Encouraging the use of wetlands in water quality trading programs: Economic and ecological considerations

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Abstract

Water quality trading has grown in popularity and scope in recent years owing to its potential as a flexible low-cost way to achieve nutrient reduction goals. Wetlands can remove nutrients from nonpoint sources of pollution and also provide the ancillary benefits of carbon sequestration and habitat and biodiversity provision. Regulators are interested in determining the best way to encourage traders, primarily agricultural sources, to use restored and protected wetlands in water quality trading programs. In this paper we examine the options of 1) including the ancillary benefits of a wetland in the market for nutrient removal through subsidies and unique trading ratios, or 2) allowing a producer to trade the various wetland services in multiple markets. The preferred option depends on the shape of the ancillary benefits curve.

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1. Introduction

Though great successes are credited to the air quality trading programs, water quality trading has proved problematic. Authors like *King and Kuch* [2003] find that there are both supply-side and demand-side obstacles to water quality trading. For example, water quality trading programs that control nutrients compete with "green payments" for reducing nonpoint sources of nutrient pollution. Green payments, such as the Conservation Reserve Program, Wetlands Reserve Program, etc., provide assistance to landowners to address environmental issues like soil erosion and damaged or lost wetlands and habitat. Thus, these activities reduce the potential supply of water quality trading credits. Point sources, or potential credit demanders, find the idea of trading with nonpoint sources inequitable given the existing subsidy or green payment programs. Perhaps the largest obstacle facing water quality trading is the fact that the markets are too small to take advantage of those things markets do well. To this end it has been suggested that increasing the size of the market for nutrient trading through the inclusion of wetlands, as a nutrient reduction technology, will increase the size of the market enough to bring about a successful program [e.g., *Raffini and Robertson*, 2005; *Heberling et al*., 2007]. There are other benefits, primarily ecological, to using wetlands that make them attractive. Wetlands sequester CO_2, and provide wildlife habitat. In this paper we consider the impact these ancillary benefits have on promoting the use of wetlands in water quality trading programs.

This paper proceeds as follows, first we discuss the nutrient removal capacity of wetlands and the ancillary ecological and economic benefits they provide. Then we look at some of the theory underlying the effect of ancillary benefits on markets. This paper focuses on three propositions: first and foremost, is it even reasonable to consider the use of wetlands to reduce nutrient runoff from agricultural properties. We show that it probably is, and give a brief overview of a "first best" solution to the regulator's problem. We then ask, can the ancillary benefits of wetlands be included, using a subsidy and trading ratios for permits traded between point and non-point sources, in a single WQT market? And third we consider the idea that instead of one market, should the regulator allow "double dipping?" That is, should the non-point source be allowed to get credit for a wetland in a WQT market and sell the various ancillary services of a given wetland in other markets?

2. Wetlands and Water Quality Trading Markets

The basic requirements for a well functioning transferable permit market have been outlined numerous times [see *Heal*, 2000; *Godard*, 2001; *Biller*, 2003]. These requirements include such things as clear, transferable property rights, bankable permits, securitization, adequate information about damages, legal cap or limit, defensible initial allocation of permits or rights, heterogeneity in ability or cost of control and damage, and a large number of participants.

Austin et al. [1997] and *Feng and Kling* [2005] look at ancillary benefits in pollution trading markets. Both papers focus on the ancillary benefits of reducing the particular pollutant when they model their problems, which is slightly different from the issue we address here. When using wetlands in water quality trading programs, it is not the reduction in the pollutant that "co-causes" the ancillary benefit; rather, it is the abatement activity or specific technology itself that creates the ancillary benefits.

Recently a significant amount of literature has questioned the effectiveness of water quality trading markets, and there is a general feeling that limited participation or "thin markets" is the main problem [*King and Kuch*, 2003]. There are few opportunities for traders to realize the full potential of the market if robust and efficient trades are seldom seen. Allowing the use of wetlands in water quality trading programs serves many purposes including increasing the size of the market and increasing the acres of wetlands.

Assuming we can find watersheds where the supply-side and demand-side obstacles are minimized, why do we need to specifically discuss wetlands and trading markets? If wetlands were, in most respects, similar to other nutrient abatement technology, no further discussion would be needed. Producers would choose from a suite of available abatement technologies based on minimizing their costs and would choose wetlands if they represented the least cost method of creating nutrient credits. But wetlands are not like other abatment technology, they provide a variety of services beyond nutrient abatement; wetlands may control nutrients, and they may also produce habitat for birds, control flooding, and reduce sediments. These other services may accrue to the agent who constructs or maintains a wetland for nutrient reduction or these services may accrue to other agents, or to populations outside the market for nutrient reduction. To encourage a socially optimal provision of the services wetlands offer, the social costs and benefits should enter into the decisions surrounding their construction or maintenance.

Byström [1998] examines the abatement costs of using wetlands to control nutrients. He suggests that the social benefits could substantially lower the abatement costs of using wetlands, but he does not explicitly estimate these costs. *Ribaudo et al*. [2001] looks at reducing nitrogen in the Mississippi Basin through fertilizer reduction or wetland restoration. *Ribaudo et al*. [2001] include the private costs and social benefits, such as erosion benefits and wetland benefits. They find that the social marginal costs of control using wetlands become lower after about 1250 tonnes of nitrogen reduction which occurs when the marginal cost of control of fertilizer reduction catches up to the opportunity costs of land.

Regardless of the wetland functions, economic theory suggests that the producer will not consider the ancillary benefits (positive externality of producing wetlands) because the benefits do not enter the profit-maximizing decision. If the externality were internalized, then, and only then, would the producer face the social (net) costs. What regulators need to determine is whether the ancillary benefits actually should play a role in the decision of the credit producer.

3. Proposition 1: Command-and-Control

Regulators could require all producers of pollution credits to build wetlands to abate nutrients. This, in effect, takes the decision out of the hands of the producers. There would likely be situations where wetlands are not the least cost option and requiring the use of wetlands would not be cost-effective (e.g., limited land space and increasing opportunity costs). Forcing a particular abatement technology goes back to the problem with command-and-control policies which are rarely cost-effective. If regulators decide these ancillary benefits should be considered, and U.S. EPA [2003] suggests they should, are there other approaches that make economic sense?

If emissions, damages, and control costs from different sources were known with certainty, we could graph the optimal allocation of pollution (see Figure 1). The social marginal control costs (SMCC) are the sum of the marginal private control costs (MCC) and the marginal external benefits. The intersection of the marginal damage cost (MDC) and SMCC suggests that internalizing the external benefits increases the optimal level of control (moving from Q to Q*) and reduces the costs of meeting that amount (C to C*). Incorporating more wetlands that produce ancillary benefits would, therefore, increase the optimal amount of control at lower costs.

Wetlands would not likely be used for all abatement if there are other, less expensive, options for reducing nutrients (see Figure 2). Points A and B represent kinks in the curve where a new abatement technology becomes less expensive. For example, point B represents the change from reducing fertilizer (MCC_F) to restoring a wetland (MCC_W) when the ancillary benefits are not internalized. Point A is the switch from fertilizer to wetlands when the benefits are internalized. Suppose the ancillary benefits are not internalized (as shown by MCC_W) and the MDC crosses MCC_W to the left of point B. For this situation, no wetlands would be used to abate nutrients; all units of nutrient reduction would be from reducing the application of fertilizer because it is less expensive. Now, if the benefits were internalized leading to $SMCC_W$, and the MDC crossed it above point A, then some amount of wetlands would be restored or constructed because wetlands become less expensive than reducing fertilizer above point A. The internalization of the externality would make the wetland technology less expensive at more points of pollution reduction and possibly making wetlands more attractive for sources to use. Notice that the internalization still does not necessarily make wetlands the preferred abatement technology; reducing fertilizer will still be preferred below point A. Graphically speaking, internalizing the ancillary benefits could create incentives for using more wetlands to control nutrients.

4. Model

For this paper, we assume that the water quality trading market is the primary market and follow the model presented in *Horan and Shortle* [2005], who focus on a trading program based on expected loadings for the nonpoint source (rather than on inputs). The model assumes a single point source (e.g., a municipal separate storm sewer system (MS4)) and a single nonpoint source (e.g., a farm) in a watershed.

Emissions for the point source, e, are controlled with certainty and known costs c(e). The nonpoint source emissions are considered random, $r(\mathbf{x}, \theta)$, with jth element of $\mathbf{x}$ (a mx1 vector) representing the set of production decisions related to the technology for production and pollution control. The random variable, θ, represents stochastic events that affect runoff, like weather. We assume the nonpoint source profit depends on the choice of $\mathbf{x}$ and the difference between the profits with no regulations ($\mathbf{x_0}$) and profits under regulations ($\mathbf{x}$) is the nonpoint source pollution control costs, $c_r(\mathbf{x}) = \pi(\mathbf{x_0})-\pi(\mathbf{x})$. Pollution from each source causes damage costs, D(e, r) and social costs are then $TC=c(e) + c_r(\mathbf{x}) + E[D(e, r)]$.

We assume that some pollution abatement technology provides benefits to third parties outside of the market; an additional component representing ancillary benefits is needed. This assumption differs from *Austin et al*. [1997] and *Feng and Kling* [2005], who model the benefits as a function of the reduction of the pollutant, not the technology. Therefore, total ancillary benefits are $B(x_j)$; however, $B(x_j)>0$ only when j=w where w represents a specific pollution control technology that affects individuals outside of the market. We assume $B(x_j)$ is known with certainty for this paper, but we understand that this is an oversimplification. When j=w, the benefit function is twice continuously differentiable, increasing in x_j ($B'(x_j)>0$) and exhibits decreasing marginal returns ($B''(x_j)<0$). Therefore, the total social cost (TSC) that should be minimized is

$$TSC=c_e(e) + c_r(\mathbf{x}) + E[D(e, r)]- B(x_j).$$

4.1 Market Equilibrium

Following existing trading markets, we use two sets of permits: point source, $\hat{e}$, and nonpoint source, $\hat{r}$. The MS4 must have a mix of these permits at least equal to their emissions. A trading ratio, t, equates emissions to expected loadings:

$$t = \left| \frac{d\hat{r}}{d\hat{e}} \right| \tag{1}$$

For market equilibrium, we expect the appropriate level of inputs of capital and labor to be chosen such that the marginal contribution to revenue is equal to the marginal cost of using the input. In this case, inputs and permits should be chosen to minimize costs. Therefore, the point source will choose permits such that the marginal control costs are equal to the price of the permits. The point source will choose nonpoint source permits similarly, knowing that the two types of permits are similar at the margin, suggesting that the trading ratio is $t=q/p$. First order conditions of minimizing costs for the MS4 remain unchanged from *Horan and Shortle* [2005]. We provide the first order conditions for the MS4 in Appendix A.

The nonpoint source's first order conditions to minimize costs are similar to the MS4. The farmer will choose abatement technology to minimize costs such that the marginal control costs are equal to the marginal expected revenue generated. First order conditions for the nonpoint source are the same as *Horan and Shortle* [2005]. We assume that changes to the farmer's profit will lead to changes in the farmer's behavior. Since the ancillary benefits do not accrue to the farmer, his optimization does not include them explicitly. However, to encourage the production of wetlands, some subsidy approximating $B(x_j)$ from the TSC equation above, is included in $c_r(\mathbf{x})$.

The control cost function for the nonpoint source is $P=c_r(\mathbf{x}) + q(\hat{e}_{nps} - \hat{e}^0_{nps}) + p(\hat{r}_{nps} - \hat{r}^0_{nps})$, where superscript 0 represents the initial holdings of permits. We assume that the nonpoint source does not hold any point source permits initially and it faces a loadings constraint, $r \leq \hat{r}_{nps} + t\hat{e}_{nps}$, where t is the trading ratio. Assuming the constraint is met as an equality, we can rewrite costs as $P=c_r(\mathbf{x}) + p\{E[r(\mathbf{x}, \theta)] - \hat{r}^0_{nps}\}$. The first order condition for optimal input use is

$$\frac{\partial P}{\partial x_j} = \frac{\partial c_r(\mathbf{x})}{\partial x_j} + pE\left(\frac{\partial r}{\partial x_j}\right) = 0, \forall j \qquad (2)$$

Finally, we know that for the market to clear, we need to have more permits than emissions and expected loadings:

$$\hat{e}^0 + \left(1/t\right)\hat{r}^0 \geq e + \left(1/t\right)E[r(x_j, \theta)] \qquad (3)$$

By basing the number of permits allocated and trading ratios on the results above, we can create the optimal water quality trading program. For policy purposes, however, we follow the more policy-relevant model of *Horan and Shortle* [2005] who propose a "conditionally optimal" trading program that better reflects existing conditions. The fundamental distinction is that the conditionally optimal model assumes, correctly, that an environmental authority chooses the number of emission permits based on such regulatory programs as the National Pollutant Discharge Elimination System (NPDES) and Total Maximum Daily Load (TMDL) policies.

We follow the approach of *Horan and Shortle* [2005] for determining the prices and conditionally optimal trading ratio, but we further the literature by including a term that represents ancillary benefits when wetlands are chosen as the abatement technology. We substitute the derived demands **x**(p) and e(q) into the total social cost function subject to the market clearing constraint. The Lagrangian is

$$L = c[e(q)] + c_r[\mathbf{x}(p)] + E(D\{e(q), r[\mathbf{x}(p), \theta]\}) - B[\mathrm{x}_j(p)] + \lambda\left\{[\hat{e}^0 - e(q)] + \left(\frac{p}{q}\right)(\hat{r}^0 - E\{r[\mathbf{x}(p), \theta]\})\right\} \quad (4)$$

where lambda equals the shadow value of increased permit numbers.

The important necessary conditions when ancillary benefits are produced are the market clearing constraint and

$$\frac{\partial L}{\partial p} = \frac{\partial c_r(\mathbf{x})}{\partial x_j}\frac{dx_j}{dp} + E\left(\frac{\partial D}{\partial r}\frac{dr}{dx_j}\right)\frac{dx_j}{dp} + \lambda\frac{1}{q}[\hat{r}^0 - E(r)] - \lambda\frac{p}{q}E\left(\frac{dr}{dx_j}\right)\frac{dx_j}{dp} - B'(x_j)\frac{dx_j}{dp} = 0 \quad (5)$$

From equation (5), we can estimate the conditionally optimal price for the expected loadings permit and the conditionally optimal trading ratio. Suppose the only change a nonpoint source makes on the land is adding wetlands for controlling nutrients and it creates additional habitat for wildlife. Substituting the necessary condition for the nonpoint source from the market equilibrium (equation 2) and the estimate of the trading ratio into equation (5), we can solve for p:

$$
\begin{aligned}
p &= \frac{E\left(\frac{\partial D}{\partial r}\frac{dr}{dx_j}\right)}{E\left(\frac{\partial r}{\partial x_j}\right)} + \frac{\lambda \frac{1}{q}[\hat{r}^0 - E(r)]}{E\left(\frac{\partial r}{\partial x_j}\right)}\frac{dp}{dx_j} - \lambda \frac{p}{q} - \frac{B'(x_j)}{E\left(\frac{\partial r}{\partial x_j}\right)} \\
&= E\left(\frac{\partial D}{\partial r}\right) + \frac{\text{cov}\left(\frac{\partial D}{\partial r}, \frac{\partial r}{\partial x_j}\right) - B'(x_j)}{E\left(\frac{\partial r}{\partial x_j}\right)} - \lambda \frac{p}{q} + \lambda \frac{p}{q}\left\{\frac{[\hat{r}^0 - E(r)]}{E(r)}\right\}\varepsilon_{pr}, \forall j = w
\end{aligned}
\qquad (6)
$$

where $\varepsilon_{pr}<0$ is the nonpoint source's inverse elasticity of demand for expected pollution loads. With ancillary benefits, the change in price depends on the sign of the covariance. A negative sign suggests that expected loadings permit price should be higher when ancillary benefits are created. With a positive sign, the change in price depends on whether $\text{cov}(\partial D/\partial r, \partial r/\partial x_j)$ is greater, less than, or equal to $B'(x_j)$. This differs from the result in Figure 1 because the nonpoint source emissions are random.

If the damage function is convex in r, then the covariance term has the same sign as $\text{cov}[r, E(\partial r/\partial x_j)]$. The sign of this equals the change in the variance of nonpoint source pollution given a change in the level of abatement. If the level of abatement decreases the variance of nonpoint source pollution, then the covariance is negative. The sign of the covariance term is the subject of considerable discussion [*Malik et al*., 1993; *Shortle*, 1987; *Horan and Shortle*, 2005].

While one would intuit increasing the level of a specific abatement technology to always reduce the variance of the targeted pollution this is not necessarily the case in such complex systems as wetlands. *Bÿstrom et al*. [2000] and *Mitsch and Gosselink* [2000] indicate that wetlands are able to reduce the variance of the nonpoint source pollution. If true, the covariance term is negative and price should be higher when ancillary benefits are generated. But evidence from constructed wetlands in Ohio gathered by *Spieles and Mitsch* [2000] points to a possible increase in variance in a high nutrient riverine system which means the covariance term is positive. And *Moustafa et al*. [1996] find in a wetland in south Florida covariance for abatement of phosphorous decreased but that for nitrogen did not, further highlighting the complexity of these systems.

The trading ratio is the ratio of permit prices (based on market equilibrium), we can use the results above for p and q and develop a trading ratio when ancillary benefits are generated:

$$t = \frac{E\left(\frac{\partial D}{\partial e}\right) - \lambda\left[\frac{(e-\hat{e}^0)}{e}\right]\varepsilon_{qe} - \lambda\left\{\frac{[\hat{r}^0 - E(r)]}{E(r)}\right\}\varepsilon_{pr}}{E\left(\frac{\partial D}{\partial r}\right) + \left[\frac{\operatorname{cov}\left(\frac{\partial D}{\partial r}, \frac{\partial r}{\partial x_j}\right) - B'(x_j)}{E\left(\frac{\partial r}{\partial x_j}\right)}\right]} \tag{7}$$

If nonpoint loadings are known, no ancillary benefits are produced, and the number of permits is set optimally, the trading ratio reduces to the ratio of damage impacts from emissions and loadings [*Horan and Shortle*, 2005]. Incorporating stochastic nonpoint loadings adds the second term in the denominator, what *Malik et al*. [1993] call the “marginal damage premium.” It becomes apparent for this trading ratio that the sign of the marginal damage premium depends on the covariance term. When ancillary benefits occur, the marginal damage premium includes the marginal external benefit. The sign for the marginal benefit is assumed positive. We assume that the loading function is decreasing in x_j, meaning the denominator is negative. If the covariance is negative, the term in the large bracket is positive and the trading ratio should be smaller when ancillary benefits occur. With a positive sign for the covariance term, the size of the trading ratio depends on whether cov(∂D/∂r, ∂r/∂x_j) is greater than, less than, or equal to B′(x_j).

When we assume multiple changes by the nonpoint source, the trading ratio becomes

$$t = \frac{E\left(\frac{\partial D}{\partial e}\right) - \lambda\left[\frac{(e-\hat{e}^0)}{e}\right]\varepsilon_{qe} - \lambda\left\{\frac{[\hat{r}^0 - E(r)]}{E(r)}\right\}\varepsilon_{pr}}{E\left(\frac{\partial D}{\partial r}\right) + \left[\sum_{j=1}^{m}\frac{\operatorname{cov}\left(\frac{\partial D}{\partial r}, \frac{\partial r}{\partial x_j}\right) - B'(x_j)}{E\left(\frac{\partial r}{\partial x_j}\right)}\right]} \qquad (8)$$

We propose two ways to internalize this positive externality: one is to provide some kind of subsidy and unique trading ratio within the program that specifically rewards the use of wetlands over other technologies and further that rewards "better" wetlands incrementally. The other way is to allow wetlands to be traded in multiple markets. That is, the nonpoint source would get credit for the creation of a wetland in the water quality trading program, and could solicit credit for the same wetland in a carbon sequestration market and if applicable a biodiversity market.

5. Proposition 2: Subsidy and Unique Trading Ratio

To incorporate the above findings into a WQT program we first look at the use of the subsidy with the trading ratio. Given that the marginal external benefits from abatement technology only enters the price of the loadings permits and the trading ratio, there are likely incentives within those components that might increase the market size and encourage the construction or restoration of wetlands.

The appropriate subsidy will encourage the farmer to construct or restore a wetland that creates the largest ancillary benefits possible (given land and cost constraints). The ancillary benefits will affect the price of the loadings permit, and the difference between the conditionally optimal price and equation (6):

$$\frac{-B'(x_j)}{E(\partial r / \partial x_j)} \tag{9}$$

is the measure to be estimated by the regulating agency to be able to determine the appropriate total subsidy to the farmer. The subsidy does not equal the marginal benefits; it differs because we cannot measure loadings with certainty. Because loadings are estimated, the marginal benefits are adjusted depending on how the runoff function is affected by the abatement technology. Equation (9) underscores the complexity of both the proposed policy that relies on a single market, and the complexity of wetlands themselves: the two crucial measurements are the marginal benefits of the ecosystem services offered by constructed wetlands and the variance of their effectiveness as a nutrient control technology.

From equation (7) we know that ancillary benefits lead to either a higher or lower trading ratio depending on how wetlands affect the variance of the loadings. According to *Malik et al*. [1993], sources will take into account the abatement costs when conducting trades, but not costs from the variability of nonpoint source pollution. This would be similar when the ancillary benefits are included in the trading ratio. *Malik et al*. [1993] propose that adjusting the trading ratio will help to internalize the costs. Therefore, we are proposing a unique or variable trading ratio that depends on the abatement technology used and the ancillary benefits produced; this unique trading ratio is the incentive for the buyer to enter the nutrient market.

6. Proposition 3: Multiple Markets

The other way to include the ancillary benefits of wetlands is to allow producers to sell different types of credits in different markets (Kieser and Associates, unpublished report, 2004). ‘Multiple markets’ refers to the producer’s ability to sell different types of credits in different markets [*Woodward and Han*, 2004; *ELI*, 2005]. If well-functioning markets (as described above) were to exist for the different services provided by wetlands, the ancillary benefits would be accounted for and the externalities would be internalized. Building wetlands might create credits for nutrient abatement, endangered species habitat, flood mitigation, and greenhouse gases. The services are no longer externalities of the water quality trading market as they are sold as credits in other markets. The incentive for constructing or restoring wetlands, then, becomes the additional income from trading in other markets. The socially optimal level of wetlands would occur once markets exist for all relevant wetland services. If this were the case, the prices for the water quality permits and the trading ratio would be the same as *Horan and Shortle* [2005]. The marginal benefit term would drop out of equations (6) and (7), leading to the conditional optimum.

If the producer can sell different credits in different markets, then they may have incentive to build wetlands. Producers will react to the multiple markets and make their decisions based on their profits. Holding the number of acres constant, the producer, of course, would choose the mix of abatement technologies that produce the most money. Unlike trading ratios and subsidies, the incentives created by multiple markets are the prices received for the credits (not the value of the ancillary benefits), which are weighed against production and monitoring costs. However, using multiple markets provides no new incentives for buyers to enter the nutrient trading market. While the unique trading ratio might encourage their participation, multiple markets assumes that the demand for credits will exist.

7. One market or multiple markets?

To decide on what option makes the most sense, we return to the figures showing the optimal allocation of pollution. Figure 3 shows marginal control costs for both fertilizer reduction and wetlands with the kink at point B (MCC_F and MCC_W). If MDC crosses above point B, then some acres of wetlands (a*) will be used in the abatement of nutrients. Suppose that there is a market for aquatic habitat for an endangered species (Figure 4) and that habitat is a function of acres of wetlands (ψa^*). By ignoring the habitat produced in the water quality trading market, we can create the marginal cost of producing habitat (MC_W) or incorporating the habitat produced, we have MC_W^*. *Montero* [2001] and *Woodward and Han* [2004] suggest that the decision to combine all services into the nutrient market using trading ratios and subsidies or to create multiple markets depends on the relative shape of the marginal benefits and marginal cost curves and the underlying ecological attributes. In Figure 4, the relative shape of the marginal benefits curve for habitat [B′(H)] and the marginal cost curves of producing habitat matter [*Woodward and Han*, 2004]. Based on *Weitzman* [1974], a flatter marginal benefit curve relative to the marginal cost curve suggests that multiple markets (MM) cause a larger dead weight loss than a single market (i.e., trading ratio and subsidy, TR/S).

This result assumes that multiple markets exist for different services produced. Initially, we may be limited to using subsidies and unique trading ratios to encourage the use of wetlands in water quality trading markets. If this is the case, a source of funds would be necessary for the subsidies. In the long run, after additional markets have been created, we must decide between multiple markets vs. single markets. Following *Montero* [2001] and *Woodward and Han* [2004], it becomes apparent that it is critical to have an accurate portrayal of the benefits curve, an exercise that should not be considered elementary.

8. Conclusions

In this paper we do not argue that wetlands can or should be included as nutrient abating technology in a point-nonpoint source water quality trading program. Rather we answer whether abatement producers can be encouraged to use wetlands as a means to reduce nutrients in a water quality trading program. The program that does incorporate wetlands needs to take into account the ancillary benefits created by wetlands. We propose two ways to account for the ancillary benefits: 1) the ancillary benefits are included in the market price for expected loadings permit and the point/nonpoint source trading ratio is adjusted to account for the ancillary benefits, or 2) the producer of wetlands can sell the nutrient trading capacity of the wetland in the nutrient market and the ancillary benefits are sold in other markets, should they exist. We have shown a novel approach toward the adjustment of the point/nonpoint source trading ratio in that the choice depends on whether the wetland serves to reduce or increase the variance of the loadings from the nonpoint source of nutrients and the size of the marginal benefits.

The policy choice of using one market with appropriate ratios versus allowing trading in multiple markets depends on the shape of the curve representing the marginal ancillary benefits. If the curve is relatively steep the policy maker should allow the nonpoint source to trade the wetland ancillary benefits in a separate market. If the marginal benefits curve is relatively flat, the policy maker should allow the nonpoint sources extra credit, through the corrected trading ratio, in the single market. The shape of the benefits curve will differ according to type and location of the wetland. Future research requires a multidisciplinary approach to this problem wherein the benefits curves for several wetlands are measured empirically.

Appendix A

The MS4 will choose emission levels that minimize costs, given price p for emission permits and price q for expected loadings permits to minimize costs, $C = c(e) + q(\hat{e}_{ps} - \hat{e}^0_{ps}) + p(\hat{r}_{ps} - \hat{r}^0_{ps})$, where superscript 0 represents the initial holdings of permits. It faces the constraint that emissions cannot be greater than the permits it holds, $e \leq \hat{e}_{ps} + (1/t)\hat{r}_{ps}$, where (1/t) is the trading ratio to convert nonpoint source permits to emissions. Assuming that the constraint is satisfied as an equality and assuming the initial allocation of nonpoint source permits for the MS4 is zero, we can substitute the constraint into the cost function. First order conditions are from *Horan and Shortle* [2005].

$$\begin{aligned} \frac{\partial C}{\partial e} &= c'(e) + q = 0 \\ \frac{\partial C}{\partial \hat{r}_{ps}} &= -\left(\frac{1}{t}\right) q + p = 0 \end{aligned} \qquad \text{(A1)}$$

We learn that the trading ratio at the margin is t=q/p and the MS4's costs can be simplified to $C = c(e) + q(e - \hat{e}^0_{ps})$.

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Figure captions

Figure 1: Optimal allocation of pollution

Figure 2: Marginal control costs for two types of abatement alternatives: fertilizer reduction and wetlands

Figure 3: Optimal allocation of pollution with two abatement technologies, fertilizer reduction and wetlands

Figure 4: Market for habitat, where acres (a*) of wetlands are converted to a habitat quantity. Modified from *Woodward and Han* [2004]. Copyright (2004), with permission from authors.

Figure 1: Optimal allocation of pollution

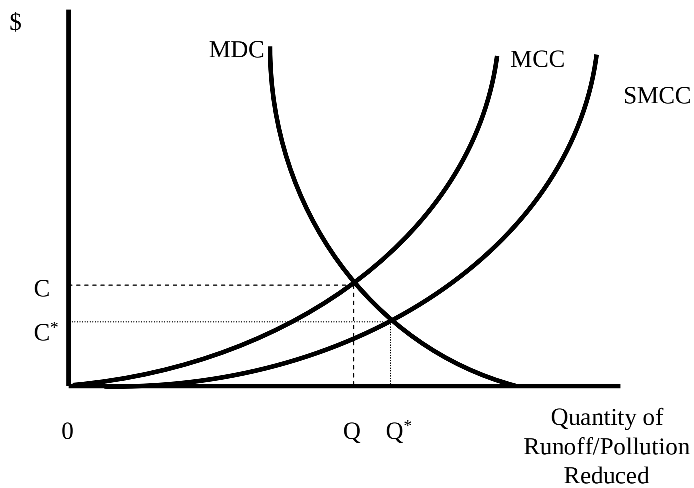

Figure 2: Marginal control costs for two types of abatement alternatives: fertilizer reduction and wetlands

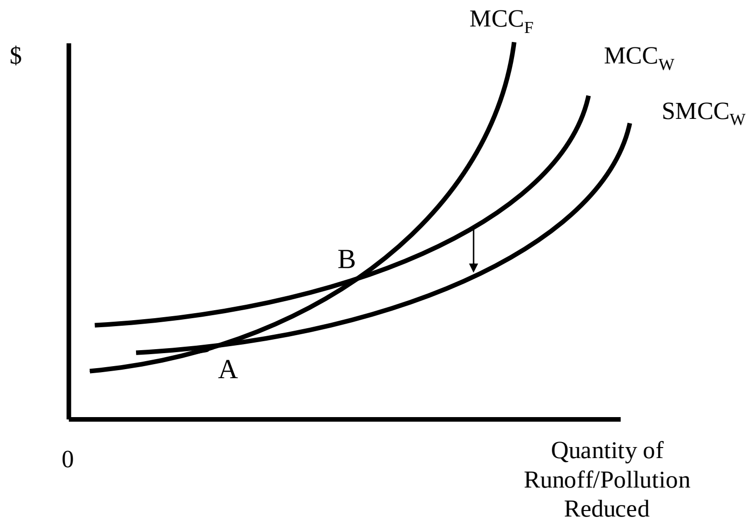

Figure 3: Optimal allocation of pollution with two abatement technologies: fertilizer reduction and wetlands

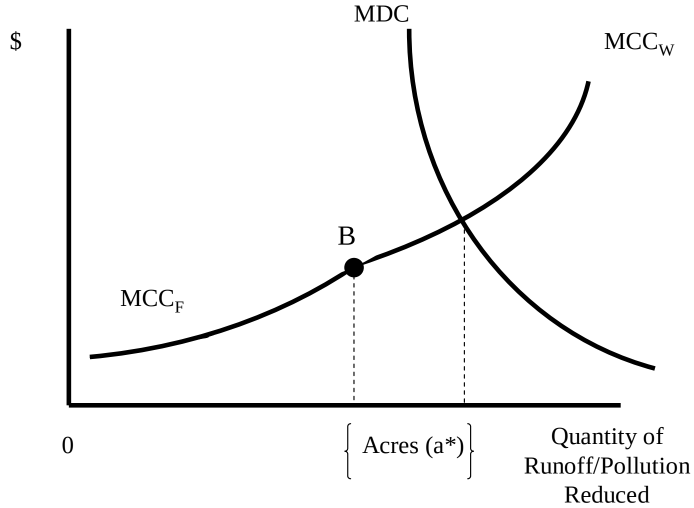

Figure 4: Market for habitat, where acres (a*) of wetlands are converted to a habitat quantity. Modified from *Woodward and Han* [2004]. Copyright (2004), with permission from authors.