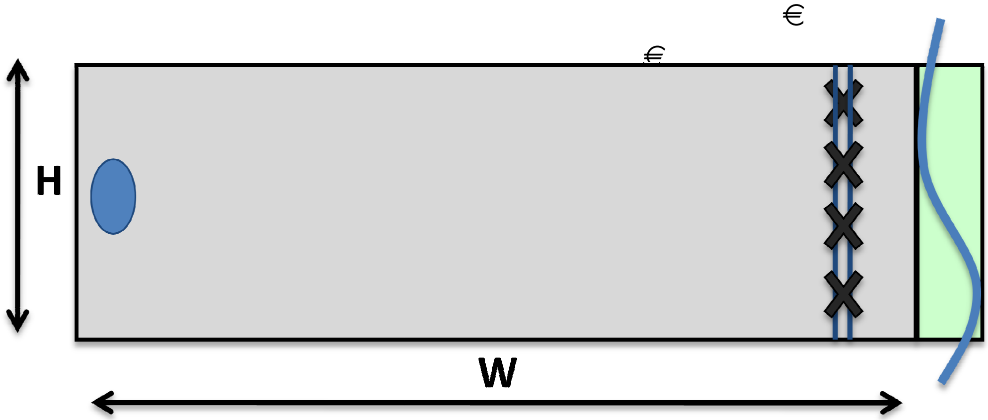

Figure 2.2.2: Off-Stream Watering with Fencing (Scenario 2)

Scenario 3 – Off-Stream Watering with Fencing and Stream Crossing

Scenario 3 illustrates the situation when both fencing and a stream crossing are required. Using the geometry shown in figure 2.2.3, and the same relative areas as in the previous scenarios; an identical water requirement of A*75 gallons per day carried over a distance of $5*\sqrt{A/5}$ (where A is the pasture acreage), is combined with fencing construction of length $2*\sqrt{A/5}$ and a stream crossing. According to the Maryland Agricultural Water Quality Cost-Share (MACS) Program, cost-sharing is provided for a 12-foot maximum-width crossing perpendicular to the water flow. However, according to CBF staff[7], the average length of a stream crossing is approximately 25ft, and most farmers build their stream crossings 16ft wide so that equipment can be moved across. Accordingly, 400 square feet is assumed to be the area for all stream crossings.

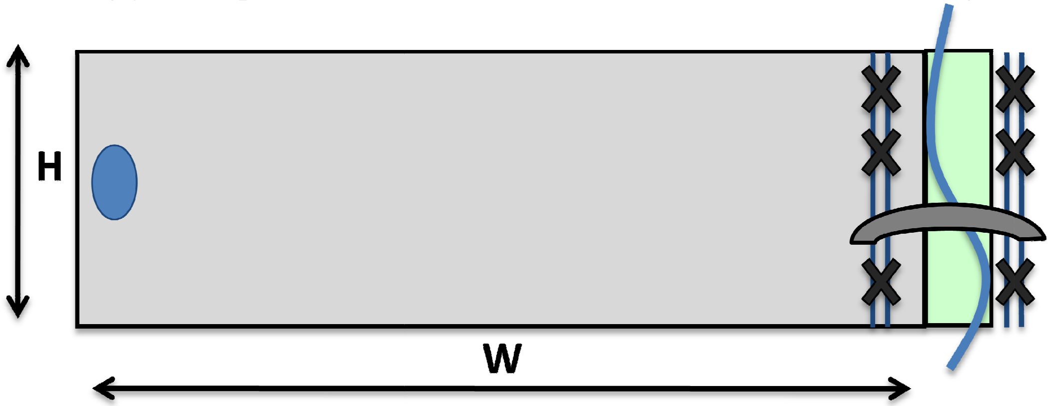

Figure 2.2.3: Off-Stream Watering with Fencing and Stream Crossing (Scenario 3)

Maintenance

Maintenance costs are assumed to be nil for this particular BMP. In particular, such equipment as the water pump, piping, and fencing material are assumed to last longer than the design life of the BMP. Together with the fencing practice and watering facility, MACS specifies that a minimum of 15 animals regularly use the stream crossing, and that it retain its function for a minimum of 10 years. Hence, we assume that equipment lasts longer than 10 years and that no upfront discounted maintenance costs are included.

Input Costs

In this BMP estimate, as throughout this report, flat-rate schedules from various counties were used for costs. Costs from five counties – Washington, Montgomery, Calvert, Harford and Talbot – were deflated into 2007 dollars and an average cost was calculated and used as the input for the model.

Watering Costs

Because of the relatively low level of required water flow rates to supply the herd - on the order of gallons per day rather than gallons per minute - a small diameter pipe (2”) is assumed to satisfy the piping needs for the watering facility. If a well is drilled, it is assumed to be drilled to the depth of 250 ft, a number that is based upon anecdotal evidence that the average well depth

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[7] Conversation with R. Schnabel, Chesapeake Bay Foundation, 3/27/09.

on the non-Coastal Plain is between 200 and 300 feet.[8] If no well is drilled, the pipe distance required is equivalent to the distance from the streamside to the far end of our hypothetical farm, that is, the distance W ($5*\sqrt{A/5}$, where A is the pasture acreage) in figures 2.2.1 – 2.2.3. This distance scales with farm acreage. A farmer is assumed to select the cheaper pair between: (i) a drilled, cased well 250ft deep supplying a pressure-fed trough with a float kit; and (ii) a concrete trough supplied by piping from the streamside. Because the pipeline cost scales with farm area but the well cost does not, a hypothetical farmer in our example would select a well at larger acreages: piping at smaller ones.

Trough size, which intuitively should increase as acreage and herd size increases, is specified by assuming a linear relationship between trough cost and volume. Once the water requirement exceeds 100gallons, which is the smallest trough cost, we assume that the cost of the trough (both concrete and pressure-fed) increases linearly with the volume requirement. The slope of this relationship is determined by averaging the slopes of the other trough costs available. The average cost of the float kit is added to each pressure-fed trough, but only once: in essence, we are assuming an infinitely scalable trough, located ever further away from the streamside, will be sufficient for all watering needs.

Total Cost

Using the methodology, farm geometrics and cost assumptions spelled out above, the costs of an off-stream watering facility without fencing, a watering facility with fencing, and a watering facility with fencing and a stream crossing, are approximately $10,330, $13,200, and $26,250 respectively for a hypothetical 50 acre farm. More detail on input costs and explicit assumptions are provided in the accompanying spreadsheet.

Cost Efficiencies for Off-Stream Watering

Given a cost for off-stream watering and the Bay Model nutrient reduction efficiencies for the practice (Table 2.2.1), calculating a cost efficiency should be straightforward. Unfortunately, it is not. Several problems arise in estimating relevant cost efficiencies for this BMP. First, our costing of the practice assumes specific conditions in order to develop scalable, relevant costs. However, the technical efficiencies are less specific, providing just a percentage reduction, independently of specific conditions (i.e., pasture stocking rates, pasture size/riparian exposure conditions, etc.).

Secondly, it is not clear what are the appropriate “before” and “after” loading rates for this practice. This is in part a function of how loading rates are measured in the Bay Model. The land-use category “degraded riparian pasture” is relevant to riparian acres that might benefit from fencing and off-stream watering. However, it is not clear whether the hypothetical pasture developed for our cost estimate is entirely contained within the category or whether some of it is not simply “pasture”, a separate land-use.

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[8] Conversation with R. Schnabel, Chesapeake Bay Foundation, 3/27/09.

Useful cost efficiencies could be developed for this BMP with more refined reduction efficiencies and loading rates. Absent those, our cost estimates provide information for the cost part of that calculation.

References

Buchanan-Smith, J., University of Guelph (Dept of Animal and Poultry Science) "Budgeting Feed Requirements for Beef Cattle on Pasture" undated article, www1.foragebeef.ca/

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2.3. Riparian Buffers

The nutrient reduction efficiencies of riparian buffers are estimated for the Chesapeake Bay Model as described in *Riparian Forest Buffer Practice (Agriculture) and Riparian Grass Buffer Practice* by Simpson and Weammert, 2007. The difference between loads under the original land-use and the new land-use is part of the mitigation benefit of riparian buffers. In addition, riparian buffers treat loads from up-gradient acres. This mitigation is added to the effect of the land-use change.

Buffer practices are defined generally in Simpson and Weammert, and mitigation efficiencies are differentiated only between base rates for forested buffers versus grassed buffers and for both by geographic region. These reduction efficiencies are reported in Table 2.3.1 and Table 2.3.2 for nutrients and suspended solids.

Table 2.3.1: Riparian Forest Buffers Nutrient and Sediment Reduction Efficiencies (%)

	TN	TP	TSS
Inner Coastal Plain	65	42	56
Outer Coastal Plain Well Drained	31	45	60
Outer Coastal Plain Poorly Drained	56	39	52
Tidal Influenced	19	45	60
Piedmont Schist/Gneiss	46	36	48
Piedmont Sandstone	56	42	56
Valley and Ridge -	34	30	40
Valley and Ridge - Sandstone/Shale	46	39	52
Appalachian Plateau	54	42	56

The nutrient reduction benefit credited to riparian buffers includes both the change in land-use associated with putting an acre of land (generally cropland) into grass or forest, and the buffer's treatment of the effluent from a fixed number of upland acres. Planting an acre of riparian buffer is assumed to treat four upland acres with respect to total nitrogen loads and two upland acres with respect to phosphorous and total suspended solids.

Table 2.3.2: Riparian Grass Buffers Nutrient and Sediment Reduction Efficiencies (%)

	TN	TP	TSS
Inner Coastal Plain	46	42	56
Outer Coastal Plain Well Drained	21	45	60
Outer Coastal Plain Poorly Drained	39	39	52
Tidal Influenced	13	45	60
Piedmont Schist/Gneiss	32	36	48
Piedmont Sandstone	39	42	56
Valley and Ridge -	24	30	40
Valley and Ridge - Sandstone/Shale	32	39	52
Appalachian Plateau	38	42	56

Nutrient load values (that which is reduced at the reduction efficiency rate) are estimated in proportion to the non-urban land-uses in the buffer's watershed so that, in a watershed where non-urban uses were 40% forest and 60% agricultural, each acre of buffer is accounted as reducing 1.6 acres of forest nitrogen load and 2.4 of agricultural nitrogen load. Total suspended solid reductions are calculated as a constant proportion of phosphorous reductions.

This way of calculating nutrient load reductions greatly simplifies the estimation of buffer effects on total loads in a watershed. On the other hand, it is only an approximation of what is happening to nutrient loads when buffers are created. It is likely that significant information is lost in this approximation. Potential factors whose effect cannot be distinguished include: the age of the buffer, stocking rates, species composition, subsurface flow, slope, and up-gradient land-uses.

Riparian Forest Buffers (CP22)

The definition of riparian forest buffers is particularly general, encompassing a variety of practices with a range of costs. One can specify a scenario – such as planting 400 trees per acre with spot herbicide treatments and 200 tree shelters per acre – and estimate the costs entailed in such a scenario to evaluate along with the appropriate riparian forest buffer mitigation efficiencies. But, there are a large number of alternative, qualifying scenarios. Current practice for establishing riparian forest buffers in Maryland is driven largely by the USDA-funded Conservation Reserve Enhancement Program (CREP) and associated support from the Maryland Agricultural Cost Share (MACS) program. Below, we examine some cost factors for riparian forest buffers along with averages of establishment costs under CREP funding.

CREP riparian forest buffer plantings are bound contractually according to a general set of conditions and definitions. In widths varying from 35 to 150 feet[9], riparian forest buffers should be (formerly) tilled cropland "adjacent to and up-gradient from waters of the state", and they should be composed of trees and woody shrubs[10] such that there will be at least 50% crown cover and a canopy that is as high or higher than the width of the adjoining watercourse. CREP agreements for riparian forest buffers run for 15 years.

In the mid-Atlantic, trees will colonize most sites that are left undisturbed for several years. However, in the presence of browsing animals and competition from other plants, trees will not come to dominate an area as fully or as quickly as when they are planted and the site is managed. Given the fifteen year life of CREP riparian forest buffer contracts, 50% crown cover can be difficult to achieve without planting and active management in the buffer. In Maryland, the 50% crown cover requirement is taken to imply a minimum of 200 trees per acre. Establishing a riparian forest buffer with this tree density generally requires planting and management practices that constitute an important component of the overall cost of the practice.

Lynch (undated) estimates the costs of establishing a riparian forest buffer in Maryland as between $218 and $729 per acre. These costs are based on planting rates of 436 to 550 trees per acre, chemical control for plant competition, maintenance and replanting. In interviews undertaken for the current project, 2008 establishment costs were given as approximately $800 per acre for plantings of 435 hardwoods (10 by 10 spacing) with spot herbicide treatments. As noted above however, herbivores can be a serious problem at some sites. For these sites foresters typically prescribe tree shelters as protection against browsing. Tree shelters are priced at $3.35 – $6.50 per shelter, installed. If 200 trees per acre are sheltered, the cost of planting roughly doubles.

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[9] This width has been extended to 200 feet and greater under some CREP/MACS riparian buffer contracts.

[10] Some riparian forest buffers are designed with adjoining grassed buffers and, in that case, terms change.

Examining the effect of shelters on riparian forest buffer planting success in Maryland, Hairston-Strang (2002) finds that trees planted with shelters enjoyed 80 percent survival rates, against an overall planting survival rate of 65 percent. In a more controlled experiment on the Eastern Shore of Maryland, Sweeney and Czapka (2004) found that in their fifth year of growing, sheltered trees were 26 percent more likely to have survived than unsheltered trees. In addition, sheltered trees had much more vertical growth than unsheltered trees. While these improved survival and growth effects are considerable, it is not clear that they fully compensate for a doubling of establishment costs.

When we speak of the cost of a good or service, it is generally assumed that we are talking about the least cost required to produce it. In competitive markets, production costs are assumed to be minimized because competing suppliers survive off of the margin between their production costs and the price at which their product can be offered in the marketplace. At a given market price, minimizing production costs increases suppliers' margins.

In the case of riparian forest buffers, however, the incentive structure is different. New riparian forest buffers are motivated by payments for a general outcome, as described above (i.e., at least 200 trees per acre at specified widths). Payments for this include buffer establishment cost-shares of 50% from CREP and 37.5% from MACS. The remaining 12.5% is sometimes available through third-party private sources but is otherwise payable by the participant. However, the CREP program also pays an amount equivalent to 80% of their (50%) cost share as a one-off incentive payment for implementing the practice. Including this final payment, the participant gets more money, the more expensive the cost of establishing the buffer.

This is not a claim that the program is being abused. Technical specialists are involved in developing planting and management plans that determine riparian buffer establishment costs under CREP. As sign-ups have been low in recent years (Table 2.3.3), whatever rents there might be from participation in the buffer program do not appear sufficient to bring in many new participants. The point is that the incentive to minimize costs, generally assumed in the analysis of market costs, is not present here. Consequently, the historical costs discussed below are not necessarily "least-cost" costs.

In addition to establishment costs, the CREP program provides payments to cover the opportunity cost of land placed in riparian forest buffers. Since land placed in this use had value to its owner as productive farmland, this cost is calculated as the rent that could be obtained by farming it. In addition to rental payments, the CREP program makes annual incentive payments of $200/acre[11] for the first 50 feet of riparian forest buffer and $50/acre for the next 51 to 100 feet from the watercourse. Some small maintenance payments are allowed and there is a one-time signing bonus of $10/acre for enrolling a riparian forest buffer into CREP.

CREP payments toward establishment costs, rental value, and the owners' interest seem considerable, given expected returns to farming the land. That so many acres remain outside the program raises the question of what loss owners perceive that they choose to forego CREP riparian forest buffer payments. These may include, among others, the high cost of ever

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[11] These incentive rates have changed over the years and rates referenced have only been in place since May, 2004.

reversing riparian forest buffers, wildlife impacts (forest buffers as wildlife corridors to crop fields), moisture, nutrient and sunlight impacts of trees on surrounding crop acres, and buffers' potential as reservoirs of weeds. A valuation of the true cost of these factors is beyond the scope of the current study.

The average annual establishment costs for riparian forest buffers funded under the CREP program in Maryland are reported in Table 2.3.3, along with the number of acres enrolled in each year. The average at the bottom of the table is a weighted average calculated as total acres divided by total cost share. CREP cost share is roughly one half the total establishment costs for CREP practice CP22 (riparian forest buffers) so the actual cost[12] of installing these practices are double the figures reported in the table. Moreover, including the cost share payments of MACS and the practice incentive payment, the total price paid for the establishment costs of these riparian forest buffers is 2.275 times the cost share figures reported in the table.

Table 2.3.3: CREP Establishment Cost Share and Acres Enrolled for Riparian Forest Buffers

Year	Acres Enrolled	Total Cost Share ($)	Average CS ($/A)	Deflated Avg. CS ($/A)
1998	485	133,027	274.40	376.18
1999	1,454	367,162	252.59	368.10
2000	1,467	373,419	254.55	366.85
2001	4,227	1,587,928	375.64	518.94
2002	4,420	1,573,373	355.95	515.59
2003	2,716	965,571	355.49	457.19
2004	902	346,867	384.60	447.29
2005	118	86,476	731.61	885.34
2006	244	235,121	964.40	1182.01
2007	144	67,201	467.00	467.00
2008	124	91,692	740.65	646.83
Totals	16,333	5,830,948	357.00	484.70

Source: USDA CREP data (http://content.fsa.usda.gov/crpstorpt/r7crepyr/md.htm)

Riparian Grassed Buffers (CP21 – Filter Strips)

When grassed filter strips are placed along qualifying waterways, they are treated as riparian grassed buffers. They serve a function similar to riparian forest buffers and in comparing Tables 2.3.1 and 2.3.2, both practices can be seen to have precisely the same mitigation efficiencies for phosphorous and suspended solids pollution mitigation. Nitrogen mitigation efficiencies for riparian grassed buffers are somewhat lower than those for riparian forest buffers.

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[12] To the extent that the cost-share amount is an accurate representation of true costs.

A wide variety of waterways qualify for riparian grassed buffers, including drainage ditches[13]. Filter strips can be up to 100 feet wide but must be at least 35 feet wide to qualify. On the Eastern Shore, the maximum width can be expanded to 150 feet if the land is highly erodible or if the practice qualifies as wildlife habitat enhancement. West of the Chesapeake Bay, the maximum width is expanded to 300 feet under those same qualifications.

Filters strips must be established and maintained in herbaceous cover, using an approved list of seed mixes. The buffers cannot be harvested or used for grazing animals and they must be kept free of noxious weeds. Acres enrolled into the program must remain in the program for ten years. As was the case for riparian forest buffers, establishment costs for riparian grassed buffers are paid through CREP/MACS cost share and continuing costs are paid through CREP rental and incentive payments. Incentive payments are currently $150/acre for the first 50 feet from the watercourse and $50/acre for widths in excess of 50 feet up to 100 feet.

Lynch estimates the establishment costs of grassed buffers from $168 to $400 per acre, including site preparation, seeds and seeding, and other management costs. Current costs from the FSA County Flat Rate Schedules average $325 per acre for cool season grasses and $425 per acre for warm season grasses. These flat rates are not drastically different from implied CREP average establishment costs of $377 per acre (Table 2.3.4).

Table 2.3.4: CREP Establishment Cost Share and Acres Enrolled for Riparian Grassed Buffers

Year	Acres Enrolled	Total Cost Share ($)	Average CS ($/A)	Deflated Avg. CS ($/A)
1998	294	65,383	222.77	305.40
1999	2,955	447,412	151.42	220.67
2000	2,671	407,240	152.50	219.78
2001	3,605	447,931	124.26	171.67
2002	8,147	1,176,052	144.35	209.09
2003	11,643	1,650,122	141.73	182.28
2004	5,221	722,514	138.38	160.93
2005	197	28,158	143.08	173.14
2006	614	85,082	138.50	169.75
2007	523	71,468	136.65	136.65
2008	467	67,872	145.21	126.82
Totals	36,745	5,216,876	141.97	188.60

Source: USDA CREP data (http://content.fsa.usda.gov/crpstorpt/r7crepyr/md.htm)

CREP records show fairly flat riparian grassed buffer establishment costs over the past 12 years but when these are adjusted for changes in the general price level (measured by the producer price index), they appear to be falling. Grassed buffers also enjoy higher sign-up levels than riparian forest buffers. Table 2.3.4 reports establishment cost share and acres signed into

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[13] Widths on infield drainage ditches and channelized intermittent streams are limited to 35 feet

riparian grassed buffers from 1998 to 2009. As in Table 2.3.3, these figures only account for approximately one half of the establishment costs of this practice.

Cost Efficiencies of Riparian Buffers

The imprecision of the available technical efficiencies with respect to implementation practices and site conditions has been noted. It has also been noted that there are two relevant sets of costs; one composed of the minimum costs required to implement the practices and the other composed of the price paid under the program that motivates most of the new practice acres (i.e., CREP). Current establishment costs for a forested buffer are estimated to be $800 to $1,600 per acre, depending upon whether shelters are used or not. The actual record of deflated CREP establishment costs falls at the lower end of this range, and is taken to be an adequate estimator for resource costs.

Our calculation of the mitigation of nutrient pollution loads by forest buffers will depend on geological type, the former land-use on buffered acres and the land-use of upgradient acres. The annual cost of the practice is calculated as the average CREP establishment cost ($969/acre) amortized (equally) over the life of the contract (15 years), plus the average annual incentive payment and soil rent (proxies for opportunity costs) discounted by the agricultural commodity producer price index[14] ($212/acre). With those costs, one can generate as many riparian forest buffer cost efficiencies as there are combinations of land-uses across geological types.

Table 2.3.5: Riparian Forest Buffer Nitrogen Reduction on Low-till Agricultural Land at Average Loads and Costs

	Upland % Load Red.	Own Acre Load Red.*	Reduction (lbs)	$/lb Reduction
Inner Coastal Plain	260	22.13	85.70	3.23
Outer Coastal Plain Well Drained	124	22.13	52.45	5.27
Outer Coastal Plain Poorly Drained	224	22.13	76.90	3.60
Tidal Influenced	76	22.13	40.71	6.79
Piedmont Schist/Gneiss	184	50.04	153.48	1.80
Piedmont Sandstone	224	50.04	175.97	1.57
Valley and Ridge - Marble/Limestone	136	50.04	126.50	2.19
Valley and Ridge - Sandstone/Shale	184	50.04	153.48	1.80
Appalachian Plateau	216	50.04	171.48	1.61

*Assumes: Nitrogen export (lbs) for coastal plain: 1) forest = 2.32, 2) nutrient management low-till = 24.45; Nitrogen export (lbs) for non-coastal plain: 1) forest = 6.18, 2) nutrient management low-till = 56.22.

Table 2.3.5 provides an example of cost efficiencies for forest buffer acres from a nutrient management low-till land-use, with upland acres in the same land-use. For the first four coastal geological types, appropriate coastal plain loads are applied. For the five upland geological types, appropriate loads for non-coastal plain are used. The "Own Acre Load Reduction" is

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[14] 2008 Economic Report of the President.

assessed as the prior nitrogen loading rate (nutrient management low-till land) minus the loading rate for the new land-use (forest). Upland percentage load reduction is the reduction efficiency for each geological type, times four to account the load reduction from upgradient acres.

Table 2.3.6 reports a similar scenario for grassed buffers. At $377/acre, average establishment costs are lower, but these are amortized over the ten years of a grassed buffer contract, versus fifteen years for forested buffers, for an annualized cost. Annual incentive payments are also somewhat lower for grassed buffers, compared to forested buffers ($185/acre versus $212/acre[15], respectively). While the nitrogen reduction efficiencies for grassed buffers are somewhat lower than those for forested buffers, the lower annual costs of the practice brings the cost efficiencies of grassed buffers very near to those for forested buffers.

Table 2.3.6: Riparian Grassed Buffer Nitrogen Reduction on Low-till Agricultural Land at Average Loads and Costs

	Upland % Load Red.	Own Acre Load Red.*	Total Reduction	$/lb Reduction
Inner Coastal Plain	184	20.25	65.24	3.41
Outer Coastal Plain Well Drained	84	20.25	40.79	5.46
Outer Coastal Plain Poorly Drained	156	20.25	58.39	3.81
Tidal Influenced	52	20.25	32.96	6.76
Piedmont Schist/Gneiss	128	45.30	117.26	1.90
Piedmont Sandstone	156	45.30	133.00	1.67
Valley and Ridge - Marble/Limestone	96	45.30	99.27	2.24
Valley and Ridge - Sandstone/Shale	128	45.30	117.26	1.90
Appalachian Plateau	152	45.30	130.75	1.70

*Assumes: Nitrogen export (lbs) for coastal plain 1) Hay without fertilizer = 4.2, 2) nutrient management low-till = 24.45, Nitrogen export (lbs) for non-coastal plain 1) Hay without fertilizer = 10.92, 2) nutrient management low-till = 56.22.

References

Sweeney B.W. & Czapka S.J. (2004) Riparian forest restoration: why each site needs an ecological prescription. Forest Ecology and Management, 192, 361–373

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Lynch, L. (undated). When a Landowner Adopts a Riparian Buffer – Benefits and Costs. Maryland Cooperative Extension Service Fact Sheet 774.

Maryland Department of Agriculture. 2008. Maryland Agricultural Cost Share Manual.

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[15] These are average incentive payments since 1998 deflated with the producer price index for agricultural commodities.

Simpson, T. and S. Weammert. 2007. Riparian Forest Buffer Practice (Agriculture) and Riparian Grass Buffer Practice Definition and Nutrient and Sediment Reduction Efficiencies For use in calibration of the Phase 5.0 of the Chesapeake Bay Program Watershed Model. Chesapeake Bay Program/Mid-Atlantic Water Program (UMD).

USDA/FSA Conservation Reserve Program On-line Data:
http://content.fsa.usda.gov/crpstorpt/r7crepyr/md.htm

2.4. Wetland Restoration and Creation

Wetlands serve water quality goals by removing nutrients and particulates from water that flows through them. Following Jordan, Simpson and Weammert (2007), the amount of nutrients and particulates that wetlands remove from water flowing through them is estimated as a function of their size relative to the land area that drains into them. The function used for this estimation is $Removal = 1 - e^{-k\,(area)}$, where area is the ratio of wetlands area to total drainage area and k is an estimated parameter. This equation is used for estimating the effect of both restored and created wetlands. In the Chesapeake Bay Model, the load reduction impact of wetlands on water passing through them is supplemented by crediting the difference between the old land-use and the wetlands land-use for any given area of wetland restoration or creation.

The mitigation equation provides a straight-forward means for estimating cost efficiencies for this BMP. To the extent that the costs of restoring or creating wetlands are independent of their share of the drainage area (i.e., the per acre cost is not determined by the ratio of wetland size to the size its drainage area), cost per acre can be used to convert any reduction efficiency to a cost efficiency in a linear fashion. For any given wetland restored or created, cost efficiency can be estimated as the total cost (cost/acre * acres) divided by pounds of nutrient reduced (removal per wetland ratio * load for any given upgradient land-use*drainage acres).

Other factors affect the nutrient removal efficiency of wetlands. These include the age of the wetland, flow variability factors, landscape, and sediment accumulation. These factors are not distinguished in the technical efficiency estimates and so cannot become part of any cost efficiency estimate. When these factors are considered, the estimation of cost efficiencies will become more complicated but also more precise.

Wetland creation undertaken on former cropland qualifies for CREP funding under CP23 (wetland restoration) and CP30 (marginal pasture wetland buffer). Up to the end of 2008, in Maryland, 2,447 acres were committed to CP23 through ten year contracts. Approximately 5 acres were committed under CP30. Total cost share for establishing CP23 acres deflated by the producer price index (2007 = 1) was $ 2.461 million and the average establishment cost share (50%) per acre was $1,006. Annual incentive payments for this practice are $50, and those payments are added to the annual soil rental payment ($78 in 2008). At a ten year amortization of establishment costs (calculated as 2 times the cost share) the annual cost for wetland restoration is $329/acre.

Unit nitrogen reduction efficiencies can be estimated for each wetland area ratio across all possible upgradient land-uses. Table 2.4.1, reports cost efficiencies for several area ratios on an assumed 100 acre drainage with upgradient acres assumed to be in “low-till with manure” land-use. The removal estimate is applied to all the acres upgradient of the wetland, and not to the wetland acres themselves. When considering these numbers, it is useful to remember that the life of the practice is unknown and time is not captured in the removal estimate. By these numbers, wetlands seem to be very cost effective nitrogen mitigation practices.

Table 2.4.1: Wetlands Removal Efficiencies for Low-till w/ Manure Land-Use and 100 Acre Drainages

Wetland Acres	Removal Proportion	N Removed on CP (lbs)	N Removed on Non-CP (lbs)	Total Site Cost ($)	CP Eff. ($/lb)	Non-CP Eff. ($/lb)
1	0.06939	190.44	521.03	329.2	1.73	0.63
2	0.13397	363.95	995.74	658.4	1.81	0.66
3	0.19407	521.83	1427.68	987.6	1.89	0.69
4	0.25000	665.28	1820.15	1316.8	1.98	0.72
5	0.30204	795.40	2176.17	1646.0	2.07	0.76
6	0.35048	913.24	2498.55	1975.2	2.16	0.79
7	0.39555	1019.72	2789.88	2304.4	2.26	0.83
8	0.43750	1115.72	3052.54	2633.6	2.36	0.86
9	0.47653	1202.06	3288.76	2962.8	2.46	0.90
10	0.51286	1279.48	3500.56	3292.0	2.57	0.94

Low-till w/ manure land-use N export on the Non-Coastal Plain 75.84
Low-till w/ manure land-use N export on the Coastal Plain 27.72
K = 0.07192 (calculated from data in Jordan, Simpson and Weammert 2007)

In addition to CREP CP23 practices, wetlands are sometimes created or restored as mitigation for wetlands that are lost to development or for other reasons that do not entail retiring agricultural land. When wetlands are created where they did not previously exist, significant earthmoving is generally required. This earth moving and shaping and subsequent planting implies much higher costs than are evidenced in the CREP figures. If creating a wetland requires moving 2 feet of soil and planting wetland plants (at $1.00 per plug) on 18 inch centers, costs can easily rise to $40,000 per acre[16]. Even when restoring an existing wetland, plugs sold at $1 – $1.50 and planted 18 inches apart would sum to much higher costs than those implied by CREP wetland establishment payments.

It can be deduced from the wide range in costs of creating and restoring wetlands that there is also a wide range of implementation practices. But these are not specified in the description of the BMP or in the accounting of their nutrient reduction impact, so they cannot be a part of this analysis. It may be that higher cost wetland creation and restoration is more often linked to new development that will generate significant changes in local hydrology due to large additions of impervious surface, but data for that conjecture has not been identified under this project.

References

Jordan, T, T. Simpson, and S. Weammert. 2007. Wetland Restoration and Wetland Creation Best Management Practice: Definition and Nutrient and Sediment Reduction Efficiencies. Mid-Atlantic Water Program.

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[16] Personal conversation with Gene Slear, Environmental Concern, Inc.

2.5. *Conservation Planning*

Conservation Planning: Field and Pasture Erosion Control Practices are a combination of practices that reduce soil loss. Practice components meet criteria standards under the USDA-NRCS National Handbook of Conservation Practices (NHCP) and associated Field Office Technical Guides. The practices help to control erosion and nutrient runoff by modifying management or structural practices. Management practices may change from year to year and include changes to crop rotations. Conservation planning does not include reduction credits to certain cultural practice changes on crop or hay land, such as conservation tillage or cover crop practices, which are credited as individual BMPs. However, management practice changes are reflected in pastureland reduction efficiencies.

Structural practices, consisting of longer term conservation measures in the *Field and Pasture Erosion Control Practices* include, but may not be limited to, a number of USDA-NRCS conservation practices. Credit cannot be taken for each practice implemented under a farm erosion and sediment plan or a NRCS Conservation Plan; the suite of practices listed in the plan are prescribed to meet a USDA-NRCS Revised Universal Soil Loss Equation, (RUSLE2) prediction of soil losses at or below the soil loss tolerance value (T) for the accredited acreage.

Qualifying practices include:

- Access Road (560)
- Alley Cropping (311)
- Animal Trails and Walkways (575)
- Conservation Cover (327)
- Conservation Crop Rotation (328)
- Contour Buffer Strips (332)
- Contour Farming (330)
- Critical Area Planting (342)
- Diversion (362)
- Field Border (386)
- Filter Strip (393)
- Grade Stabilization Structure (410)
- Grassed Waterway (412)
- Lined Waterway or Outlet (468)
- Residue Management, Seasonal (344)
- Rock Barrier (555)
- Row Arrangement (557)
- Sediment Basin (350)
- Strip-cropping (585)
- Structure for Water Control (587)
- Terrace (600)
- Underground Outlet (620)
- Water and Sediment Control Basin (638)
- Windbreak/Shelterbelt Establishment (380)

These practices are implemented as needed and on the basis of site-specific assessments. Simpson and Weammert (2007) note that the technical efficiencies for this BMP with respect to the reduction of total nitrogen, total phosphorous and total suspended solids is left unchanged from existing Chesapeake Bay Model estimates. Those estimates are described as being based on a presumed combination of practices such that soil loss is reduced to tolerances or lower with respect to a universal soil loss equation. A “before implementation of the practice” level of soil loss is therefore implied in the reduction efficiencies reported in Table 2.5.1, but calculating them would be a circular exercise and would not provide better understanding of the frequency with which specific practices are employed to achieve those outcomes. The latter information is crucial to costing the BMP.

Table 2.5.1: Conservation Planning Nutrient and Sediment Reduction Efficiencies (%)

Land-Use	TN	TP	TSS
Conventional Tillage	8	15	25
Conservation Tillage	3	5	8
Hayland	3	5	8
Pastureland	5	10	14

Source: Simpson and Weammert, 2007

Practices employed for this BMP are given a fixed unit cost in a payments schedule[17] developed for USDA's Environmental Quality Incentives Program (EQIP). While one could simply factor each of the relevant costs by the reduction efficiency in Table 2.5.1 times some expected nutrient load export, it does not seem to the authors that this would provide useful information in terms of cost per unit nutrient load reduction for this "averaged" BMP.

References

Simpson, T. & S. Weammert. 2007. Conservation Planning: Field and Pasture Erosion Control Practices Definition and Nutrient and Sediment Reduction Efficiencies.

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[17] ftp://ftp-fc.sc.egov.usda.gov/MD/web_documents/programs/eqip/2008/EQIP_2008_payment_rates.pdf

2.6. Forest Harvest BMPs

Forest harvesting BMPs include a suite of practices that reduce sediment and nutrient pollution to water bodies originating from forest harvests and related activities. These activities include: road, trail, and landing construction, use, and closure; harvesting and log removal activities; and site preparation or within-rotation treatments. Practice components meet criteria standards under the USDA-NRCS National Handbook of Conservation Practices (NHCP) and associated Field Office Technical Guides.

Forest harvesting is evaluated in the Bay Model as a change in land-use from forest to harvested forest. Harvested forest is estimated to comprise 31,500 acres in Maryland with 16,797 acres in the coastal plain and 14,708 acres in the non-coastal plain. Total forest acres are 3.1 million acres for the state with 1.7 million acres in the coastal plain and 1.5 million acres in the non-coastal plain. Table 2.6.1 reports average per acre N loads across the two land categories and per acre difference implied by a shift from forest to harvested forest. Loads increase by factors greater than ten when forests are harvested. Forest harvest BMPs are designed to reduce the increase in load from harvesting.

Table 2.6.1: Average Nitrogen Export Loads for Forests and Harvested Forest on Coastal Plain and Non-Coastal Plain (lbs/A)

Land-Use	Avg. N Exported (CP)	Avg. N Exported (Non-CP)
Forest	2.32	6.18
Harvested Forest	30.41	71.05
Difference	28.09	64.87

Source: Chesapeake Bay Program Watershed Model Phase 5.1 Edge of Stream Loads

The shift from forest to harvested forest is time-limited. The number of harvested forest acres across the state can be thought of as residing in the "harvested forest" land-use for just a single year, after which they either return to the forest or, when the harvest is followed by a land-use change, some other land-use category. Therefore, the effect of forest harvest BMPs is limited to reductions in increased loads only for the year following a harvest.

At the current estimated reduction efficiency of 50%, the per acre N load reductions of harvest BMPs amount to 14.05 lbs/A on the coastal plain and 32.44 lbs/A on the non-coastal plain. These reductions provide the denominators for the cost efficiency of forest harvest BMPs. Estimating the cost of implementing forest harvest BMPs is made difficult by the fact that each harvest has its own set of appropriate BMPs and there are limited empirical studies on which to base generalizations about the costs of potential BMPs across harvest sites.

Aust, et al. (1996) estimate that forest harvest BMPs cost \$12.40/A on the coastal plain and \$38.00/A in the piedmont of Virginia. The set of BMPs considered for Virginia are similar to those in Maryland and the current study adopts those cost estimates, adjusted for general price changes over the period, as an estimate of the cost of implementing forest harvest BMPs in

Maryland. In 2007 dollar terms, those values become $14.53 and $44.52 for coastal plain and non-coastal plain, respectively.

In addition to the cost of implementing forest harvest BMPs, there remains a question about the frequency of compliance or non-compliance with the required practices. Hairston-Strang (2002) in an internal DNR memo reports compliance rates of 82% for all forest harvest BMPs. Compliance will affect the average reduction efficiency of the practice, since an acre where BMPs were not implemented will not receive any of the expected reduction. In a very general sense, this uncertainty has been incorporated into the estimation of nitrogen reduction efficiencies for the practice, as the recommended reduction from the literature was 60% (Simpson and Weammert 2007), but the CBPO retained the current 50% reduction efficiency.

Table 2.6.2 reports per acre load reductions and cost efficiencies by coastal plain and non-coastal plain acres. Although these point estimates share a great deal of variance with respect to actual reductions and costs of implementation, harvest BMPs seem to have higher cost efficiencies (lower $/lb) on the coastal plain, even though load reductions are much lower there.

Table 2.6.2: Nitrogen Reduction and Costs for Forest Harvest BMPs

	N Reduction (lb/A)	**Implementation Cost ($/A)**	**Cost Efficiency ($/lb)**
Coastal Plain	14.05	14.53	1.03
Non-Coastal Plain	32.44	44.52	1.37

Sources: Chesapeake Bay Program Watershed Model Phase 5.1 Edge of Stream Loads, implementation costs from Aust, et al. (1996)

References

Aust, W.M., R.M. Schaffer and J.A. Burger. 1996 Benefits and costs of forestry best management practices in Virginia. Southern Journal of Applied Forestry 20(1): 23-29.

Edwards, P. and K. Williard. 2007. Forest Harvesting Practices Definition and Nutrient and Sediment Reduction Efficiencies. For use in calibration and operation of the Chesapeake Bay Program's Phase 5.0 Watershed Model

Hairston-Strang, Anne. 2002. Maryland Forestry Information for Chesapeake Bay Program Model Use Attainability Analysis. MD DNR

Simpson, T. and S. Weammert. 2007 Forest Harvesting Practices Definition and Nutrient and Sediment Reduction Efficiencies. For use in calibration and operation of the Chesapeake Bay Program's Phase 5.0 Watershed Model

2.7. Conservation Tillage

Conservation tillage consists of cropping methods that minimally disturb the soil surface of the field. The practice involves two primary components. First, after planting and harvesting, a set amount of the field surface remains covered by crop (or other organic) residue, and second, a non-inversion tilling method is used in the planting process. Both components of conservation tillage promote the same set of positive outcomes. These include decreased soil erosion and increased overall soil health.

Three general types of tillage/planting methods fit under the description of conservation tillage: Mulch-till, No-till/Strip-till/Direct Seed (hereafter referred to as No-till), and Ridge-till. Mulch-till consists of the deliberate practice of leaving organic matter on the planting surface after the tilling/planting process is completed. No-till is the process of planting with the goal of disturbing the actual planting surface as little as possible. Ridge-till is the practice of planting specifically on ridges in the field separated by furrows containing organic matter. In addition to the three practices listed above, mulching may fit into the category of a conservation tillage practice, but will not be addressed here.

All practice components listed above meet criteria standards under the USDA-NRCS National Handbook of Conservation Practices (NHCP)[18] and associated Field Office Technical Guides[19] for each state. Specifically, Conservation Tillage contains, but is not limited to, the following components:

- Mulching (484)
- Residue and Tillage Management, Mulch-till (345)
- Residue and Tillage Management, No-till/Strip-till/Direct Seed (329)
- Residue and Tillage Management, Ridge-till (346)

Residue and Tillage Management: Mulch-Till

Mulch-till is defined as "managing the amount, orientation and distribution of crop and other plant residue on the soil surface year round while limiting the soil-disturbing activities used to grow crops in systems where the entire field surface is tilled prior to planting." It is differentiated from the other components of Conservation Tillage by its focus on the organic matter that is left or placed on a field after the previous cropping year. This organic matter serves to reduce erosion, reduce emissions, and improve both soil condition and soil moisture.

Traditional field practices eliminated much of the organic material left in the field by collecting and baling, or burning and eliminating, organic residue after the harvest. Any remaining residue is pushed downward into the soil in the next year's field preparation through the use of inversion tilling.

Mulch-till requires little additional effort from the farmer in terms of actual labor. Requirements for certain parts of the practice include uniform distribution of the organic matter across the field,

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[18] http://www.nrcs.usda.gov/technical/standards/nhcp.html

[19] http://www.nrcs.usda.gov/technical/efotg/

and a percentage (chosen based on farm conditions) of overall coverage. To fully carry out the practice, the farmer may need to change crop rotation or crop varieties to increase crop residue.

Residue and Tillage Management: No-Till/Strip-Till/Direct Seed

The No-till practice includes all the requirements of the Mulch-till practice, with the additional requirement that no full-width tillage can be done, regardless of the depth used. This emphasis on disturbing the surface of the soil as little as possible defines No-till. The goal of a No-till practice is to preserve the root structures directly under the planting surface as little as possible to increase infiltration and reduce nutrient loss.

Traditional tilling practices include ripping and turning the soil. This has the effects of removing much of the surface organic residue, and destroying the surface the soil has developed. This contributes to an overall loss of nutrients in the soil, increased runoff, evaporation, and carbon dioxide loss, and the overall lowering of crop production.

Implementing the No-till practice requires the purchase of a different style of planter than is traditionally used. However, it correspondingly reduces the number of field operations a farmer needs to carry out, saving fuel and labor, and reducing overall machine wear. Additionally, there may be changes in fertilizer and herbicide usage due to the implementation of the practice.

Residue and Tillage Management: Ridge-Till

The Ridge-till Practice is defined as "Managing the amount, orientation, and distribution of crop and other plant residues on the soil surface year-round, while growing crops on pre-formed ridges alternated with furrows protected by crop residue." Both the amount of residue and the height of the ridges are mandated in the practice, with the goal that ridge height is maintained over a succession of years, and substantial amounts of organic residue are left in the furrows. These furrows serve to direct and filter water flow off the field, reducing the amount of nutrients and other materials lost from runoff.

Runoff Effects

The Bay Program's assessment of the effectiveness of conservation tillage for nutrient and sediment reduction produced the estimates reported in Table 2.7.1.

Table 3: Conservation Tillage Nutrient and Sediment Reduction Efficiencies (%)

	TN		TP	TSS
Separate Flow Paths	Surface 18	Subsurface 0	22	30
Combined Flow Paths	8		22	30

Source: Simpson and Weammert (2007).

Costing Conservation Tillage

Because No-Till practices have their largest effect on runoff, and they include all of the requirements of Mulch-Till, studies of the costs of Conservation Tillage have focused on comparing traditional tillage costs against No-Till costs.

The biggest change imposed on a farm adopting No-till practice is the requirement for a No-till planter. Costs for a No-till planter can range from as low as $25,000 to over $70,000 dollars depending on machine size, spacing, and type. When compared to similar planters that are not used for No-till operations, No-till planters are generally more expensive. Comparing grain drills, a traditional end-wheel drill with 21 openers and 7.5 inch spacing carries a base price of $14,276, while a no-till drill with the same features had base price of $40,372. (John Deere, 2009)

Planters are not the only machine costs a farmer must choose between. If a farmer does not implement No-till, he will need other soil preparation equipment and if he does choose No-till, he will need some way to deploy herbicides on the field. Clearly, costing this type of purchase requires consideration of the timing of the farmer's decision to adopt the practice. If the farmer is planning on purchasing a new planter, then the additional cost of moving to a No-till system is only the difference between the two (approx $26,000), whereas if the farmer has a fully functional planter and wants to adopt No-Till, then the cost of the entire machine should be considered. Finally, in many situations, it may be possible for the farmer to rent or share the No-till drill. In this case, the farmer would not face the full burden of the machinery purchase price.

A strong argument for adopting No-till is that it reduces the number of passes a farmer must make across the field. This has the effect of lowering labor, machine wear and tear, and fuel costs. In a 2005 study considering wheat production in Arizona, Epplin found that using a No-till system reduced the number of hours/acre from 1.21 to 0.29 for small farmers. This savings fell as farm size increased. Additionally, fuel and repair costs per acre dropped from $9.62 to $3.03 for small farmers. This effect did not diminish as farm size increased. (Epplin et.al., 2005)

However, not all input prices fall with the adoption of a No-till system. Because the soil is no longer turned over, herbicide use may increase. Epplin found that for all farm sizes, herbicide costs increased $11.25 per acre. Table 2.7.2 summarizes the results of these two studies in 2007 dollar terms.

Ignoring changes in output, the cost - benefit picture for No-Till adoption is mixed. In 1991, Bradley found that overall costs for corn planting dropped by $18.41 per acre when No-Till practices were used. On the other hand, Epplin found that for small farmers, the large cost of the equipment overwhelmed farmer benefits. As farm size grew, this difference shrank, and for larger farmers, the benefits from reduced field time dwarfed machinery costs.

With respect to production benefits, the literature reviewed concludes that No-Till production raises output if it is used over a period of years. Bradley documents that over the 10 year period from 1981 to 1991, soybean output per acre averaged over 2 bushels more on fields that had No-Till practices used on them.

Table 4: Input Cost Comparison for No-Till vs. Conventional Tillage ($/ac, 2007 prices)

	Bradley 1991 (Corn)		**Epplin 2005 (Wheat, 320 acre farm)**	
	No-till	**Conventional**	**No-till**	**Conventional**
Seed	$19.61	$16.34	$11.73	$11.73
Fertilizer	$52.55	$52.55	$25.18	$25.18
Herbicide	$30.20	$17.84	$12.56	-
Machine Repairs	$14.87	$22.75		
Fuel	$ 4.70	$ 9.09		
Labor	$ 7.62	$15.58		
Fuel, Lube, Repairs			$ 3.38	$10.74
Machine Fixed Costs[20]	$46.35	$67.01	$31.14	$38.62

Corn and Soybean News, a publication of the University of Kentucky, reported in 2007 that across a range of fertilizer amounts, No-till corn averaged 8 bushels more per acre per year than traditional tillage systems, and up to 16 bushels per year at optimal fertilizer amounts. Valued at 2007 corn prices, an estimated gain of $17.04 per acre is implied from adopting No-till methods.

Given the production benefits of adopting No-Till, and evidence that net costs are either very small or negative, the cost per acre for a farmer to adopt this BMP becomes a benefit per acre. Thus, the $/pound N reduced used in the rest of this report makes little sense here. We can look at the benefits of adopting No-Till by summing Bradley's 1991 corn production cost reduction estimates, discounted to 2007 dollars, with expected increases in output valued at the 2007 corn floor price. This generates an estimated gain from no-till of $42/acre.

This gain of $42 is accompanied by an average nitrogen reduction of 8 percent. Thus, for the relevant land-uses, we can examine how many pounds of nitrogen reduction are achieved in conjunction with the shift to no-till (Table 2.7.3). But, since we do not find a positive cost for the practice, a cost efficiency is not calculated.

Taken together, the benefits of using No-till are shared by both the farmer and the local watershed. The farmer is able to realize higher per acre profits while at the same time reducing the waste runoff his farm produces. Unlike many other BMP's, Conservation Tillage can be considered a win-win for both the farmer and the watershed.

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[20] For Bradley, fixed costs include machine interest and depreciation. For Epplin, it includes depreciation, insurance, interest on average investment and taxes.

Table 5: Nitrogen Reduction Benefits to Adopting No-till

Land-Use	TN/A (lbs)	N Reduction/A @8% (lbs)
Coastal Plain		
High-till w/o manure	24.27	1.94
High-till w/ manure	33.97	2.72
NM high-till w/o manure	7.56	0.60
NM high-till w/ manure	27.66	2.21
Non-Coastal Plain		
High-till w/o manure	82.75	6.62
High-till w/ manure	84.47	6.76
NM high-till w/o manure	20.67	1.65
NM high-till w/ manure	65.32	5.23

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2.8. Stormwater Management BMPs: Dry Detention Basins, Extended Detention Basins and Wet Ponds

Stormwater management BMPs seek to reduce the surge of surface water flow that results when rainfall encounters man-made impervious surface. The three practices treated here include dry detention basins, extended detention basins and wet ponds.

Dry Detention Basins

Dry detention basins are depressions or basins created by excavation or berm construction that temporarily store runoff and release it slowly via surface flow or groundwater infiltration following storms. They are designed to dry out between storm events, in contrast with wet ponds, which contain standing water permanently. The surface of the detention basin itself often consists of planted grass or can consist of concrete or some other liner. Grassed surfaces require periodic mowing, but improve trapping of sediments compared with smooth surfaces such as concrete, and also allow infiltration of stormwater if the underlying soil is permeable. Structures to reduce flow velocity such as rock berms may also be included. Dry detention basins can also consist of belowground tanks or vaults that temporarily store stormwater (i.e., hydrodynamic structures).

Hydrodynamic structures are devices designed to improve quality of stormwater using features such as swirl concentrators, grit chambers, oil barriers, baffles, micropools, and absorbent pads that are designed to remove sediments, nutrients, metals, organic chemicals, or oil and grease from urban runoff. These are generally proprietary devices that are installed belowground, thereby allowing aboveground space for parking or other uses. However, they also require greater maintenance than other BMPs and may not be economical for large runoff volumes.

Dry detention ponds improve water quality primarily by removing suspended particles via settling due to decreased water velocity. If plants such as grasses are present, they further reduce velocity. Nitrogen and phosphorus are removed via settling of particulates and plant and microbial uptake. Phosphorus may also sorb to soil particles. Significant nitrate removal is unlikely because the aerobic soil conditions are not favorable to microbial de-nitrification. These stormwater BMPs are designed to store surface runoff and release it slowly to streams, attenuating storm flood peaks. This hydrologic effect is considered a water quality function that helps to reduce stream channel incision, bank erosion, and loss of in-stream habitat structures typical of streams in urban areas with extensive watershed areas covered by impervious surfaces.

Dry detention ponds provide overbank flood protection for the peak flow reduction of the 25-yr storm event. They are also designed to control runoff volume during 2, 10, and 100 year storm peak management.[21]

Dry Extended Detention Ponds

Dry Extended Detention (ED) basins are also designed to dry out between storm events, yet they are distinguishable from dry detention basins by their additional water residence-time requirement. In Dry Extended Detention Basins, a low-flow outlet releases water over a given

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[21] Comments from Ken Pensyl, MDE.

period of time.

The surface of the detention basin often consists of planted grass, but can be constructed with a concrete or other liner. Ancillary treatment structures such as wetlands or permanent pools may also be built in series with dry ED basins, an arrangement sometimes referred to as a "treatment train."

The water quality functions of dry extended detention ponds are similar to dry detention ponds, but with improved settling and adsorption due to increased residence time. Detention basins provide little habitat value for organisms other than soil invertebrates, and, if they are constructed from cement, even that function is negligible.

Because of their additional design requirements, extended detention ponds have additional costs. Maintenance costs include mowing and elimination of woody vegetation, which (by law) may not be planted on or allowed to grow within 15 feet of the toe of the embankment and 25 feet of the principal spillway structure. Annual mowing of the pond buffer is also required along maintenance rights-of-way and the embankment. Additionally, the extended detention pond requires special drainage. The pond needs a low-flow orifice, sheltered from trash accumulation, as well as a drain capable of emptying pond in 24hrs, with a riser access point (valve sticking out of water).

Urban Wet Ponds and Wetlands

Wet ponds and wetlands are man-made landscape features that have characteristics and functions similar to their natural counterparts. Simpson and Weammert (2007) provide detail about the benefits and classes of urban wet ponds and wetlands. The characteristic of concern is the water quality function of this BMP. Wet ponds operate to settle out suspended particles through reduced water velocity (sedimentation) and remove nutrients via plant and microbial uptake.

Below, we model the cost of constructing a wet pond or wetland that achieves these benefits. Accordingly, we model wet ponds and wetlands as versions of dry extended detention ponds – roughly, wet extended detention ponds, albeit with different maintenance requirements. We abstract from the different construction requirements for wet ponds, and model this as a doubling of maintenance costs for wet ponds versus dry extended detention basins.

Nutrient and sediment reduction efficiencies for these practices are reported in three different BMP assessments compiled by Simpson and Weammert. Those efficiencies are summarized in Table 2.8.1.

Table 2.8.1: Water Retention Nutrient and Sediment Reduction Efficiencies (%)

	TN	TP	TSS
Detention Basin	5	10	10
Extended Detention Basin	20	20	60
Wet Ponds	20	45	60

Source: Simpson and Weammert (various, 2007)

Performance Criteria and Costs

The Maryland Department of the Environment (MDE) stormwater program website is the principal source for the cost-estimate methodology and implementation detail for these BMPs. MDE's stormwater program goal for new development (adopted here) is zero net impact from impervious surface. A description of the design parameters from MDE's stormwater design manual is provided in Table 2.8.2. The requirements are defined below.

Table 2.8.2: Summary of Statewide Stormwater Criteria

Sizing Criteria	Description of Stormwater Sizing Criteria
Water Quality Volume (WQ_v) (acre-feet)	$WQ_v = [(P)(R_v)(A)]/12$ P = rainfall depth in inches and is equal to 1.0" in the Eastern Rainfall Zone and 0.9" in the Western Rainfall Zone R_v = volumetric runoff coefficient, and A = area in acres.
Recharge Volume (Re_v) (acre-feet)	Fraction of WQ_v, depending on pre development soil hydrologic group. $Re_v = [(S)(R_v)(A)]/12$ S = soil specific recharge factor in inches
Channel Protection Storage Volume (Cp_v)	Cp_v = 24 hour (12 hour in USE III and IV watersheds) extended detention of post-developed one-year, 24 hour storm event. Not required for direct discharges to tidal waters and the Eastern Shore of Maryland.
Overbank Flood Protection Volume (Q_p)	Controlling the peak discharge rate from the ten-year storm event to the pre development rate (Q_{p10}) is optional; consult the appropriate review authority. For Eastern Shore: Provide peak discharge control for the two-year storm event (Q_{p2}). Control of the ten-year storm event is not required (Q_{p10}).
Extreme Flood Volume (Q_f)	Consult with the appropriate reviewing authority. Normally, no control is needed if development is excluded from 100-year floodplain and downstream conveyance is adequate.

Source: MDE Stormwater Manual

Requirement - Water Quality Volume - WQv

Maryland has established a minimum water treatment volume at all stormwater treatment sites: the water quality volume WQ_v. Mindful of under-provisioning, MDE specifies the minimum requirements for water quality volume: *"A minimum WQ_v of 0.2 inches per acre shall be met at sites or in drainage areas that have less than 15% impervious cover."* By implication, and as spelled out in the other design parameters, impervious cover greater than 15% results in further water quality treatment requirements. MDE defines WQ_v (in units of acre-feet) as the storage needed to capture and treat the runoff from 90% of the average annual rainfall, or, as described in the manual, "*…equivalent to an inch of rainfall multiplied by the volumetric runoff coefficient (R_v) and site area.*" The formula for calculation of water quality volume is:

$WQ_v = [(1.0)(R_v)(A)]/12$ (Eastern Rainfall Zone P = 1.0 inches of rainfall)
$WQ_v = [(0.9)(R_v)(A)]/12$ (Western Rainfall Zone P = 0.9 inches of rainfall)

where: WQ_v = water quality volume (in acre-feet)
$R_v = 0.05 + 0.009(I)$ where I is percent impervious cover
A = area in acres

Requirement - Recharge Volume
The recharge volume (the second row in Table 2.8.2, above) is based upon the hydrologic soil group, a calculated recharge factor, the size (acreage) of the drainage, as well as the amount of impervious acreage. The soil groups are determined by USDA, NRCS soil surveys or from site investigations and are given below in Table 2.8.3.

Table 2.8.3: Hydrologic Soil Group Specific Recharge Factors

A	B	C	D
0.38	0.26	0.13	0.07

The formula for the calculation of recharge volume is:
$Re_v = [(S)(R_v)(A)]/12$
where: $R_v = 0.05 + 0.009(I)$ where I is percent impervious cover
A = site area in acres

Another 'percent area' method is also included in the manual, but, as it is technically equivalent, it is not shown here. The recharge volume is considered part of the total WQ_v that must be provided at a site and can be achieved either by a structural practice (e.g., infiltration or bio-retention), a non-structural practice (e.g., filter strips or buffers), or a combination of both.

Requirement - Channel Protection Storage Volume (Cp_v)
The Channel Protection Storage Volume is a requirement to protect channels from erosion during a '24 hour storm event', but is only required for Western Maryland (the Eastern shore is excluded), and thus will not be included in the cost analysis here. Rather, we seek to make our cost estimate general enough that site-specific factors can be used to improve it, without making it too onerous or complex to use.

Requirement - Overbank Flood Protection Volume Requirements (Q_p)
Overbank flood protection for the ten-year storm is a requirement issued only if local authorities have no control of floodplain development, no control over infrastructure and conveyance system capacity design, or determine that downstream flooding will occur as a result of the proposed development. Anticipating this to be a special case for stormwater detention projects, overbank flood protection is ignored here.

Requirement - Extreme Flood Volume (Q_f)
Extreme flood volume protection is the most stringent and expensive level of flood control and is generally not needed if the downstream development is located out of the 100-year floodplain. It is not included in the cost scenario developed here.

Calculation of the design scenario

Our scenario is constructed using the stormwater design parameters.

- **Step 1: Calculate Water Quality Volume (WQ_V)**
  $WQ_V = [(P)\ (R_v)(A)] / 12$
  P = 1.0 in Eastern, 0.9 in Eastern; use 0.95.
  $R_v = 0.05 + 0.009(I)$ where I is percent impervious cover; use 50% impervious cover.
  $R_v = 0.05 + 0.009(50) = 0.05+0.45 = 0.50$

  $WQ_V = [(0.95)\ (0.5)(A)] / 12 = 0.475A / 12 = 0.0396$ ac-ft per Acre
  $WQ_{V,\ MIN} = [(0.2)(A)] / 12 = 0.0167A = 0.0167$ ac-ft per Acre

- **Step 2: Compute Recharge Volume (Re_V)**
  $Re_V = [(S)(R_v)(A)]/12$ or $Re_V = (S)(A_i)$ where A_i is the measured impervious cover
  As above, $R_v = 0.50$
  S = Hydrologic Soil Group Soil Specific Recharge Factor, among 4 types: Type A (0.38), Type B (0.26), Type C (0.13), and Type D (0.07)

  Here we assume S is either a 'high' type (average of A and B) or a 'low' type (average of C and D: 0.32 and 0.10, respectively.

  $Re_{V,\ HIGH} = [(0.32)(0.5)(A)]/12 = 0.16A/12 = 0.0133$ ac-ft per Acre
  $Re_{V,\ LOW} = [(0.10)(0.5)(A)]/12 = 0.05A/12 = 0.0042$ ac-ft per Acre

- **Step 3: Compute Runoff Volume (R_v)**
  Q_a = runoff volume, in inches (equal to $P \times R_v$)
  From above (step 1), we have R_v=0.50 and rainfall P = 0.95 inches;
  Q_a = 0.475 watershed inches of runoff volume

- **Step 4: Compute Curve Number (CN)**
  Using the WQ_V methodology, a corresponding Curve Number (CN) is computed utilizing the following equation:

  $$CN = \frac{1000}{[10 + 5P + 10Q_a - 10\sqrt{Q_a^2 + 1.25Q_aP}]}$$

  where: P = rainfall, in inches (use 1.0" or 0.9" for the Water Quality Storm)

  $CN = 1000/\ (10+5(0.95) + 10(0.475) - 10(0.475^2 + 1.25(0.475*0.95))^{0.5}) = 94.219$
  From Figure D.10-1 in [A], it appears that the Curve number associated for 50% impervious cover is approximately 94

  Initial abstraction (**I_a**) for CN of 94 is **0.123**: (TR-55) [$I_a = (200/CN) - 2$]

- **Further Steps: Compute t_C, peak discharge, and design parameters**
  Once a CN is computed, the time of concentration (t_c) is computed (based on the methods identified in TR-55, Chapter 3: "Time Of Concentration And Travel Time") according to the location of the project, the basin design, and the materials used in construction. This is a software program that generates outputs as a function of specific inputs[22].

  Using the computed CN, t_c drainage area (A), in acres, the peak discharge (Q_p) for the Water Quality Storm is computed (based on the procedures identified in TR-55, Chapter 4: "Graphical Peak Discharge Method").

The design output is as follows:

Step	Requirement	Calculated Value	Notes
WQ_v	Water Quality Volume	0.0396 (.0167)	ac-ft/A
Re_v	Recharge Volume	0.0133 (.0042)	ac-ft/A
Qa	Runoff Volume	0.475	Watershed inches
CN	Curve Number	94.2	-
t_C	Concentration Time	0.20	Hours
I_A	Initial Abstraction	0.123	-

MDE also gives other project restrictions in the stormwater manual, namely,

- *Stormwater ponds shall have a minimum contributing drainage area of ten acres or more (25 or more are preferred), unless groundwater is confirmed as the primary water source (e.g., pocket pond).*[23]
- *Flow paths from inflow points to outlets shall be maximized. Flow paths of 1.5:1 (length relative to width) and irregular shapes are recommended.* [24]

In this exercise, creating an illustrative scenario to show costs for this BMP, we endeavor to express everything in terms of acreage. Because of this, it may not be possible to generate peak discharge flow rates. However, using some of the examples in the stormwater manual, we can estimate required volume by interpolating between our numbers and the example numbers.

Construction of Costs and Assumptions

Input Costs

In this BMP estimate, as throughout this report, flat-rate schedules from five counties (Washington, Montgomery, Calvert, Harford and Talbot) were deflated into 2007 dollars[25], and an average cost was calculated and used as the input for the model.

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[22] see appendix c.1 of MDE's Stormwater Design Manual for an example.
[23] http://www.mde.state.md.us/assets/document/chapter3.pdf
[24] ibid, 3.1.4
[25] Using, for consistency, the Producer Price Index, major agricultural commodities.

Pond Geometry

A square geometry is assumed (the characteristic pond length, **a**, is some length determined by total capacity *V*), with a uniform pond depth of 6ft throughout, such that:

- Volume, V = 6*a^2 (in units of feet)
- Surface Area, SA= a^2 + 4*6a (top is uncovered)

Pond Excavation

For dry detention ponds, excavation costs are calculated for the removal of 2*V* cubic ft per acre of land drained by the retention pond (equivalent to twice the area of land developed or converted to impervious cover). The removal costs are doubled to reflect the additional cost required to construct a maximized flow path in the retention pond (i.e. a meandering channel), which will inevitably require some bank engineering as opposed to simple material removal.

Pond Paving/Lining

The material costs are assumed to be equivalent to lining *SA* square ft per acre of land. The pond is assumed to be lined to a depth of 6 inches with sand or stone – the cheapest average construction material available according to the flat rate schedule input prices. The construction material is assumed to have a density on the order of concrete – 2000 kg/m^3, an assumption that is necessary to arrive at a total cost for lining material[26].

Other Construction Costs

A grassed waterway is assumed in addition to the pond, at a distance of 5 times the characteristic length of the pond (*a*). Piping costs commensurate with a pipe length of 2 times the characteristic length of the pond are assumed. Piping is assumed to be solely 12-inch diameter corrugated plastic piping (Hi-Q), and a similarly-sized rodent guard (corrugated polyethylene perforated drain tube), where required. Hickenbottom outlets, when specified, are 6-inch diameter.

Additional costs, such as establishment of a surrounding filter strip, or purchase/design costs for orifices and engineered drainages, are considered incidental to the establishment of the retention pond itself, and are therefore not estimated individually.

Design Parameters

To be conservative, we use the highest of the parameter values calculated in the design exercise above, the WQ_v value calculated, 0.0396 A-ft per acre. The result is a volume (V) of 0.0396 A-ft, or 48.8 cubic meters per acre. This equates to material removal rate of (2V) or 97.7 cubic meters, and a paving requirement of 113.1 square meters per acre of drainage. Given a minimum drainage of 10 acres (and an example average[27] of 17 acres), we get material removal and paving requirements of 976 (1660) cubic meters and 703 (1129) square meters, respectively.

Materials Used

MDE's Stormwater Manual includes material requirements for basins and ponds. All extended detention ponds and wet ponds are required to have Hickenbottom (perforated) inlets and rodent guards, although dry detention ponds are required only to have piped outlet. Grassed waterways

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[26] Lining material is quoted in tons and not volume.

[27] average of the acreages of the scenarios included in the stormwater manual

are assumed to be 5x the characteristic length, *a,* of the pond, piping distances are assumed to be twice *a*, and Hickenbottom inlets are assumed to be equal to that length *a*.

Maintenance Costs

Maintenance costs for detention ponds are expected to be mostly the upkeep and mowing of any grasses or plants that provide some of the water filtration or water quality improvement characteristics of the BMP. Extended detention basins, especially, are expected to have additional maintenance costs associated with the low-flow orifice cleaning.

Opportunity Cost of Land

The opportunity cost of land is expected to be a large source of cost for any stormwater retention project, especially in urban areas. Valuing the land using real estate averages for the relevant counties, however, would both cause the costs to vary wildly, and would grossly overstate the opportunity cost. Development planners and designers are required to create a plan to treat stormwater created by impervious surface construction, and typically incorporate this planning at an early stage in order to minimize costs. Because of the incorporation of water treatment into the initial planning, standalone costs for earthmoving and paving may be overstated as well, because the marginal cost of operating earthmoving equipment may be small if it is already onsite preparing home sites. Certain aspects of stormwater basins, such as the establishment of a wet pond that draws wildlife, may in fact increase the value of the surrounding development and thus further mitigate the opportunity cost of the land.

It should be recognized that, especially for developments featuring more impervious surfaces, the construction of stormwater basins are too costly, so subterranean hydrodynamic structures may be chosen as an alternative method of treatment. Because we did not attempt to price such structures, we forfeit another possible approach to estimating the opportunity cost of land. Still, a stormwater management plan (including construction and maintenance of a basin) is typically a requirement for site development. Our retention pond scenarios are constructed conservatively, so as to overestimate stand-alone pond construction costs, but still provide a good estimate of overall costs (which may include forgone land value). While an imperfect approach, it is transparent and sites with greater expected land cost can be revised upwards.

Cost Estimates for Detention Basins and Wet Ponds

Because of the ambiguity regarding exactly what differentiates an extended detention basin from a detention basin, and a wet pond from either (at least in terms of design requirements), some crude cost approximations were used to extend the dry detention basin estimates to extended detention basins and wet ponds.

Extended detention basins require more resources to build than dry detention basins of the same size, because of the extra piping requirements needed to achieve the heightened retention time and discharge flow reduction. In addition, and in contrast to detention basins, extended detention basins require annual maintenance estimated at 5% of their construction costs for the design life of the basin (10 years). Wet ponds will have identical construction costs to ED detention basins, but are assumed to require that 10% of the construction cost be spent annually on maintenance for the life of the pond (10 years). A 5% discount rate is assumed for both wet ponds and extended detention ponds.

Table 2.8.4 shows the results of our calculation of costs for three different sized development projects. Each of the three project sizes assumes 50 percent impervious surface coverage at the site. Costs are expressed in 2007 dollars.

Table 2.8.4: Estimated Stormwater Retention Costs for Various Sized Development Projects

Project Type	10 acres	50 acres	100 acres
Detention Basins	$19,492	$86,689	$168,274
Extended Detention Basins	$37,971	$129,332	$229,982
Wet Ponds	$39,102	$133,184	$236,831

Source: Project data

Cost Efficiencies for Stormwater Management

If we simply amortize the estimated costs from Table 2.8.4 equally over their ten year expected life, we can then divide that annual cost by the nutrient load reductions reported in Table 2.8.1, and obtain a cost per percentage reduction for these BMPs. To obtain a cost per pound nitrogen reduced, we need to consider loading rates, which are assumed best represented by the "impervious urban high density" (imh) land-use. [28]

Cost efficiencies, using the costs reported in Table 2.8.4 and impervious urban high density land-use as the nitrogen loading rate, are shown in Table 2.8.5. Costs for each BMP are calculated as the total establishment and maintenance cost divided by ten years. The denominator (lbs N reduced) is calculated as the nutrient load times the appropriate reduction efficiency times the number of acres draining to the BMP. [29] There appear to be returns to scale in these BMPs under this calculation.

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[28] It is possible that these practices have a longer useful life than the ten years used here. If that is the case, amortizing these costs over a longer period would reduce $/lb cost efficiency of the practice.

[29] It is not clear that the reduction efficiency of this practice should accrue for all of the acres draining to the BMP or whether only those acres given over to the practice are treated.

Table 2.8.5: Nitrogen Reduction Cost Efficiencies for Stormwater Management BMPs

	10 Acres ($/lb)	50 Acres ($/lb)	100 acres ($/lb)
Coastal Plain			
Detention Basins	210.73	187.44	181.92
Extended Detention Basins	102.62	69.91	62.16
Wet Ponds	105.68	71.99	64.01
Non-Coastal Plain			
Detention Basins	121.11	107.72	104.55
Extended Detention Basins	58.98	40.18	35.72
Wet Ponds	60.74	41.37	36.79

Source: Project data

Given that our costing scenario makes a number of assumptions that may or may not apply to any specific case, these cost efficiencies should be treated with caution. But since the method applied is transparent, it would not be difficult to adapt these calculations to any specific case.

Another issue that is raised with these estimates, however, is that the focus on nitrogen reduction (consistent throughout this report) misses the point of higher phosphorous and sediment load reductions from these BMPs. This is especially relevant because the high density impervious urban nitrogen loads, although significant, are not robustly mitigated by these stormwater BMPs.

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3. Costs, Efficiencies and Nutrient Load Mitigation Policies

The BMP costs addressed in the previous chapter, along with estimates of their pollution reduction efficiencies and estimates of the loads available to be mitigated, generate point estimates for cost efficiencies. To the extent that they allow policy-makers to target practices with higher cost efficiencies, accurate estimates of cost efficiencies are useful for designing programs that generate greater pollution reduction. Of course, the accuracy of our cost efficiencies is dependent on the accuracy of the technical efficiencies and nutrient load export estimates.

Another significant caveat with respect to our cost efficiency estimates is that they are snapshots in a moving world. Changes in input prices can be reasonably expected, and they will change the resource costs for implementing a practice in the short term. Over the longer term, changing technology will impact cost efficiency. As monitoring data improves, both the mitigation efficiencies and the nutrient pollution export estimates should become more accurate. In light of all this, we emphasize the temporal limitations of our estimates.

Though our estimates of costs and cost efficiencies are limited to a single point in time, this does not preclude using those estimates to illuminate the longer-term problem of optimizing expenditures for nutrient pollution mitigation. In this chapter we discuss some implications of our cost efficiency estimates, with special regard to cover crops.

3.1. The good being purchased

The true costs of reducing nutrients from surface waters of the state are obscured by the fact that existing programs pay for implementing qualified BMPs and not for directly reducing nutrients. Existing programs do not offer to buy a specified amount of nutrient reduction at some agreed upon price as would happen in a market or performance-based payment regime that sought to specifically buy nutrient reductions. Instead, they compensate participants for implementing BMPs that will, in varying amounts, mitigate nutrient pollution in the state’s waters. The important phrase in the preceding sentence is “in varying amounts”.

Applied on different acres, similar practices achieve different nutrient reduction results. As described in the previous chapter, some nutrient mitigation practices have a range of implementation methods, each of which has different costs and some of which have different reduction efficiencies. And, since different acres have different amounts of nutrients to be reduced, a practice’s ($/lb) reduction efficiency will also change depending on the land-use it is applied to and where that land is located.

The disconnect between payments and the thing being purchased is a result of the character of nutrient pollution mitigation. Nutrient mitigation cannot be seen with the naked eye. Estimates of nutrient mitigation are derived from test plots and field monitoring data. Uncertainty about what is being purchased, then, has led to policies that buy something that can be seen – a cover crop, a fence or a riparian buffer.

As an intermediate step, such policies seem highly appropriate. They allow the expansion of pollution mitigating practices while generating information about what works and what doesn't. However, as field research delivers more specific reduction estimates under a wider variety of conditions, nutrient mitigation efficiencies and their cost efficiencies become more apparent. As they become more apparent, or less uncertain, it is possible to refine the focus of purchases. To some extent, this can be done by graduating payments to encourage specific practices within a BMP. But we argue that in several aspects, more detailed payment specifications cannot compete with an economic optimization of those purchases. We demonstrate this increased economic efficiency in our pricing example for nitrogen that follows.

3.2. The cover crop example

The cover crop BMP provides a useful example of how refined measures of nutrient mitigation cost efficiencies allow us to identify more cost-effective purchases. This BMP is straight forward in its costing and its nutrient reduction efficiency has been defined over a wide variety of conditions and practices. To the extent that current estimates of the nutrient reduction efficiencies for cover crops are accurate, we can compare the overall effectiveness of different regimes for purchasing nutrient reductions through cover crops. The metric for these comparisons should be total pounds of nitrogen (lbs/N) mitigated for a given budget.

We have, from Table 2.1.4, estimates of both total expenditure and total nitrogen reduction under the 2008 cover crop program. If early plantings of cover crops were paid $50, normal plantings $40, and late plantings $30, then we simply multiply those prices times the appropriate number of acres planted for a total cost. By that method, total cost in FY 2008 comes to $6.67 million. Reductions are tallied by summing the total load reduction column and this gives 1.14 million pounds of nitrogen reduction. The average mitigation cost using this approach is $5.83/lb N.

We can compare this scenario with a hypothetical one in which no premium is paid for earlier planting. If no premium was paid for earlier planting, then there would be no financial incentive for a farmer to plant earlier, rather than later. With the bonus for earlier planting, 70% of the acres planted were planted early, 20% were planted normally, and 10% were planted late in the fall of 2007. Assuming that it was the bonus that motivated that planting pattern, we expect that without the bonus, planting would be timed differently.

In our first hypothetical scenario, we assume that plantings are apportioned across the three planting periods equally. We model this by shifting acres out of the early category and into the normal and late categories so that acres are equally apportioned across planting dates. We maintain the apportionment of acres across the land-use types and planting practices within each of the categories. In the scenario with acres distributed equally across all three planting periods, total nitrogen reduction goes from 1.14 million pounds to 0.96 million pounds, a reduction of 16% from what was achieved under the actual 2008 program.

It could also be argued that without the bonus for the early and normal planting periods, in fact much more of the cover crop would have been left to later plantings. If we allocate planted acres at a rate of 20% early, 30% normal and 50% late, then nitrogen reduction falls to 0.83 million pounds, or a 27% drop in nitrogen mitigation. Unless we have a good reason to predict what sign-ups would have been in the absence of the premium for early planting, any of these scenarios is possible. But it does seem likely that the early planting bonuses generated additional nitrogen mitigation, relative to what would have been obtained without it.

In another, bolder scenario we can assess what might be obtained if the payment system for cover crops was changed so that, instead of paying some graduated rate per acre, farmers were paid for the number of pounds of nitrogen reduced by their cover crops. We base our assessment of this scenario on Tables 2.1.3 and 2.1.4, which report nitrogen mitigation cost efficiencies by cover crop seed, cropping practice, planting date and geographic region. We establish two prices for cover crops, one each for coastal plain acres and non-coastal plain acres.

Since we are interested in the total yield of nitrogen mitigation, we must first establish what resources are available to deliver that mitigation. Land that would otherwise lay fallow in the winter is the binding resource constraint for the practice. In the corn-soybeans-wheat rotation, acres will only be in winter fallow every second year.[30] Clearly, when a crop of winter wheat is being grown, the land is not fallow in the winter. As a simple and conservative estimate, we reduce the total acres in each of the six Bay Model land-uses relevant to cover crops by 50%. This, along with potential total reductions, is reported in Table 3.2.1 for the relevant land-uses in both the coastal plain and the non-coastal plain.

Table 3.2.1: Potential Supply of Nitrogen Reduction from Cover Crops Given Acreage Constraints

	Land-Use	Available Acres	Total Available Reduction	Total Cost @ $3/lb	$/A
Coastal Plain	High-till w/o manure	11,014	119,200	357,601	32.47
	High-till w/ manure	98,800	1,496,798	4,490,395	45.45
	Low-till w/ manure	128,709	1,591,518	4,774,553	37.10
	NM high-till w/o manure	6,483	21,852	65,555	10.11
	NM high-till w/ manure	50,301	620,560	1,861,679	37.01
	NM low-till	94,635	1,032,056	3,096,169	32.72
	Land-Use	**Available Acres**	**Total Available Reduction**	**Total Cost @ $2/lb**	**$/A**
Non-Coastal Plain	High-till w/o manure	2,979	83,816	167,632	56.27
	High-till w/ manure	35,154	1,009,633	2,019,266	57.44
	Low-till w/ manure	63,341	1,633,201	3,266,401	51.57
	NM high-till w/o manure	2,035	14,298	28,596	14.05
	NM high-till w/ manure	22,913	508,912	1,017,823	44.42
	NM low-till	49,549	947,203	1,894,405	38.23

Source: Chesapeake Bay Model Edge of Stream Loads (ver. 5.1) and Simpson and Weammert

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[30] We do not address the commodity grain cover crop program as it is unclear what nutrient reduction benefit accrues to this practice.

Table 3.2.1 reports nitrogen reductions that could ensue if suppliers of cover crops were paid for each pound of nitrogen that they reduced. Total available land is calculated as described above – as one half the total croplands in each land-use. Total reduction for any given land-use is estimated as if farmers use the most efficient practice available for reducing nitrogen loads from cover crops – that is, rye drilled at an early date. At the purchase prices chosen for the coastal plain ($3.00) and the non-coastal plain ($2.00), several other practices could produce a profit for the farmer, but we have no way of knowing how farmers would choose among those prospects and so simply assume that they would use the practice which our estimates show would generate the highest nitrogen reduction, which would be early rye, drilled.

We estimate total reduction available as pounds per acre reduced by early rye drilled times the number of acres available. We then cost that reduction as the fixed price for nitrogen reduction in either region times the total reduction there.

While the thing being purchased in Table 3.2.1 is measured in pounds of reduction, the farmer's costs are still accounted in terms of costs per acre to produce that reduction. That is, the farmer will focus on net returns per acre planted. Gross return per acre is the price per pound times the number of pounds of nitrogen reduced per acre (given early rye, drilled).

In 2007, when prices for early cover crops were $50/acre, not all acres available were entered into the program. Therefore, $3.00 per pound of nitrogen reduction would not likely generate the reductions suggested in Table 3.2.1. However, at $2.00 per pound on the non-coastal plain, 2007 per acre payments would have been significantly higher than what was offered under the existing program, indicating that more acres might have been entered under a price per pound purchasing arrangement.

If we limit our expected sign-ups to those acres generating payments greater than $50/acre, then the $2.00 price on the non-coastal plain could generate up to 2.7 million pounds of nitrogen reduction at a total cost of $5.45 million dollars. No cover crops would be grown on the coastal plain. If we expect all the acres with greater than $40/acre to enter, then the program could generate up to 4.7 million pounds of nitrogen reduction at a total cost of about $11 million.

These calculations are admittedly general. However, they provide an example of how pricing the service that is desired (nutrient reduction) might lead to more efficient outcomes. We cannot predict with certainty what the precise uptake will be for nitrogen mitigation at some given price, but we can assert with confidence, that those practices with the better cost efficiencies will be more attractive to suppliers than a random draw in the current acre-based payment system.

While pricing nutrient reduction by the pound should generate efficiency gains, this type of pricing clearly carries hazards. If the per pound price is too low, no one will sign up. If it is too high, then sign-ups may break the bank. Our hypothetical prices were chosen to make our point. We are not suggesting that these prices are the most appropriate ones, though they may be in the range with respect to the 2007 planting year. Additional research would be required to establish an appropriate price per pound under current conditions.

A second concern accompanying a shift to per pound reduced pricing has to do with information. How does the farmer know how many pounds of nitrogen will be reduced if he plants cover crops on any given acre? Furthermore, how does the buyer know that what the farmer says will be reduced is what will actually be reduced? This problem can be overcome by developing a standard calculator, based on the same efficiencies and load estimates as were used to create Table 3.2.1 (or improved estimates as these become available). Such a calculator could be a computer program or a series of tables. As long as the farmer checks the box that matches his or her site conditions and planting offer, the expected nitrogen reduction would be given by the standard calculator. Oversight would simply entail ensuring that the correct site conditions were stated and that the cover crop was planted as offered.

A third concern arising from per pound reduced pricing is the regional effect shown in Table 3.2.1. Non-coastal plain acres have much higher nutrient export numbers than coastal plain acres. That is what drives their higher (lb/acre) technical efficiencies. Because of that, at a true single price, most reduction from cover crops will happen on the non-coastal plain. We dodged that problem by (inefficiently) suggesting a two-tiered pricing system. While this reduces the efficiency in terms of buying the largest amount of nitrogen reduction into the Bay as a whole, it shows how one might resolve these local effects. If markets are segmented between the coastal plain and the non-coastal plain or even by tributary, per pound pricing would force similar efficiency gains within each market segment.

Another concern is the choice of good (pollutant) that is being purchased. We have used nitrogen here, but in the Chesapeake Bay, we are also concerned about phosphorus and sediment. To date, most market-like programs have created parallel markets for nitrogen and phosphorus (Pennsylvania, Virginia and Maryland). Programs are being designed to simultaneously accommodate multiple pollutants (see the Greater Miami River Basin Nutrient Trading Program in Ohio) but the required information concerning the pollutants' interactions is high.

Finally, the question may arise, why bother changing the focus of payments when we know everything that we need to know to value nitrogen reduction purchases by the acre? First, it would be difficult for an agency that serves the farming community in all of Maryland to propose paying farmers in one region more money than it pays farmers in another region to do the same thing. While this same outcome would obtain in a price per pound reduced purchasing arrangement, the benefit is more transparent under this regime. Just as similar farming practices are rewarded differently on different land in terms of crop yields, different cover crop practices can be expected to generate different rewards based on the amount of nitrogen reduced.

Secondly, the cost estimates used to generate the cost efficiencies in Table 3.2.1 are based on 2007 factor costs. Those are already out of date, as input costs have changed in the intervening years. Even with additional analytical effort, costing nutrient mitigation practices will always be based on what is past and will not carry as precise information as is available to the farmer at the time that a planting decision has to be made. Because of this, it would be difficult achieve maximum nutrient reduction from cover crops with prescribed practices and acre-based incentive payments[31].

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[31] Since the government is a sole-buyer here, it is possible that it could, through discriminatory pricing, generate greater purchases of reductions than through fixed-price purchases. That possibility is ignored in this discussion.

3.3. Other cost and cost efficiency issues for non-point source BMPs

Cover crops provided a good example of how changing the payment regime for BMPs might generate efficiency gains because cover crops is one of the better-understood nutrient reduction practices and because its efficiencies are specified over a range of conditions and practices. Moreover, it is an annual practice, and programs that support it can be adjusted relatively easily, as new information becomes available. Practices such as wetlands, riparian buffers and retention basins have a longer expected life and programs supporting their adoption need to take account of a longer time horizon. This makes support regimes for those BMPs less flexible and more difficult to change.

It is noteworthy that, at $200/acre and $150/acre plus land rental values and up-front bonuses, few additional riparian buffer acres are being offered at present. At lower prices, even fewer wetland acres are being created or restored. With the exception of grassed buffers, these practices imply a longer time horizon than current 15 or 10 year contracts fully capture. If riparian forest buffers are to be cleared at 15 years, the load reduction estimates used for them in this study probably overstate their nutrient reduction value. While clearing existing riparian forest buffers may be precluded by other terms and conditions, a 15 year life for riparian forest buffers and a 10 year life for grassed buffers and wetlands were used in our estimates of annual costs for procuring those acres and their nitrogen reduction.

Considering the present value of the riparian forest buffer program over a more realistic time horizon – say 60 years – the discounted sum of continuing payments ($285) net of establishment costs amounts to a lump-sum present payment of $10,105 at a two percent interest rate and $4,281 at seven percent. Only 27% of the establishment cost accrues to the participant, and at our calculated average cost of $714, plus the $10 signing bonus, this would amount to an additional $203. The average acquisition cost for permanent easements on agricultural land in Maryland was just under $6,000 in 2007[32].

If it is envisioned that acres will be maintained in a riparian buffer land-use long enough to achieve desired nutrient reduction values, an argument can be made for changing the payment system from medium term contracts to longer term contracts (i.e., permanent easements). The undiscounted sum of 60 payments of $285 is $17,100. However, the price of gaining acceptance for a permanent easement is highly variable and, the more targeted the purchase, the higher the price is likely to rise. Moreover, gaining an easement ignores the costs of establishing trees on sites that do not currently have trees.

In addition to those limitations, from the point of view of the State of Maryland, funding from the federal government through CREP is additional to State nutrient reduction efforts. Unless CREP funding could be shifted to the purchase of permanent riparian easements, the comparison of costs between existing versus longer-term arrangements is merely informational – not actionable.

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[32] Maryland Agricultural Land Preservation Foundation data: www.malpf.info/tables/HistoricalValues.pdf.

Stormwater management BMPs (i.e., detention basins and wet ponds) do not suffer this timing miss-match, to the extent that our expected lives of the BMPs are correct. If, after ten years, these structural BMPs must be effectively rebuilt, then the annual costs developed in Chapter 2 are accurate and the question becomes how to ensure that those costs are paid. The high margins common at the development phase of property development may not extend into the depreciation phase, which could make paying stormwater quality management costs more problematic over the longer-term.

4. Summary and Recommendations

The paper has reported costs and cost efficiencies for a set of non-point source nutrient mitigation BMPs, using technical reduction efficiencies as reported in the CBP/MAWP review. These cost efficiencies are shown to be numerous, both across BMPs and, for some practices, within a single BMP implemented in different ways at different sites. While this profusion of cost efficiencies is inconvenient for reporting purposes, it illuminates the point that, by rank ordering them from smaller numbers to larger numbers, one identifies the practices that will gain the most nutrient reduction at any given budget.

It is noted that the accuracy with which costs and cost efficiencies for BMPs can be calculated is vulnerable to different kinds of error. But, given the effort that has been made to refine estimates of the technical efficiencies and loading rates, it is reasonable to expect that those estimates represent actual conditions with some degree of accuracy. On that basis, the paper makes suggestions about how policy-makers might use knowledge of the cost efficiency of practices to improve nutrient mitigation at any level of expenditure.

Using the technical efficiency of BMPs and loading rates to estimate unit reductions of nutrients and sediments it is possible to value those reductions, specifically in $/lb reduced. If a price were applied to the number of pounds of nutrient reduced, then any potential supplier of reductions faces a better financial result, the greater the efficiency of their practice. This incentive would group suppliers from most efficient to least efficient, and the supply of nutrient reductions would be maximized at any given price.

While no market yet exists for nutrient reduction, *per se*, in the Chesapeake region, it is possible to advance the goal of greater nutrient reduction by employing BMP cost efficiency information with the fundamental economic insight that pricing the thing desired gives a more certain and preferable outcome than pricing some freely varying approximation of the thing desired. The report provides an example of such a shift with respect to purchasing cover crop implementation.

Of the current non-point source BMPs, cover crops provide the most precise definition of load reduction across implementation practices. This precision would allow farmers to estimate their production of nutrient reduction, given their existing cropping pattern and their range of potential implementation practices (and, given a standard estimator based on the technical efficiencies). If the farmer knew the price per unit of reduction, then he could use this to estimate his expected gross income from implementing the practice. Such a pricing scheme should improve the efficiency of cover crop expenditure with respect to the volume of nutrients reduced. Regional impacts may require multiple prices, however.

Other BMPs – particularly wetlands and stormwater management – might gain from more precise pricing of the benefit they deliver. But, since the policy application of cost efficiency information was an ancillary goal of the project, an examination of the potential efficiency gains in purchases of those BMPs was not undertaken. Further study of the potential gains from a more precise valuation of the reductions from other BMPs is recommended.

The report identifies some limitations in the estimates of the technical reduction efficiencies for some BMPs with respect to costs. Extensions and refinements of those reduction efficiencies, capturing a wider range of specific conditions and outcomes, would permit more precise cost efficiency estimates. In this respect, the review of the technical efficiencies recently undertaken might be better viewed as a starting place, rather than a final resolution of the technical efficiency question. Other BMPs, not addressed under the current study, need to be addressed.

The report did not endeavor to rank order different BMPs on the basis of their cost efficiency. While such an effort could be useful, it is not clear that our understanding of the relative value of BMPs is sufficient to the task. Moreover, none of the BMPs are adequate, alone, for achieving water quality goals, so it is likely that series of BMPs will be necessary. This complicates the choices. Optimizing reductions across BMPs or via bundles of BMPs may await a better understanding how their interactions affect total nutrient and sediment loads and how this works over the longer term.

The report also did not explicitly assess the question of who pays the cost of BMPs, except with respect to potential differences between prices paid to get a BMP implemented and the resource costs required for implementation. The nutrient mitigation BMPs discussed in the report are largely funded by public resources. The exceptions are the stormwater BMPs, which are set by regulation and, therefore, are an out-of-pocket expense for property development investors. Who pays is a significant issue for the development of policies and programs to mitigate nutrient loads, and one worthy of additional study.

Finally, the report focused on a sole nutrient (N) in its cost efficiencies. While it is simple enough to adapt the cost efficiency calculations for phosphorous and/or suspended solids, there could be cases where it is preferable to manage for combined reductions. Further research on programs to simultaneously manage multiple pollutants is warranted.

Appendix: Detail on the datasets

1. **Cover Crops** (file name Covercrops.xls)

This data file contains both "constructed" cost estimates (i.e., those using factor costs to estimate average costs) and the "program costs" (i.e., what participants are paid for implementation), based on the FY2008 cover crop program. Named worksheets are described, below, with respect to calculations and sources.

1.1 **Factor Costs**: This sheet stores cost data for the factors necessary to participate in the cover crop program. It also stores seeding rates and provides a basis for estimating the cost of using "retained seed" as opposed to "purchased seed." Data sources are given in comment tabs.

1.2 **Cost by Practice**: This sheet gathers factor costs for five different planting practices and sums them at 2007 prices for a total practice cost by seed type and planting method. The sheet provides a way to incorporate cost differences with respect to retained and purchased seeds even though this distinction was not significant in the fall 2007 planting (it will be for 2008).

1.3 **Efficiencies and Costs (CP)**: For the coastal plain, this sheet compiles the technical efficiencies given in Simpson and Weammert and the practice costs from the previous sheet to calculate a percentage cost efficiency for each practice (table titled: **Technical Efficiencies and Costs ($/A)**). To the right of that table, loading rates taken from the Chesapeake Bay Model's edge of stream export estimates (version 5.1) are given under the title, **Chesapeake Bay Model Nitrogen Export Estimates by Land-Use & Geology**. Below the load table is a series of tables which calculate the number of pounds of nitrogen reduced by land-use for each of the alternative implementation options and then uses the percentage efficiencies and practice cost information to calculate an estimate of the $/lb nitrogen reduced for each practice in each land-use.

1.4 **Efficiencies and Costs (non-CP)**: This sheet does the same thing as the previous sheet but using non-coastal plain technical efficiencies and loading rates.

1.5 **Optimization**: This sheet calculates state-wide nitrogen reduction supply based on 50 percent of the land-base for the six land-uses being available in any given year and using the technical efficiency for early rye, drilled, which is the most cost efficient practice from the previous two sheets. At a price of $3/lb on the coastal plain and $2/lb on the non-coastal plain, potential supply is revealed, depending on the farmer's cost per acre and the gross payment per acre.

1.6 **Program Costs (CP)**: This sheet is based on MDA annual reporting data (FY2008) for cover crop payments, paired with the technical efficiencies from Simpson and Weammert and the loading rates given by the Bay Model (version 5.1) edge of stream estimates. Each planting practice is assessed with respect to nitrogen load reductions at the three given levels of program payments per acre (50, 40 and $30) and at their respective technical efficiencies. Total cover crop acres (CA) for each practice are allocated proportionately across land-uses by crop and by time of planting for coastal plain acres. Whether a given acre used manure or not is taken from the MDA data. Appropriate technical efficiencies and loading rates are then applied to estimate total reductions for each practice. [Note: while there are a small number of late barley acres accounted in the MDA reporting, Simpson and Weammert do not report a technical efficiency for this practice. Therefore, those acres are excluded from the calculations.]

1.7 **Program Costs (non-CP)**: This sheet does the same thing as the previous sheet but for non-coastal plain acres.

1.8 **Program Scenarios**: This sheet compiles the information from the previous two sheets to estimate total load reductions if acres of sign-ups were allocated differently across the early, normal and late planting periods.

2. **Off-Stream Watering** (filename offstream.xls)

2.1 **Flat Rate**: This sheet shows costs for components of the practice taken from the MACS/FSA county flat rate schedules for 5 different Maryland counties. Since those cost estimates are from various years, they are converted to 2007 prices using the Producer Price Index for major agricultural commodities. The prices across counties are then averaged for a single state-wide estimate.

2.2 **Off-stream**: This sheet specifies the assumptions for three different off-stream watering scenarios (merely off-stream watering, off-stream watering with fencing and, off-stream watering with fencing and a stream crossing) at three different area assumptions (1, 50 and 100 acres).

2.3 **Note:** The final step of calculating a $/lb cost efficiency is not taken for this BMP because of a lack of clarity on appropriate loading rates.

3. **Riparian Buffers** (filename: riparian buffers.xls)

3.1 **Signups by CP#**: This sheet reports state-wide acres signed and total establishment cost share by conservation practice (note, this does not include additional incentive payments such as signing or practice bonuses) from FSA on-line data (http://content.fsa.usda.gov/crpstorpt/r7crepyr/md.htm and http://content.fsa.usda.gov/crpstorpt/r1meprtx/MD.HTM). The first four columns give state-wide acres signed and establishment cost share expenditure by CP# by year. The tables to the right compile those same data by CP# and calculate an average cost share by practice by year. Those annual figures are then converted to 2007 dollars using the Producer Price Index for major agricultural commodities. Coastal plain and non-coastal plain averages for the period are calculated at the bottom.

3.2 **Payments by PY**: This sheet shows annual soil rental rate averages by county by year (from: http://content.fsa.usda.gov/crpstorpt/r1meprtx/MD.HTM) and calculates, based on the soil rental rates and the history of the various CREP program offers, incentive payments for each. The program has changed over the years and each of those changes is captured in the year in which the change came about in the columns with "incentive payment" in the title (noted in comments). [Note: Formerly, incentive payments were based on rental rates, but more recently they have shifted to a flat rate, independent of the rental rate.]

3.3 **Cost efficiencies**: This sheet compiles the technical efficiency expectations from Simpson and Weammert along with annualized establishment costs plus annual rental rates plus incentive payments to calculate cost efficiencies. Cost efficiency calculations use deflated establishment costs from **Signups by CP#** times 2 and divided by 15 (the life of the contracts) for an annualized establishment cost. Annual rental rates plus incentive payments are taken from the bottom of **Payments by PY**. Load reductions for the actual buffered area are calculated as the difference between the old land-use loading rate minus the forested land-use loading rate. Upgradient load reductions are calculated as 4 times the nitrogen reduction efficiency for given geological areas. For this example, upgradient acres are in nutrient management low-till and appropriate loading rates are used.

4. **Wetland Creation** (filename: WetlandCP23.xls)

4.1 **CP23 data**: This sheet shows signups and cost share for CP23 for FY 1998 to 2009 using the same base data as referenced in the Riparian Buffers data file (i.e., (http://content.fsa.usda.gov/crpstorpt/r7crepyr/md.htm and http://content.fsa.usda.gov/crpstorpt/r1meprtx/MD.HTM). Average statewide rental rates are also shown.

4.2 **Cost Efficiency**: This sheet calculates the load reduction using Jordan's equation Removal = $1 - e^{-k\,(\text{area})}$ and assuming low-till with manure land-use in the drainage. A 100 acre drainage is considered, and 10 different wetland sizes are examined. Costs are gathered manually as defined in the text of the report.

5. **Conservation Planning** – no data file

6. **Forest Harvest BMPs** – no data file

7. **Conservation Tillage**: no data file

8. **Stormwater BMPs** (filename: Stormwater.xls)

8.1 **Flat Rate**: This sheet provides component prices for the stormwater BMPs for the same five counties that provided the basis for Off-stream watering BMPs. In fact, it is the same sheet used in the Off-stream watering data file.

    8.2 **Retention**: This sheet calculates scenario costs, based on the formulas and assumptions described in Section 2.7. Rather than cut and paste those assumptions and calculations, the reader is referred to the description provided in pages 33 through 38 of the text. Actual spreadsheet calculations can be seen using the "Trace Precedents" function.

9. **Maryland Edge of Stream Loads** (filename: Edgeofstream5.1.xls)

[Note: It is our understanding that new model runs have generated new load estimates so this file should be updated]

    9.1 **Land-use definitions**: Self-explanatory

    9.2 **By land-use (CP)**: This sheet gives nutrient loading rates and acreages for the coastal plain by land-use generated by the Bay Model 5.1.

    9.3 **By land-use (non-CP)**: This Sheet provides nutrient loading rates and acreages for the non-coastal plain acres.