Nutrient Trading, the Flush Tax, and Maryland's Nitrogen Emissions to the Chesapeake Bay

by

James C. Hanson and K.E. McConnell

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Department of Agricultural and Resource Economics

The University of Maryland, College Park

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Department of Agricultural and Resource Economics
University of Maryland

Abstract: We investigate nutrient trading for point and non-point sources for the Bay Restoration Fund in Maryland. We demonstrate how to use the proceeds from the tax revenue to mimic trading high-cost upgrades of sewage treatment plants for low-cost winter cover crops. Under an optimistic assumption about costs for non-point sources, we calculate that abatement could be increased by more than 50%, while in a pessimistic scenario, abatement could be increased by 2%. We also explore the role of uncertainty in determining the appropriate trading ratio between point and non-point sources of pollution, showing that the higher uncertainty associated with non-point sources should induce a lower trading ratio.

Key Words: Chesapeake Bay, cover crops, nitrogen abatement, nutrient trading, sewage treatment plants, trading ratios, water pollution

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Introduction

Recent initiatives in air pollution policy have emphasized the efficiency of incentive-based mechanisms for reducing pollution. The best example is the sulfur dioxide (SO_2) trading program, although there are a number of other incentive-based programs in the Clean Air Act and its amendments, including pollution permit trading programs for mercury and nitrous oxides.[1]

The success of incentive-based mechanisms in reducing air pollution has led to their use in water pollution policy, where progress has been more slow. The most familiar of these mechanisms is water pollution permit markets, which have considerable support from the U.S. Environmental Protection Agency and various state government agencies.[2] Breetz *et al*. list over 70 such programs in various stages of development (see King and Kuch and Breetz *et al*. for summary data on these programs). Unfortunately, there have been only a limited number of voluntary trades to date, suggesting that there are barriers to be overcome if nutrient trading is going to be a viable water quality policy.

The requirements for water quality pollution trading are similar to those for air pollution permit trading. The characteristics of buyers and sellers of permits must be determined. Some of the buyers or sellers must be polluters who have pollution caps on an individual or enterprise basis. The baseline levels of pollution emission of all sellers must be known. Finally, there must be active monitoring and enforcement. Since neither buyer nor seller of credits has any interest in whether the trade actually achieves the reduction in pollution, it is essential to have a public representative, such as a governmental agency, representing the public interest to ensure that the contract terms of the trade are reasonable and are met.

Water pollution comes from two sources: point and non-point. Measurement of emissions is feasible for point sources, such as a publicly owned treatment plant, but a significant challenge for non-point sources. The uncertainty that characterizes non-point sources is all the greater because weather plays a major role in these emissions. Because the link between conservation practices and nutrient abatement is uncertain, trading such practices for point source abatement is a gamble. Moreover, trading conservation practices instead of abatement greatly diminishes the ability of farms to seek more effective ways of nutrient abatement.

Much of the discussion of non-point source trading revolves around the notion of the trading ratio—the quantity of non-point source abatement traded for point source abatement. The popular argument is that the trading ratio should be greater than one, to account for the greater uncertainty of non-point source abatement (King and Kuch). This conclusion is problematic, and stumbles on the distinction between abatement uncertainty and emissions uncertainty. Shortle has observed that while increases in the

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[1] See Gayer and Horowitz for a comprehensive study of incentive-based pollution control policies

[2] The idea of nutrient trading for the Chesapeake Bay has circulated for some years. See the general ideas suggested by the Chesapeake Bay Program athttp://www.chesapeakebay.net/trading.htm.

abatement of non-point sources at the expense of point sources may increase the uncertainty of abatement, it reduces the uncertainty of emissions. Because ultimately the public is most concerned about the damages caused by emissions (and is willing to incur costs to reduce it), it makes sense in policy decisions to focus on emissions, rather than abatement. Toward that end, Shortle identifies a trading ratio less than one as a tool for encouraging non-point source abatement and reducing the uncertainty of emissions.

In this paper, we investigate nutrient trading for point and non-point sources in the specific policy presented by the Bay Restoration Fund (Maryland Senate Bill 320), widely known as the Flush Tax, in Maryland. The Flush Tax is expected to abate nitrogen emissions in the state by 7.5 million pounds, primarily from improvements in sewage treatment plants. To put that reduction in perspective, there was a flow of 56.7 million pounds of nitrogen into the Bay from all Maryland sources such as agriculture, urban non-point, and sewage treatment plants in 2002. The 2020 strategy goals require a reduction of 20 million pounds, to 37.25 million pounds. The 7.5 million pound reduction to be achieved by enacting the Flush Tax will accomplish one-third of the overall strategy reduction (Summers).

We demonstrate how to maximize the abatement of nitrogen emissions into the Chesapeake Bay from funds generated by the Flush Tax by trading high-cost upgrades of sewage treatment plants (POTWs) for low-cost winter cover crops. We show that exploiting the heterogeneous nature of abatement costs for treatment plants and for agriculture could create substantial cost savings or increases in abatement of nutrients. Under an optimistic assumption about abatement costs for non-point sources, we calculate that abatement could be increased by more than 50%, while in a pessimistic scenario, abatement could be increased by 2%. We also explore the role of uncertainty in determining the appropriate trading ratio between point and non-point sources of pollution to maximize improvements in water quality.

While it is encouraging to identify the gains that would result from exploiting differences in abatement costs, the barriers to effective trading are extensive. We identify institutional and technical barriers that might prevent taking advantage of these opportunities. We also examine the change in phosphorus loadings as a byproduct of nitrogen-based administrated trading decisions.

The Maryland Flush Tax[3]

In May 2004, Maryland Governor Robert Ehrlich signed the "Flush Tax" into law. The Flush Tax, which began January 1, 2005, requires the owner or resident of each dwelling unit to pay an additional $7.50 per quarter on its water bill. An annual fee of $30 is to be levied on homeowners with septic systems. The fund has three purposes:

[3] For a good summary of Maryland's point source strategy to upgrade wastewater treatment plants to state-of-the-art enhanced nutrient removal (ENR), see Maryland Tributary Teams (2006). The description of the Flush Tax in this section is taken from that document.

- to upgrade sewage treatment plants from biological nutrient reduction (BNR) to enhanced nutrient reduction (ENR), which are both methods that reduce nutrients from sewage,
- to expand the use of winter cover crops,
- to improve fund the improvement of homeowner septic systems that are located in areas designated as critical in the Bay tributary strategy.

The Flush Tax will raise approximately $60 million annually from users of POTWs. Another $12 million will be raised annually from the estimated 420,000 private users of septic systems. Of that amount, 60% will go to refitting failing septic systems in critical areas of the state, and the remaining 40% to funding agricultural cover crops. There are concerns, however. The current levels of funding will cover only about 54 POTWs; an additional $161–$411 million will be needed to cover the remainder (Maryland Tributary Teams). In addition, the open commitment to fund the full costs of upgrades creates an adverse incentive for the plants to design their own Cadillac version of enhanced nutrient management, perhaps exacerbating these funding shortages.

The vast majority of the funds will be used to upgrade sewage treatment plants. Specifically, funds will upgrade 66 major sewage treatment plants from biological nutrient reduction to state-of-the art enhanced nutrient reduction. With BNR, treated sewage has 8 mg/l of total nitrogen. With ENR, total nitrogen is lowered to 4 mg/l and phosphorus is reduced to .3 mg per liter. The major sewage treatment plants designated to be upgraded have a minimum daily flow of 500,000 gallons and represent 95% of the wastewater flow from Maryland into the Bay.

Nitrogen and phosphorus caps (pounds per year) have been established for each individual POTW. Each POTW has two different estimates of flow for 2020 (projected flow and design flow), as shown in their County Water and Sewer Plan. Both estimates were approved by the Maryland Department of Environment in April 2003. Design flow is larger than projected flow because it takes into account higher population growth projections.

The implication of these two flows is that, in the short run, a POTW that upgrades to ENR will be operating under its nitrogen and phosphorus caps. But, as population grows in that municipality, *reflecting* the higher design flow, the POTW will increase its emissions of nitrogen and phosphorus until it meets its caps. At that point, it would be allowed to trade with another POTW that is operating under its caps or purchase an offset to its emissions.

The aggregate nitrogen cap for Maryland is the sum of the 66 POTWs in the state, or 9,145,817 pounds per year of nitrogen (Table 1). Sewage treatments plants in Maryland are dominated by the Blue Plains sewage treatment plant (the Maryland portion not associated with Washington, D.C.) and Back River sewage treatment plant (Baltimore City), which serve the two major population centers of the state. Table 1 shows the nitrogen released under BNR and ENR technologies and the costs of abatement for ENR for the two large POTWs and the remaining 64 smaller POTWs. The two large POTWs are responsible for 48% of the nitrogen released into the Chesapeake Bay from controllable Maryland sources, and the cost of converting them from BNR to ENR will absorb 64% of the appropriated Flush Tax funds.

Administered Nutrient Trading among POTWs

We explore administrative trading, which is a more expansive version of nutrient trading than that allowed in the Flush Tax but more restrictive than would emerge under a market for nutrient emission permits. We define administrative trading as an allocation scheme in which a responsible public agency minimizes abatement costs subject to the nutrient cap by allocating abatement to the cheapest sources. Administrative trading is motivated solely by differences in the average abatement costs. To exploit the differences, we group the POTWs by trading areas (Table 2). We consider three levels of trading: tributaries, watersheds, and state. Ten tributaries are contained within four watersheds, and all are contained within the state. Blue Plains and Back River were excluded from the trading scheme because they were too large to trade with the smaller POTWs. They were assumed to have been upgraded from BNR to ENR. Any gains from trading will be seen with the remaining 64 POTWs.

The trading works as follows. Within a given trading region, we minimize the cost of meeting the aggregate cap by not upgrading high-cost POTWs. We upgrade POTW's from BNR to ENR beginning with the least cost, until the aggregate cap is met. With the savings, cover crop acreages are increased. This type of trading is not market-based, but administered by the government. Efficiencies can be achieved across enterprises, but not within enterprises, reflecting cost savings from heterogeneity but not from incentives. The greatest potential gains in cost savings, whether in a cap-and-trade program or in a market economy, come from the ability of a firm to seek new and cheaper ways of meeting goals. Frequently these cost savings involve innovations that were not apparent when there was no opportunity to save money.

The costs of abating nitrogen from sewage treatment plants are based on the annualized capital costs. For each sewage treatment plant, we have the total capital cost of upgrading from BNR to ENR. Under the assumption that the plant operates at projected flow, we calculate the annual reduction in nitrogen as a consequence of the upgrade. The average annual abatement costs for the i^{th} plant are

$$(1) \qquad \mathbf{aac_{pi} = ACC_i / [q_i * (k_{bnr} - k_{enr})]},$$

where $\mathbf{AAC_i}$ is the annualized capital costs,[4] $\mathbf{q_i}$ is projected flow of wastewater, and $\mathbf{k_{enr}}$ and $\mathbf{k_{bnr}}$ are the nitrogen concentrations for BNR and ENR (8 mg/l and 4 mg/l, respectively). Note that this abatement cost equation assumes that the baseline for all firms is BNR, a condition that is currently not true. This treatment omits variable costs, which are believed to be small but not zero. We have written the cost equation for

[4] Annualized under the assumption that the improvement will last 20 years, with an interest rate of 5%.

abatement from sewage treatment plants assuming that there is no randomness in the nitrogen emissions. There is typically randomness because of weather or surges in loads, but these effects are small in comparison with randomness from non-point sources.

Table 3 shows the trading scheme for the Choptank Tributary. The POTWs are ranked by the cost per pound for nitrogen abatement with ENR from low-cost to high-cost plants, based on projected flow. For example, the Cambridge POTW has the lowest average cost per pound of nitrogen, at $7.73, and Easton has the highest, at $32.65. Trading involves upgrading low-cost plants to ENR and leaving high-cost plants at BNR, subject to not exceeding the aggregate nitrogen cap. The aggregate nitrogen cap for this tributary equals 157,151 pounds per year. By upgrading only Cambridge to ENR and leaving Denton and Easton at BNR, the sum of nitrogen emissions is still less than the aggregate nitrogen cap (i.e., 122,045 pounds per year is less than 157,151). By not upgrading the Denton and Easton POTWs, $11,000,000 is saved. We will explore the use of these savings to increase nitrogen reductions beyond the goals of the original Flush Tax. As described above, decision making criteria are based on nitrogen. Phosphorus loadings are calculated as a byproduct of these decisions. We return to the problem of changes in phosphorus abatement later.

Table 4 expands the POTW-administered trading of the Choptank to all ten tributaries, four watersheds, and the state (excluding Blue Plains and Back River). Without any upgrades to the 64 POTWs (leaving all POTWs at BNR), 7,526,774 pounds of nitrogen will be released at projected flow. The first column shows the Flush Tax fully enacted with all POTWs upgraded to ENR. At projected flow, 3,763,387 pounds of nitrogen will be released, for a reduction of 3,763,387 pounds. (The two numbers are identical because BNR assumes 8 mg of nitrogen per liter and ENR assumes 4 mg of nitrogen per liter.) There are no savings because all funds are fully expended on upgrades. The average cost of reduction is $5.63 per pound of nitrogen.

When trading is allowed within a given tributary, but not across tributaries, 4,423,115 pounds of nitrogen will be released at projected flow, for a reduction of 3,103,659 pounds. The reduction in pounds of nitrogen is less than when the Flush Tax is fully enacted, but it is still less than the nitrogen cap. However, there are now savings of $103,142,760 that potentially can be used for nutrient reduction with lower abatement costs. The average cost of reduction decreases from $5.63 per pound of nitrogen to $4.16.

As the trading regions increase in size from tributaries to watersheds to state, the reduction in pounds of nitrogen decreases (but is still less than the aggregate nitrogen cap), the savings in dollars increase, and the average cost per pound for nitrogen abated is decreased from $4.16 to $3.65.

Tables 5 and 6 explore the use of savings for other types of nutrient reduction activities such as winter cover crops. Table 5 specifically examines the effectiveness of cover crops under different assumptions. In particular, the effectiveness of cover crops in reducing nitrogen is examined, along with the subsidy needed to induce a farmer to plant cover crops. Time of planting is critical for the effectiveness of cover crops in reducing nitrogen. In the Mid-Atlantic, for example, cover crops planted before October 1 are more effective than those planted after. However, planting cover crops early requires the previous crop to be harvested without delays due to poor weather, not always an easy task.

Nitrogen Abatement Costs with Cover Crops

The costs for farms of abating nitrogen using cover crops are based on the costs of inducing farms to adopt cover crops and the productivity of the cover crops in abating nitrogen. We estimate the costs by considering the efficiency of cover crops to reduce nitrogen emissions, conditional on the type of cultivation practiced. That is, a nitrogen cover crop will induce more abatement on high-tillage corn than on low-tillage corn, because the high tillage crop begins with higher emissions. The abatement costs are calculated as follows**:**

(2) $$\mathbf{aac_{ni} = AP/(k_{ef} * e_{i0})},$$

where $\mathbf{aac_{ni}}$ is the average abatement cost for the i^{th} non-point enterprise, **AP** is the adoption price per acre paid to farms to plant cover crops, $\mathbf{k_{ef}}$ is the proportional efficiency of cover crops in reducing nitrogen, and $\mathbf{e_{i0}}$ is the baseline level of emissions per acre for the i^{th} enterprise. The baseline level of emissions is idiosyncratic, depending on such factors as the cultivation methods adopted by farmers, previous crops grown, soil type, slope, and weather. In particular, the baseline will be lower for farms that have pursued environmentally sound cultivation techniques. In Maryland the adoption price has been determined by political forces, the state of the budget and the immediacy of the environmental issues.

Heterogeneity of costs stems from variation in the efficiency parameter $\mathbf{k_{ef}}$ and the baseline level of nitrogen loss, $\mathbf{e_{i0}}$. Early planting of cover crops yields efficiencies of 30%. Late planting (after October 1) reduces efficiency to 15%. Cover crops are more cost-effective when they follow a high-tillage crop, the baseline. For example, an acre of high-tillage corn may lose 20 pounds of nitrogen to groundwater. With the application of an early planted cover crop (30% efficiency), the reduction in nitrogen lost is 6 pounds. In comparison, a conservation tillage crop of corn may lose only 15 pounds of nitrogen. Early planted cover crops (30% efficiency) reduce nitrogen losses by only 4.5 pounds per acre.[5]

The current approach to allocating funds for the adoption of cover crops and other green practices fails to achieve the least cost for nitrogen abatement. If farms were to adopt cover crops based on the costs of abating nitrogen, then offering a fixed price for enrollment would generate a least cost approach to allocating funds to this

[5] Cover crop acreages and nitrogen loading data were taken from the Chesapeake Bay Program Watershed Model Output Data, Detailed Loads and Land Use Acreage, Edge Stream Load Land (details) http://www.chesapeakebay.net/pubs/waterqualitycriteria/Loads_Landuse_Detail.xls

practice. When farms have heterogeneous costs of adoption, as they almost certainly do, then we expect that **AP** would cover the adoption costs of the highest cost abater, giving the more efficient abaters surplus from the constant price. In Figure 1, MAC represents the marginal abatement cost from planting cover crops. It is created by ranking the farms from lowest to highest in terms of the costs of abating nitrogen with cover crops. (In practice this curve would be a step function where the horizontal length of the step would be the farm's contribution to nitrogen reduction.) The marginal farm is just induced to plant cover crops at the price **AP,** bringing the quantity of abatement to N**.** Other farms incur costs below **AP**. The net gain to farmers from this method of subsidizing cover crops and abating nitrogen is the area ONM.

In the practice of subsidizing cover crops in Maryland other states, however, farms sign up for cover crops based on the cost of cultivating the cover crops, not the cost of nitrogen abatement. For example, two farms that are identical except that one has a baseline of high-till corn and the other low-till corn would be equally eligible, though the high-till corn farm would have the lower cost in nitrogen reduction. Hence, the actual practice of allocating funds to cover crops does not yield a least-cost approach to abatement.

Our method of calculating costs in equation (2), however, does a reasonable job of locating the most efficient non-point sources first. Because we account for differences in baselines and differences in the location of farms, we have plausible estimates of the cost of abating nitrogen. As with point sources, greater savings can be achieved with efficient mechanisms for allocating funds.

We test the sensitivity of costs to different subsidies. We combine the subsidy level with differences in efficiencies to give some idea of the variability of abatement costs. Variations in the subsidy level account for heterogeneity in the costs of planting cover crops. Variations in efficiencies account for heterogeneity in baseline levels of emissions that depend on such factors as soil type, crops, cultivation technology, weather, and time of planting. Table 5 shows an optimistic and pessimistic scenario.

The first column represents the use of the Flush Tax to upgrade all treatment plants. Since there were no savings, it was not possible to subsidize cover crop production. When trading is allowed at the tributary level, there are savings of $103,142,760. In the optimistic scenario, this saving permits 331,340 acres of cover crops to be planted, resulting in an additional reduction of 1,882,336 pounds of nitrogen. With the pessimistic scenario, there are fewer acres of cover crops planted and consequently a smaller reduction in nitrogen emissions. As the size of the trading region increases, for either the optimistic or pessimistic scenario, more acres of cover crops are planted and more nitrogen reduced due to the greater level of savings created by not upgrading high-cost POTWs.

Table 6 shows trading among point and non-point sources by combining Tables 4 and 5. In the first column, nitrogen is reduced by 3,763,387 pounds per year by the upgrading of all POTWs from BNR to ENR. The second column shows that by limiting upgrading to only low-cost POTWs, a savings of $103,142,760 can be generated. However, if this money is used to plant cover crops, under an optimistic scenario 1,882,336 pounds of nitrogen can be reduced. Combining this with the reduction from the POTWs (3,103,659 pounds), then the cumulative reduction in nitrogen is even greater than that achieved with the Flush Tax (4,985,995 vs. 3,763,387).

In the most optimistic scenario and trading across Maryland, total nitrogen reduction increases by 53% or 2 million pounds annually over the level of abatement achieved in the Flush Tax legislation. In the most pessimistic scenario, total nitrogen reduction increases by 2%, or 79,000 pounds annually. In all cases, trading among point and non-point sources is more effective in reducing total nitrogen than is upgrading all POTWs to ENR.

Further Considerations

Accounting for differences in abatement costs demonstrates the savings available with the kind of administered trading considered here. Given that this is not a true incentive-based mechanism, it is possible that much higher savings would be available. Even so, various technical issues create barriers even to the simple arbitraging demonstrated here.

Hot Spots

In trading at the most aggregated level of Maryland, we implicitly assume uniform mixing of pollutants. Naturally, the broader the trading region the greater will be the gains from trading. However, increasing the size of the trading region enhances the potential for "hot spots," i.e., smaller areas that experience an increase in nitrogen pollution.

Consider the example of trading within the Choptank Tributary (Table 3). If all POTWs were upgraded to ENR, then the annual load of nitrogen would be 92,171 pounds. When only the Cambridge facility is upgraded and the Denton and Easton facilities left at BNR, then the annual nitrogen load increases to 122,045 pounds. But when the savings of $11,000,000 is invested in cover crops (optimistic scenario), it is possible to reduce nitrogen loads by 216,924 pounds per year (not shown), which far exceeds the amount emitted from the three POTWs. This implies that the use of cover crops can reduce nitrogen loading from sources of pollution other than POTWs. Yet the emissions of nitrogen for Denton and Easton from point sources increase from 29,874 pounds when each facility upgrades to ENR to 59,748 pounds when the cover crops are used to help reach the cap for the two plants. This may mean a local hot spot, depending on the location and hydrology of nitrogen from cover crops and the degree to which local emissions of nitrogen create local water quality problems.

When trading within tributaries is modeled (and the savings invested in cover crops), nine of ten tributaries have greater reductions compared to the reductions modeled when all POTWs are upgraded to ENR (Table 7). However, only one-third of the POTWs are upgraded to ENR, while two-thirds are left at BNR. This means that while a given tributary is experiencing an overall reduction in nitrogen pollution, an individual city or municipality, in which the POTW is not upgraded, would not be. As the trading size is increased to watersheds, there still exists the problem of the POTW for an individual city not being upgraded. Nine of the ten tributaries experience reductions. All watersheds have reductions in nitrogen pollution. When the trading size is increased so that only the state level cap needs to be met, the number of POTWs that are upgraded declines further. Three of ten tributaries have increases in nitrogen pollution, and one watershed has an increase in nitrogen pollution. But the greatest level of nitrogen reduction is achieved when the cap is imposed at the state level.

Phosphorus Emissions

When the goal is to maximize nitrogen reduction given the funding from the Flush Tax, phosphorus reductions suffer (Figure 2). One of the advantages of an "engineering fix" such as ENR or BNR is that systems can be designed to abate several nutrients at once, such as nitrogen and phosphorus. It may be expensive but it is feasible. The disadvantage of a "biological fix" is that it may not be feasible to abate more than one nutrient. Cover crops are a good example. They work well to inexpensively reduce nitrogen pollution, but not so well in reducing phosphorus pollution. Figure 2 shows that trading high-cost POTWs for low-cost cover crops (optimistic scenario) may increase phosphorus emissions. For example, when trading occurs across the state, then the nitrogen emissions are reduced to 47% of emission achieved with no trading, while phosphorus emissions are increased to 137%. In essence, all tributaries, watersheds, and the state show an increase in phosphorus pollution compared to the reductions achieved by each POTW being upgraded to ENR so as to meet its nitrogen cap.

Uncertainty

Uncertainty is an important aspect of the debate about point versus non-point sources and eventually brings up the idea of the trading ratio. The trading ratio is the number of units of non-point source abatement that must be provided for a one-unit reduction in point sources. In the simplest of environments, where abatement of point and non-point pollution provides certain reductions in ambient levels of pollution and there is uniform mixing of pollutants from different sources, the trading ratio should be one. The argument is then made that, because of the greater uncertainty in abating non-point sources, trading ratios should be greater than one. For example, a trading ratio of two means that abating two pounds of nitrogen from a non-point source is equal to abating one pound of nitrogen from a point source. King and Kuch suggest that the typical trading ratio lies between one and four. Horan gives trading ratios between one and three. The effect of a trading ratio greater than one is to make non-point sources more expensive and, other things equal, to restrict their use.

This argument appears solid only because it is based on what happens to abatement, not emissions. To recognize the difficulty with this argument, we focus on the primary task of Bay pollution control, that is, reduction in emissions of nutrients. Due to weather, emissions are likely to be random. We characterize randomness by discrete increases or decreases in emissions. By definition, these increases and decreases cancel out over time.[6]

In the situation where a policy attempts to reduce the random variation of emissions as well as mean emissions, control measures should adopt a trading ratio to encourage the abatement of the more random emissions. In the case of the Chesapeake Bay, emissions are more random from non-point sources than point sources. This follows as long as greater abatement of non-point sources reduces the randomness of non-point emissions, an assumption that is reasonable.[7] When resources are devoted to abating non-point emissions, there are two gains: lower mean emissions and less randomness. With point source abatement, we get only reductions in mean emissions. Reductions in point source randomness is unchanged since it is defined as "relatively certain." However, more important, the randomness from non-point sources is left unchanged.

Consider non-point nutrient emissions from 1,000 acres of agricultural land. Each acre emits an average of 8 pounds of nitrogen, with an equal chance of emitting 4 or 12 pounds. The emissions from this farm will range from 4,000 to 12,000 pounds, with a mean of 8,000 pounds. A local POTW has emissions of 15,000 pounds with little randomness. Abatement costs are similar for the POTW and cover crops. Total emissions from these two sources are 23,000 pounds, with a range of 19,000 to 27,000 pounds. When cover crops are used for abatement, the loss per acre is reduced to 5 pounds, but with equal likelihood the loss can be 2.5 or 7.5 pounds. The loadings from this farm will now range from 2,500 to 7,500 pounds, with a mean of 5,000 pounds. Total emissions from the two sources are 20,000, with a range of from 17,500 to 22,500 pounds. The use of cover crops has reduced the mean and range of emissions.

Suppose instead that we choose to abate 3,000 pounds from the POTW. When the point source is adopted, we retain the randomness from non-point sources. Total emissions from the two sources would now be 20,000, with a range of 16,000 to 24,000 pounds. When the non-point source is abated, we reduce both the mean and the randomness. So instead of advocating for a trading ratio of greater than one, as mentioned previously, a trading ratio of less than one is actually the preferred option to improving water quality.[8]

A counterpoint to this argument is that we have assumed that randomness of emissions cancels out over time. However, the damages to the environment from these random emissions may not cancel out. For example, it may be possible that a year of substantial loadings in the Bay will cause immense injury, while a year of an equal,

[6] We view the problem ex ante but compound the possible uncertainties from different sources, such as weather, how well technology works, etc. into one uncertainty. Malik, Letson and Crutchfield consider several sources of uncertainty.

[7] See Shortle 1987 for a mathematical proof of this assertion.

[8] This argument is predicated on the assumption that the randomness of the non-point system is viewed in aggregate. In other words, the randomness of the emissions from the previous crop (e.g., corn) is not separated from the randomness of the abatement associated with the cover crop (i.e., winter rye). When viewed over many years, the aggregate view is more appropriate.

offsetting decrease in emissions will provide only modest improvements. If this is the situation, then a trading ratio of more than one may be appropriate, but not for the reasons most often given. The counter argument to this observation is that the importance of uncertainty depends on the scale of the trades, which depends on the application. To begin with, nutrient flow to the Bay is made up of human-induced emissions and natural contributions. The current Chesapeake Bay agreement calls for reducing nitrogen from 285 million pounds to 175 million pounds. In this context, the difference in emissions caused by uncertain non-point source emissions is quite small. From Table 6, we see that the maximum abatement from non-point sources is about 3 million pounds. Under current circumstances this amounts to less than one percent of total current nitrogen emissions. This change in emissions represents an amount so small that curvature of abatement costs and—more important in this case—damages can hardly have a role in determining the exchange of non-point and point emission reductions. At least from the perspective of uncertainty in nutrient emissions in the Chesapeake Bay, there is no reason not to trade point and non-point source abatement one for one.

From Abatement to Ambient Water Quality: Agronomy and Hydrology

One of the biggest differences between point and non-point emissions is the lag between changes in abatement and changes in the level of emissions into the Bay (see Phillips and Lindsey). Increases and decreases in point source emissions are immediately transformed to corresponding changes in nitrogen in the Bay and its tributaries. Depending on the means of transport of non-point emissions, non-point source abatement can take from days to decades to impact the Bay. When nitrogen is part of surface water runoff, the lag time can be quite short. Nitrogen that is transported in groundwater may take up to 50 years to reach the Bay, with a median lag of about 11 years.[9] Given that about half of the nitrogen reaches the Bay through groundwater contribution to streams, this lag needs to be considered in understanding choices between point and non-point source abatement.

Conclusion

In this paper we present evidence that under an administered trading system, where the responsible public agency selects lower cost abatement, there are in principal savings that could enhance Bay water quality. There are naturally barriers to these trades. These barriers are evident in the paucity of trading for nutrient abatement across the country. Reducing the barriers to administered trading, such as we have analyzed, can provide some gains. But the real gains, those that come from true incentive-based mechanisms, require substantial improvements in our scientific understanding of the connection between non-point source abatement and the reduction of nutrients to the Bay. Despite the difficulty in obtaining complete understanding, it makes sense to continue to explore and develop opportunities to exploit differences in abatement costs either through administered trading or through the use of true incentive-based mechanisms.

[9] These figures are taken from the summary document by Phillips and Lindsey.

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Table 1. Annual emissions of nitrogen as estimated in 2000, nitrogen cap projected for 2020 (based on enhanced nutrient reduction with design flow), and the capital costs of upgrading from BNR to ENR for sewage treatment plants in Maryland

	Annual Emissions of Nitrogen (lbs/year)		
	2000 Total Nitrogen Load	ENR N Cap	Capital Costs for ENR
Blue Plains	3,367,631	2,066,108	$377,200,000
Back River	4,529,473	2,192,803	$100,000,000
64 smaller POTWs	8,681,877	4,886,906	$263,742,760
TOTAL	**16,578,981**	**9,145,817**	**$740,942,760**

Source: Maryland Tributary Teams and Levelev

Table 2. Sewage Treatment Plants (POTWs) as Allocated among the Three Levels of Trading Regions: State, Watersheds, and Tributaries

Maryland State: 64 POTWs (excluding Blue Plains and Back River)	
Watershed	Tributary
Eastern Shore Watershed (19 POTWs)	Choptank Tributary (3 POTWs)
	Lower Eastern Shore Tributary (9 POTWs)
	Upper Eastern Shore Tributary (7 POTWs)
Potomac River Watershed (23 POTWs)	Lower Potomac River Tributary (5 POTWs)
	Middle Potomac River Tributary (4 POTWs)
	Upper Potomac River Tributary (14 POTWs)
Western Shore Watershed (15 POTWs)	Lower Western Shore Tributary (6 POTWs)
	Upper Western Shore Tributary (5 POTWs)
	Patapsco/Back River Tributary (4 POTWs)
Patuxent River Watershed (7 POTWs)	Patuxent River Tributary (7 POTWs)

Table 3. Administered Trading in the Choptank Tributary among the Cambridge, Denton, and Easton POTWs

Facility	Capital Costs	Cost of Reduction: Projected Flow ($/lb)	Nitrogen Cap, ENR with Design Flow (lb/yr)	Nitrogen Load, BNR with Projected Flow (lb/yr)	Nitrogen Load, ENR with Projected Flow (lb/yr)
Cambridge	$6,000,000	$7.73	98,676	124,594	62,297
Denton	$1,000,000	$15.22	9,746	10,553	5,276
Easton	$10,000,000	$32.65	48,729	49,195	24,598
TOTAL	**$17,000,000**				
With trading					
Cambridge	$6,000,000				62,297
Denton	(don't upgrade)			10,553	
Easton	(don't upgrade)			49,195	

Notes: 62,297 + 10,553 + 49,195 = 122,045 lbs/yr, still less than the nitrogen cap (157,151 lbs/year). Total savings = $1,000,000 + $10,000,000 = $11,000,000.

Table 4. Comparisons of Reduction in Nitrogen Released and Savings in Dollars when the Flush Tax is Fully Enacted with Three Different Sizes of Trading Regions

	Flush Tax (no trading)	Trading: 10 Tributaries	Trading: 4 Watersheds	Trading: Maryland
	Nitrogen (lbs/yr)			
Projected flow, BNR	7,526,774	7,526,774	7,526,774	7,526,774
Projected ENR/BNR	3,763,387	4,423,115	4,638,554	4,718,875
Reduction	**3,763,387**	**3,103,659**	**2,888,220**	**2,807,899**
Nitrogen cap (ENR, design flow)		4,886,906		
	Expenditures (life of project)			
Planned ENR	$263,742,760	$263,742,760	$263,742,760	$263,742,760
Actual ENR	$263,742,760	$160,600,000	$137,600,000	$127,600,000
Savings	**$0**	**$103,142,760**	**$126,142,760**	**$136,142,760**
Cost ($/lb)	$5.63	$4.16	$3.83	$3.65

Table 5. Trading among Non-Point Sources (Cover Crops) with Different Assumptions

	Flush Tax (no trading)	Trading: 10 Tributaries	Trading: 4 Watersheds	Trading: Maryland
$: Savings	$0	$103,142,760	$126,142,760	$136,142,760
Optimistic: ($20 + $4 (admin) per Acre, 30% Technical Efficiency				
$: Cost/lb	na	$4.40	$3.85	$3.70
N reduction (lbs/yr)	na	1,882,336	2,630,641	2,951,805
Cover crop (acres)	na	331,340	414,049	455,511
Pessimistic: $30 + $6 (admin) per Acre, 15% Technical Efficiency				
$: Cost/lb	na	$12.19	$10.83	$10.57
N reduction (lbs/yr)	na	679,346	935,302	1,034,256
Cover crop (acres)	na	228,772	281,368	303,674

Table 6. Trading among Point Sources and Non-Point Sources

	Flush Tax (no trading)	Trading: 10 Tributaries	Trading: 4 Watersheds	Trading: Maryland
Actual ENR	$263,742,760	$160,600,000	$137,600,000	$127,600,000
Cover crops	$0	$103,142,760	$126,142,760	$136,142,760
Nitrogen Reduction (lbs/yr) from ENR and Optimistic Cover Crops ($24/acre, 30% technical efficiency)				
ENR reduction	3,763,387	3,103,659	2,888,220	2,807,899
Cover crop reduction	0	1,882,336	2,630,641	2,951,805
Total reduction	3,763,387	4,985,995	5,518,861	5,759,704
Total cost ($/lb)	$5.63	$4.25	$3.84	$3.68
Nitrogen Reduction (lbs/yr) from ENR and Pessimistic Cover Crops ($36/acre, 15% technical efficiency)				
ENR reduction	3,763,387	3,103,659	2,888,220	2,807,899
Cover crop reduction	0	679,346	935,302	1,034,256
Total reduction	3,763,387	3,783,005	3,823,522	3,842,155
Total cost ($/lb)	$5.63	$5.60	$5.54	$5.51

Table 7. The Potential for "Hot Spots" for Nitrogen Reduction

Trading within Tributaries	22 of 64 POTWs are upgrade to ENR
	9 of 10 tributaries have greater reductions
Trading within Watersheds	16 of 64 POTWs are upgraded to ENR
	9 of 10 tributaries have greater reductions, one is increased
	All watersheds have greater reductions
Trading within State	14 of 64 POTWs are upgrated to ENR
	7 of 10 tributaries have greater reductions, 3 are increased
	3 of 4 watersheds have greater reductions in nitrogen, one is increased
	The State has a greater reduction in nitrogen, and the largest reduction of nitrogen is achieved in this scenario

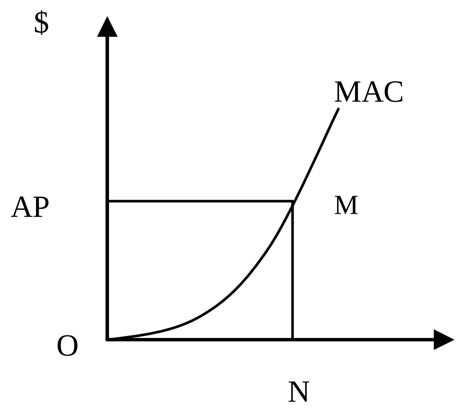

Figure 1. Nitrogen Abatement

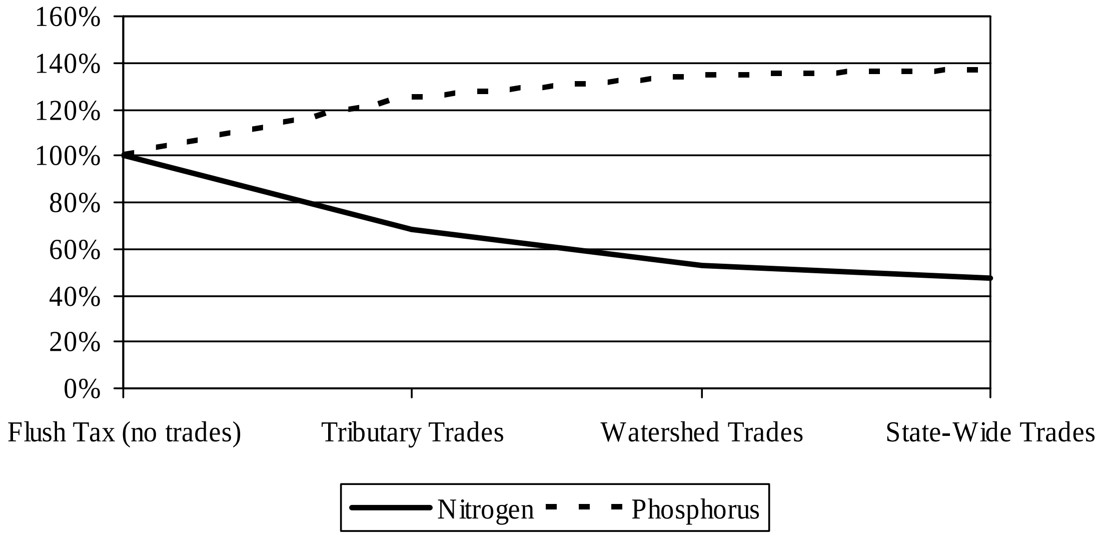

Figure 2. Nitrogen and Phosphorus Emissions across Several Different Trading Scenarios (point and non-point) Expressed as a Percent of the Flush Tax (no trading)