A Water Quality Trading Simulation for Northeast Kansas

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Abstract: A simulation model is developed to quantify the effects of information and trading ratios on the performance of a water quality market. An application of this model to a northeast Kansas watershed suggests that performance is improved by information provision and a 1:1 trading ratio between point and nonpoint loadings.

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Water Quality Trading (WQT) has received increased attention as a means to achieve water quality goals. Several such trading programs have been adopted in several states throughout the nation, with more than 30 programs now in operation. In principle, such programs could be applied to any water-borne pollutant and allow trading among point sources, among nonpoint sources, or between point and nonpoint sources (the latter is known as 'point-nonpoint trading'). Most of the existing programs are designed with point-nonpoint trading to limit nutrient loading: point sources are allowed to meet their nutrient emission limits by purchasing water quality credits from agricultural producers in the surrounding watershed. These producers are then obligated to implement a best management practice (BMP) that reduces expected nutrient loading by an amount commensurate with the number of credits sold.

Substantial evidence exists that nonpoint sources can reduce nutrient loading at a much lower cost than point source polluters in many watersheds. This suggests that a well functioning WQT program would be a more cost-effective strategy for meeting total maximum daily load requirements than regulating point source polluters alone (Faeth, 2000). The potential for pollution trading to lower control costs has already been realized in the active air quality trading markets.

Despite the potential gains from WQT, perhaps the most commonly noted feature of existing programs is low trading volume; none of the programs has had extensive trading activity and many have had no trading at all (Hoag and Hughes-Popp, 1997). Hahn (1989) discussed the example of the Fox River program in Wisconsin, which had only one trade after its inception in 1981 despite an early study (O'Neil, 1983) that found substantial gains from trading among all potential participants. Evidently, there are obstacles to trading that have prevented existing markets from achieving all potential gains from exchange.

This paper addresses two of these obstacles that are present in most existing programs. First, many programs have high "trading ratios," requiring each additional unit of point source pollution to be offset by a reduction in expected nonpoint pollution of two or more units. Such ratios have been put in place as an insurance mechanism for loading levels, based on the observation that nonpoint loadings are less certain than point source loadings. Economists have criticized this rationale, pointing out that trading ratios act just like transactions costs to dampen the incentives to trade (e.g., Malik, Letson, and Crutchfeild, 1993). The second obstacle is that the trading process in most existing programs involves bilateral agreements made with limited information (for instance, an individual seller likely does not know all potential buyers' bid prices credits). Atkinson and Tietenberg (1991) were the first to simulate a trading process that accounts for limited information among traders, and found that this process differs substantially from the gains maximizing solution obtained from conventional programming models.

This paper develops and implements a simulation model to represent a point-nonpoint market to reduce nutrient loading, taking explicit account of the obstacles mentioned above. The point sources in the model, indexed by i, differ by the cost of treating wastewater, while the nonpoint sources, indexed by j, are assumed to differ by the loading reduction obtained from BMPs. Point sources can avoid treatment costs by purchasing credits, so that firm i's willingness-to-pay for a credit, WTP_i, is equal to marginal treatment costs. Nonpoint sources are allowed to sell credits in proportion to the expected loading reduction from adopting a BMP. Thus, nonpoint source j's willingness-to-accept price for a credit, is equal to is the cost of loading reduction from implementing a BMP, c_j, multiplied by the trading ratio, α: $WTA_j = \alpha c_j$.

Following Atkinson and Tietenberg, the level of information available to traders is modeled by making different assumptions about the order in which trades occur. In the *full information* scenario, trades are executed in the order of gains from trade—i.e., the first trade occurs between the *i-j* pair with the maximum value of $WTP_i – WTA_j$. The other extreme is the *low information* scenario in which traders are paired in a completely random order. There are also partial information scenarios, where either buyers or sellers are chosen in the order of their *WTP* or *WTA*, but their trading partners are selected in a random order.

The model is applied to simulate a hypothetical phosphorus trading market in Northeast Kansas in the event that a 1mg/L phosphorus concentration limit was imposed on point sources. Observed wastewater treatment plant data for the 2160 mi^2 Middle Kansas Subbasin were used in conjunction with BMP cost data for nonpoint sources. Nonpoint sources were assumed to use filter strips to reduce phosphorus runoff.

Trading was simulated under full, partial, and low information scenarios, as well as under alternative trading ratios (2:1 and 1:1). A benchmark cost level was calculated by assuming that the phosphorous loading limit was obtained by command and control regulation of point sources. The reduction in costs or ‘cost savings’ achieved from each trading scenario was then computed. Lack of information and a higher trading ratio were both found to reduce cost savings. While much work remains in perfecting the structure and rules of trading programs, these results suggest that water quality trading has the potential to decrease phosphorus loading while decreasing costs in Northeast Kansas.

Conceptual Model

Consider a watershed where nutrient emissions are generated by both point and nonpoint sources. There is a point-nonpoint trading program that allows point sources to purchase water quality credits from nonpoint sources. Point source polluters can use a purchased credit to offset one unit of emissions, while selling credits requires the nonpoint polluter to adopt farming practices that reduce expected emissions by an amount that depends on the trading ratio. For example if the trading ratio is 2:1, then nonpoint sources must reduce expected loading by 2 units to generate 1 saleable credit.

The trading institution is assumed to be bilateral negotiation, whereby individual buyers and sellers seek each other out and agree on a traded quantity and price. Bilateral trading is the institution almost exclusively relied on in existing programs and is probably the only feasible method for new programs (Woodward and Kaiser, 2002). The objective of this section is to model point sources' credit-buying and nonpoint sources' credit-selling decisions. We consider this type of decision problem for point and nonpoint sources in turn.

Point sources are assumed to emit directly into the receiving water body and control emissions by selecting wastewater treatment technologies. Indexing the point source firms by $i = 1, ..., I$, let w_k^i denote the quantity of water treated by firm i with technology k, and let e_k^i denote the nutrient concentration of water following treatment. Total emissions by the ith source are then $\sum_k e_k^i w_k^i$.

In a trading situation where credits can be purchased at a price of p, firm i must decide how many credits to purchase at this price, which we denote q_b^i. In addition, it must select a treatment plan $\mathbf{w}^i = (w_1^i, \dots, w_K^i)$ that will satisfy two constraints. The first constraint is that all water entering the plant, $\overline{w}^i$, receive some form of treatment.Dropping the i superscript for simplicity, this constraint is:

$$(1) \qquad \sum_k w_k = \overline{w}.$$

The second constraint is a regulatory requirement. Total emissions by a given firm cannot exceed the firm's mandated emissions level, $\bar{q}$, adjusted for credits purchased:

(2) $$\sum_k e_k w_k \le \bar{q} + q_b \,.$$

The firm's objective is assumed to be one of minimizing the total costs of operating the plant and purchasing credits. Given the constraints above, the firm's decision problem can be written

(3) $$\min_{\{q_b,\mathbf{w}\}} \; pq_b + \sum_k c_k(w_k, e_k)$$

subject to: (1), (2)

where $c_k(\cdot)$ is the cost of operating the kth technology. The optimal quantity of credits, $q_b^i(p, \bar{q})$, is firm i's demand function for credits conditional on the mandated emissions requirement $\bar{q}$.

Nonpoint sources emit from various points throughout the watershed in the form of nutrient-rich runoff following rain events. Nonpoint sources, indexed by $j = 1, ..., J$, are assumed to be agricultural, and emissions from each source depend on the production practices selected. In this context, production practices, indexed by $l = 1, ..., L$, represent a particular crop grown with a given set of input levels, tillage/planting practices, etc. Let x_l^j be the acreage in the lth production practice on farm j. Expected emissions from the jth farm are represented by the function $f^j(\mathbf{x}^j)$, where $\mathbf{x}^j = (x_1^j, ..., x_L^j)$.

Nonpoint sources are sellers in the credit market. Similar to above, on a trading occasion when credits can be sold at a price of p, the nonpoint polluter must select a quantity for credits to be sold, q_s^j, and an associated production plan $\mathbf{x}^j = (x_1^j, \ldots, x_L^j)$. Also similar to above, the chosen production plan must meet two constraints. Now dropping the j superscript, let $\bar{x}$ denote the total acreage farmed by a given nonpoint source. The first constraint requires that all land farmed is assigned some production practice:

(4) $$\sum_l x_l = \bar{x}$$

The second constraint requires that emissions are no more than a predetermined baseline level, $\bar{q}$, adjusted for credits sold:

(5) $$\sum_l e_l x_l \le \bar{q} - \alpha q_s ,$$

where e_l is the expected loading from each acre of land in the *l*th practice,[1] and α is the trading ratio (e.g., if the trading ratio is 2:1 then α = 2). Assuming the second constraint is binding, equation (5) implies that the number of saleable credits, qs, is the expected loading reduction (relative to the baseline level) divided by the trading ratio: $q_s = \left(\bar{q} - \sum_l e_l x_l\right) \big/ \alpha$.

The objective of a nonpoint source is assumed to be maximizing the gains from production and credit sales. The decision problem facing a typical farmer is

(6) $$\max_{\{q_s, \mathbf{x}\}} pq_s + \sum_l \pi_l x_l$$

subject to: (4), (5)

where π_l is the profit margin of the *l*th production practice based on production costs and revenues. The solution to farmer *j*'s problem consists of a supply function for credits, $q_s^j(p; \bar{x}^i)$, which is conditioned on the acreage farmed.

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[1] For nonpoint traders, the values of the e_l's must be specified as part of the program rules, since emissions cannot be observed. Existing programs typically compute these coefficients for each polluter based on predicted farm-edge loadings from a biophysical model (Horan, Shortle, and Abler, 2002; Woodward and Kaiser, 2002). In particular, letting $\hat{f}(\mathbf{x})$ denote the model's prediction of expected loadings, then the coefficient for the *l*th practice is $e_l = \partial \hat{f}(\mathbf{x}) / \partial x_l$.

Effects on the Market Equilibrium

We now heuristically identify the effects of both the trading ratio and the sequencing of trades on the equilibrium of the credit market. Consider first a market where the trading ratio is 1:1 and all trades are made simultaneously at a uniform price. Figure 1 represents the equilibrium in such a market. The demand curve in this figure is the market-level demand for credits, which is obtained by aggregating individual point source's demands: $D(p) = \sum_i q_b^i(p;\overline{w}^i)$. Similarly, the market level supply curve is obtained by aggregating the solutions to the nonpoint sources' decision problem and aggregating across j: $S(p) = \sum_j q_s^j(p;\overline{x}^j)$. When $Q = 0$ credits, point sources are meeting their limits by controlling all of their pollution through their own facility upgrades or technological improvements. As Q increases, point sources are buying credits to allow more of the pollution to be controlled by the nonpoint sources. Thus, at any point on the

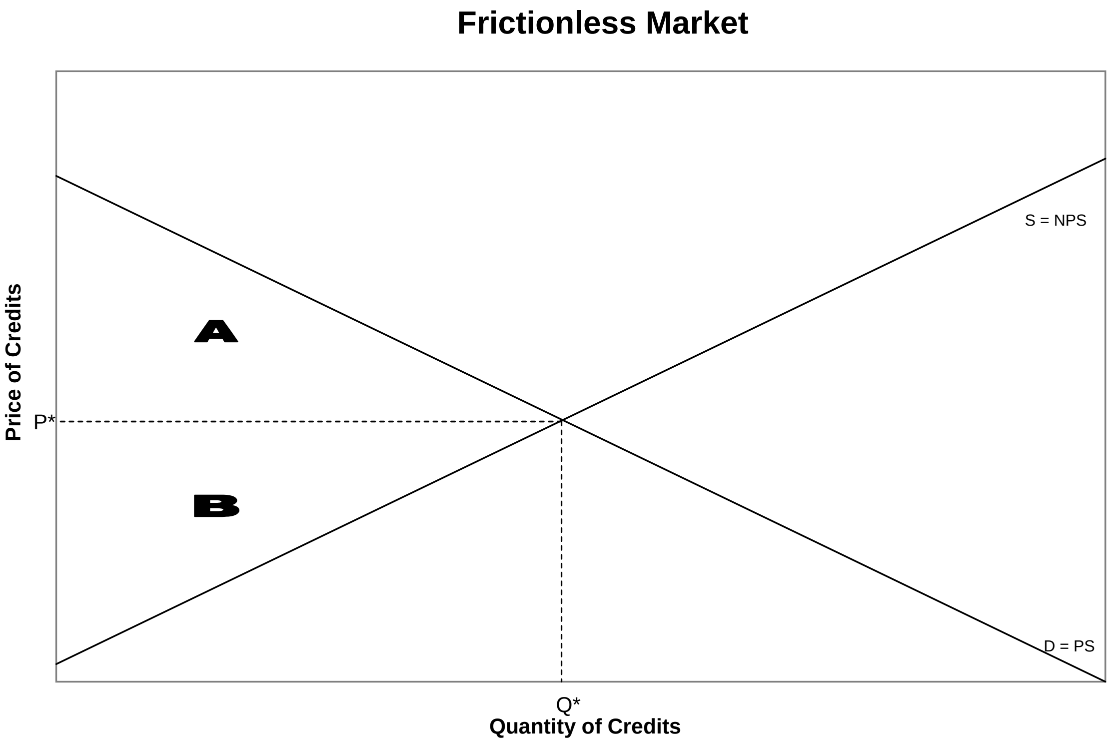


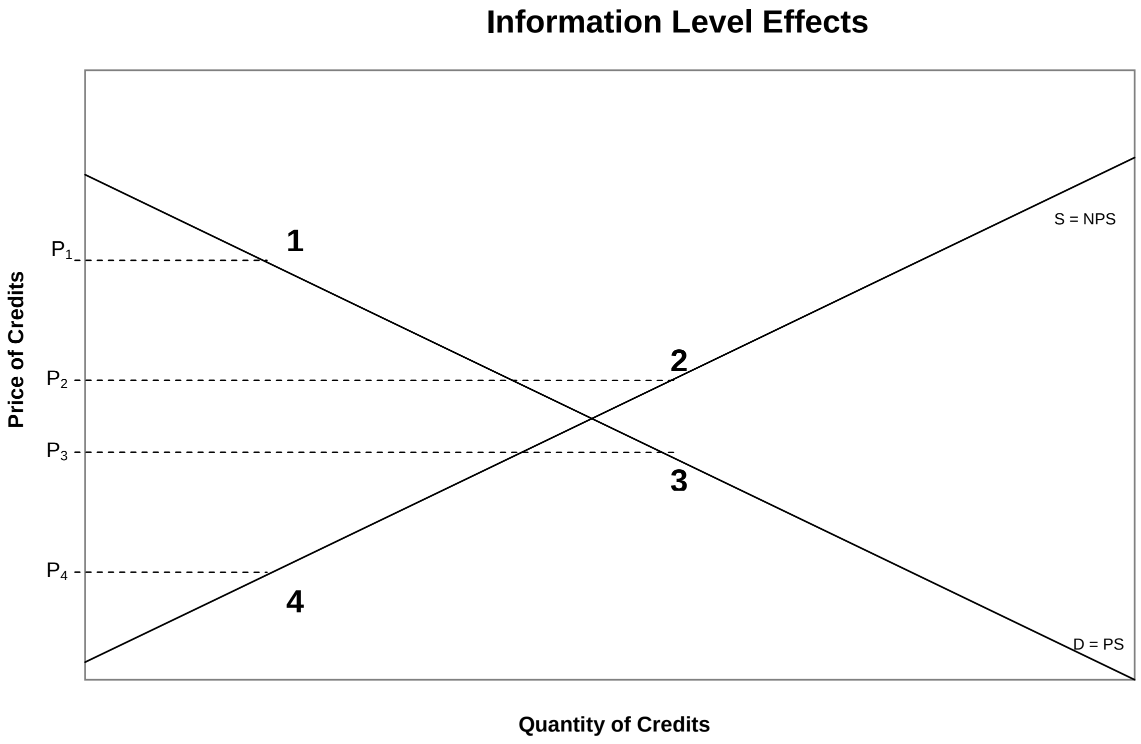
diagram the total amount of pollution control does not change; however, the sources responsible for the pollution control does change.

In the equilibrium of this market, point sources purchase *Q** credits from nonpoint sources at a price of *P**. Area *A* represents the market gains to point sources, reflecting the difference between the potential cost of technology upgrades (points along the demand curve) and the actual cost of purchased credits (the price *P**). Area *B* is the gain to nonpoint sources, or the price received for the credits sold (*P**) less the cost of generating those credits (points along *S*). The sum of these two areas is equal to total benefits or total cost savings from the program. Cost savings are maximized under these market conditions.

It is important to note that the areas delineating the gains to point source and nonpoint sources in the figure assume that every contract is traded at the equilibrium price, *P**. This would only occur under a simultaneous trading scenario. However, the way water quality markets are designed, trading must occur in a sequential and bilateral fashion, implying that each contract results in a potentially unique price. Acknowledging this would change the individual values of the point- and nonpoint-source gains, but the total cost savings (sum of the two gains) would not vary. This caveat applies to all of the following market scenarios.

Now consider the effect of sequential, rather than simultaneous, trading. If trades are made sequentially by individual traders seeking each other out in the marketplace, the pairing of traders in each transaction depends on the level of information available to agents. A full information scenario assumes that every participant in the market knows precisely their own and everyone else’s control costs. This depicts a situation in which the most advantageous trades are executed first. A low information scenario is characterized by none of the participants knowing their own or anyone else’s control cost. In this limiting case, traders would be paired together in a random order.

Figure 2 shows the effects of different information levels in the market. For this example, the focus will only be on the point sources located at points 1 and 3 along the demand curve (hereafter PS #1 and PS #3), and the nonpoint sources located at points 2 and 4 along the supply curve (hereafter NPS #2 and NPS #4). For simplicity, let us assume that all four of these entities would trade at most one credit. As in any market, the net gain from a given trade is equal to the difference between the price along the demand curve and the price along the supply curve. In a full information and frictionless market, the first transaction involving any of these traders would be between PS #1 and NPS #4. PS #3 and NPS #2 will not engage in trading because there would be a negative net gain from doing so. So, for the four traders combined, the net gain from trading under full information is $P_1 - P_4$.



A low information scenario, on the other hand, has the potential to result in different net gains (theoretically, it also has the potential to result in the same net gains). Suppose PS #1 trades with NPS #2. The resulting net gain from this transaction is $P_1 – P_2$. Suppose also that PS #3 trades with NPS #4 for a net gain of $P_3 – P_4$. The combined net gain from this sequence of trading is $(P_1 – P_2) + (P_3 – P_4) = (P_1 –P_4) – (P_2 – P_3)$. So, assuming that all other traders are paired the same as the full information scenario, this "ill-odering" of trades would reduce the overall market gains by $(P_2 – P_3)$. This suggests that lower information is likely to increase trading volume while reducing the total gains from trading.[2] However, whether point sources or nonpoint sources gain or lose from less information depends on the order of trading that is realized and cannot be unambiguously predicted.

Lastly, consider the effect of the trading ratio, which is depicted in Figure 3. Imposing a trading ratio of $\alpha > 1$ would affect the nonpoint sources or the suppliers in the market, as they would be required to reduce phosphorus loading by α pounds in order to receive one saleable credit. This essentially increases the cost of all credits sold by a factor of α, resulting in the steeper supply curve shown in Figure 3. The equilibrium quantity of credits traded in this market is reduced to Q' and the equilibrium price of credits increases to P'. The gains to point sources with the higher trading ratio is area A, implying a loss of area $B + C + D$ relative to the efficient market. The gains to nonpoint sources in the 1:1 market was equal to area $E + F + G$. With a trading ration of $\alpha > 1$, their gains area is $B + E$. Thus, the net effect of the increase in the

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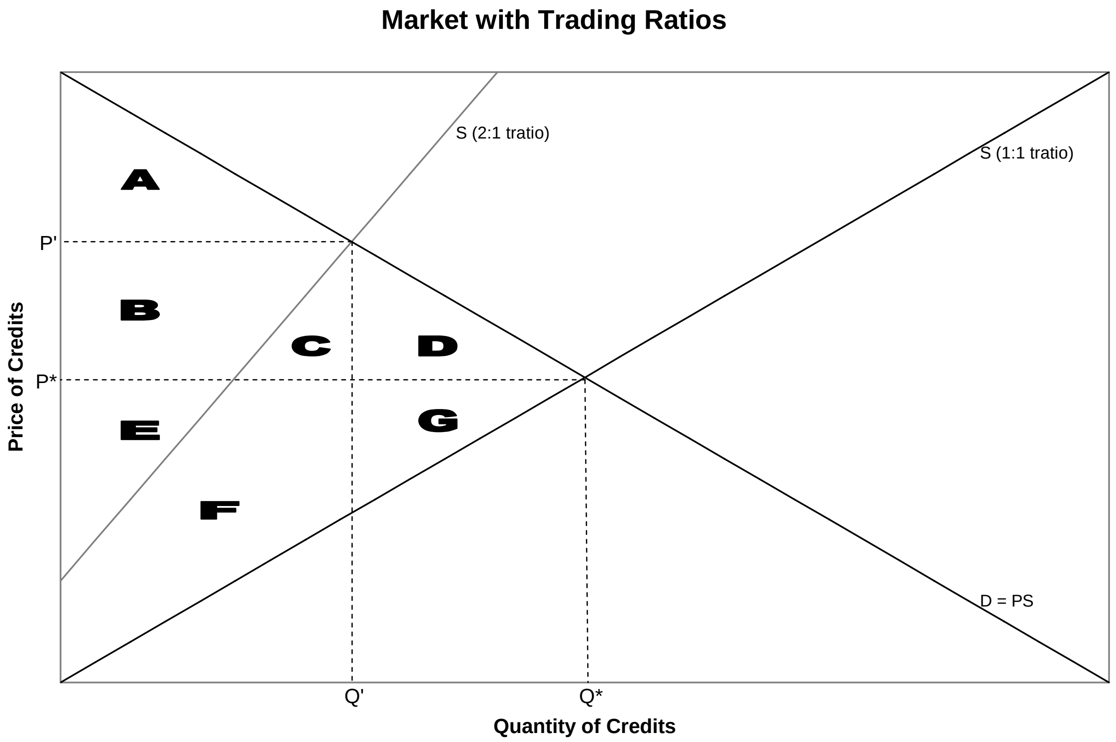
[2] Ermoliev et al. (2000) actually proved that random-ordered, sequential trading can lead to an efficient outcome (Q* in Figure 1). However, this can only occur when every participant has the ability to be a buyer or a seller and there are no transaction costs. That is, traders can back out of earlier trades at no penalty if they find a new trading partner that is more advantageous. This assumption is unlikely to hold for water quality trading programs in practice, where each trade usually involves a binding contract that can only be breached at some financial penalty. In this paper, we are concerned with a market where only point sources are able to buy credits, only nonpoint sources can sell credits, and that the penalties for breaching trade contracts are prohibitively large. Since Ermoliev et al.'s (2000) assumptions are not met in our models, different information levels should result in different levels of cost savings.



trading ratio to the nonpoint sources is equal to $B – (F + G)$. If B is larger than the sum of F and G, then the nonpoint sources benefit from the trading ratio. The change in total cost savings from the higher trading ratio is equal to a loss of area $C + D + F + G$.

Although there is an apparent cost to the higher trading ratio in terms of market gains, the benefit is a net improvement in environmental quality. Unlike the market depicted in Figure 1, expected loading in this case does respond to changes in the volume of credit trades. Because nonpoint traders must reduce loading by α pounds for every 1 pound emitted by point source traders, there will be a net reduction of $\alpha – 1$ pounds of expected loading for each trade. For the equilibrium shown in Figure 3, point sources increase their expected loading by Q' pounds, while nonpoint sources reduce expected loading by $\alpha Q'$ pounds. Expected total loading will therefore be reduced by $\alpha Q' – Q' = (\alpha – 1)Q'$ pounds.

Data

Data on point and nopoint sources were assembled for a study region comprised of the Middle Kansas subbasin. The subbasin is located in Northeast Kansas and represents 2,160 square miles. The area is comprised primarily of small towns but also the Kansas capital, Topeka, with a population of 125,000 people. The principal crops are corn, soybeans, sorghum and wheat, with cropland occupying most of the bottom land and about 50% of the upland acreage. The average rainfall in this area is 32 inches per year and most of it comes during the three months of April, May and June. Additional details about the study region and the point- and nonpoint-source data are in Smith (2004).

The point source dataset consists of information on the 30 municipal wastewater treatment plants (WWTPs) in the study region. This information was obtained from the dataset used by Greehalgh and Sauer (2003), which was assembled by the World Resources Institute. The relevant point source data included each plant's flow rate (in million gallons per day), the phosphorus concentrations of their effluent and the current treatment system used (either chemical secondary or biological secondary), both based on information in the year 1996. From this information, the loading reduction and control costs needed to meet a particular environmental target could be derived.

We set this target at phosphorus emissions corresponding to a concentration of 1mg/L in the treated wastewater for all plants. Based on this value and the current effluent concentrations, the amount each plant would have to decrease its emissions in order to meet the 1mg/L standard was calculated. The cost of this reduction was then calculated based on the treatment cost functions estimated by Greenhalgh and Sauer (2003). Finally, each cost was divided by the phosphorus reduction to obtain each plant's willingness to pay per unit of phosphorus. Plant *i*'s willingness to pay for phosphorous credits, WTP_i, represents the price below which the plant would prefer to buy an emission permit rather than invest in the capital needed to reduce its own emissions.

Nonpoint sources were assumed to generate credits by converting a portion of their fields to a grass filter strip. Based on research on the design of filter strips (Barden et al. 2003), it was assumed that 1 acre of filter strip was needed for each acre cultivated and that the filter strip would reduce field-edge phosphorous loading by 40%. To translate this percentage reduction into a quantity of loading reduction (pounds per acre), it is necessary to have data on initial phosphorous loading quantities. Because nonpoint loading levels are by definition unobservable, no such quantity data exist. Therefore, we generated data on phosphorous loading levels for 500 fields representative of the area based on varying field sizes and phosphorous loading rates per acre. 500 observations of initial phosphorous loading levels were generated by randomly choosing a field size in the range of 25 to 200 acres and a phosphorous loading rate in the range of 0.74 to 2.9 pounds per acre. The latter range was set based on field level research (Buckley-Zeimen 2004). The loading reduction from filter strips was then computed as a 40% reduction from the initial level for each data point. All of the fields included in the nonpoint data set were assumed to be in a corn-soybean rotation, reflecting a typical cropping pattern in the region (KWO 2004). The generated dataset of 500 fields totals 56,236 acres, equivalent to 88 square miles or 4% of the total watershed area.

The cost per acre of filter strips was assumed constant across the region. Filter strip costs include the installation expenses for the filter strip itself (e.g., tillage and seeding) plus the opportunity cost of lost production on the area converted. These costs are taken from Ohlenbush (1997) and Dhuyvetter and Kastens (2003). The cost per unit of loading reduction, c_j, was then computed for each data point by dividing the filter strip cost by the quantity of loading reduction. Under a trading ratio of α, the minimum price a farmer would accept for selling a water quality credit is $WTA_j = \alpha c_j$.

Simulation Procedures

Trading was simulated using a variant of the sequential bilateral (SB) algorithm developed by Atkinson and Tietenberg (1991). In this algorithm, trades are consummated sequentially and the order of trading depends on information available to market participants. Every potential trade is analyzed on the basis of the potential gains or losses that could result. In particular, a "gains" matrix was developed that consisted of rows $1,\ldots,I$ and columns $1,\ldots,J$, where cell contained the potential gains per credit to be made through trading: $\text{Gains}(i, j) = WTP_i - WTA_j$.

The simulations described below represent varying levels of trader information, and each was run under two alternative trading ratios, 1:1 and 2:1. In each simulation, the maximum quantity traded by a given participant consisted of the amount of credits required to meet the emissions requirement for the point sources and the number of credits generated by the 1/25th filter strip conversion by the nonpoint sources. The individual sources were removed from the market when their quantity purchased (for point sources) or quantity sold (for nonpoint sources) of credits equaled the maximum quantities.

Simulation 1: Full information trading, gains-ranked

The first simulation modeled a full information trading scenario. This scenario assumed that every point source and every nonpoint source in the watershed knew precisely their own and everyone else's phosphorus control costs. This depicted a situation in which the most advantageous trades were executed first. Action began by the point source with the highest marginal cost of control trading with the nonpoint source exhibiting the lowest marginal cost of control. This was determined by the element in the "gains" matrix that exhibited the greatest positive value. The point source would purchase as many credits as it needed or until it bought out the nonpoint source, whichever occurred first. The quantity data and the "gains" matrix were both updated accordingly when the trade was consummated.

The second trade began by finding the greatest positive number in the updated "gains" matrix. This determined the next two trading partners. The aforementioned process was then run again. This gain-ranked process continued until there were no more gains to be made by trading.

Simulation 2: Low information trading

The second simulation modeled a low information trading scenario. This represents a situation in which none of the stakeholders knew their own or anyone else's phosphorus control costs. Therefore, the trades occurred in a completely random order.

Once again, a "gains" matrix of size (I x J) was developed, which represented the possible gains that could be achieved through each trade. One restriction was that only trades resulting in positive gains were eligible to be chosen. A single element from this matrix was chosen at random and this determined the trading partners. This trade was consummated and the "gains" matrix and quantity data were updated.

The second trade operated in the same random fashion. Trading partners were picked at random and the trade was consummated. This process continued until no potential positive gains remained.

Simulation 3: Partial information trading

The third simulation modeled the case where point sources' control costs were known, but nonpoint sources' costs were unknown. This depicts a situation in which the point sources drive the market.

Trading began by first choosing the point source with the highest *WTP*. The nonpoint source trading partner was then chosen at random. After the trade was consummated, the "gains" matrix and quantity data were updated. This process continued until no potential positive gains remained from trading.

Simulation 4: Partial information trading

The fourth simulation modeled the case where nonpoint sources' control costs were known, but point sources' costs were unknown. This scenario assumed that nonpoint sources drive the market.

Trading began by first choosing the nonpoint source with the lowest *WTA*. The point source trading partner was then chosen at random. As above, after the trade was consummated, the "gains" matrix and quantity data were updated. This process continued until no potential positive gains remained from trading.

Results

To evaluate an alternative policy, it is necessary to make comparisons back to a situation under the current command and control policy approach. If the point sources in the watershed were required to meet the 1 mg/L phosphorus limit without the flexibility of trading, they would incur costs of $3,926,471. This value was set as baseline cost level. A more cost effective policy will result cost savings relative to the baseline.

The cost savings from trading in each simulation are presented in Table 1.Under a 1:1 trading ratio, all of the simulations resulted in positive economic benefits. Simulation 1 exhibited $860,436 net cost savings and 40,515 traded credits, or a 28% cost reduction from the baseline level. This was set as the maximum savings to which other scenarios were compared. Under a 2:1 trading ratio, the cost savings of all simulations are smaller, and the trading volumes are smaller as well. These results are consistent with the predictions of the conceptual model presented above.

Some important principles and relationships can be derived from these results. First, there is an unambiguously positive relationship between the amount of information known and the net cost savings from trading. This is illustrated by the results in Table 1. For example, under a 2:1 trading ratio, simulation 1 (full information) resulted in net cost savings of $468,474 while simulation 2 (low information) resulted in savings of only $413,950. This relationship between simulations 1 and 2 held true for a 1:1 trading ratio as well. These results are similar to the findings by Atkinson and Tietenberg (1991).

Table 1. Results summary

Simulation	Total Costs ($/yr.)	Net Cost Savings ($/yr.)	Credits Traded	% of Max. Cost Savings
No trading	$3,926,471	$0	0	0%
1:1 Trading Ratio				
Simulation 1	$3,066,035	$860,436	40,515	100%
Simulation 2	$3,126,362	$800,109	40,515	93%
Simulation 3	$3,066,034	$860,437	40,515	100%
Simulation 4	$3,135,969	$790,502	40,515	92%
2:1 Trading Ratio				
Simulation 1	$3,457,997	$468,474	18,123	54%
Simulation 2	$3,512,521	$413,950	20,241	48%
Simulation 3	$3,465,022	$461,449	19,921	54%
Simulation 4	$3,515,640	$410,831	20,207	48%

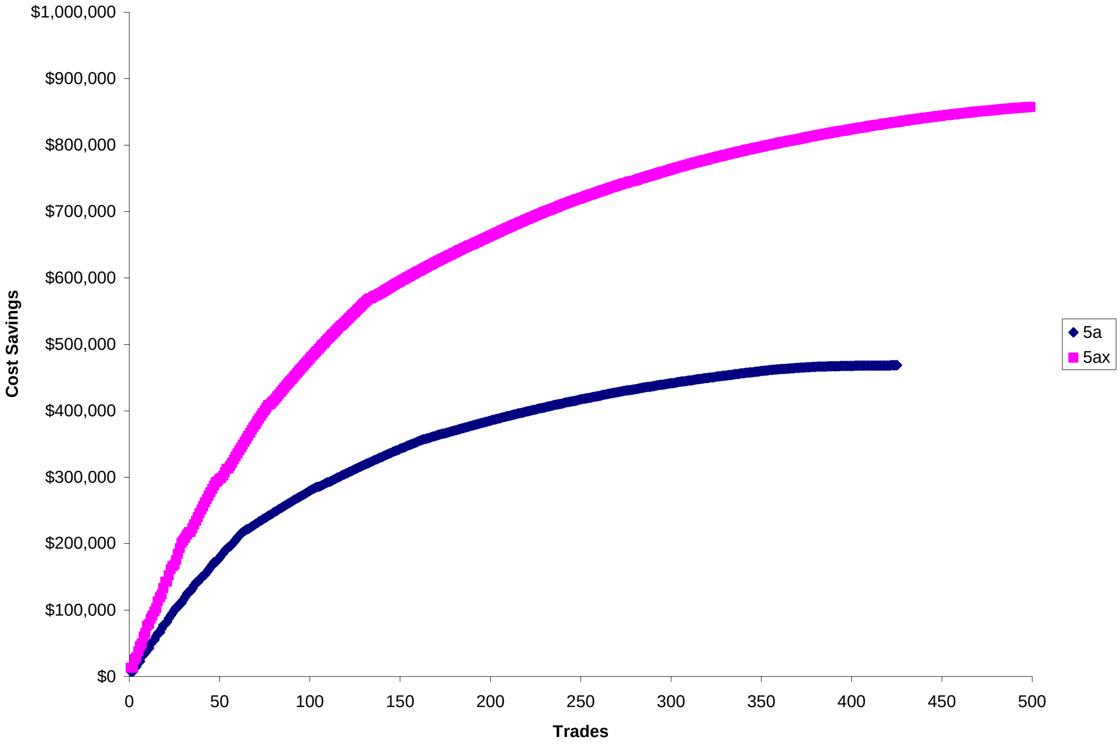
The full information scenario is very optimistic and should be viewed as the upper bound for cost savings. In the real world, it is very unlikely that participants would know their own and everyone else's phosphorus control costs. The low information scenario, on the other hand, should be at the lower end of the benefits spectrum. It is reasonable to suggest that some of the participants would have an idea about their own or other's costs. The actual cost savings would probably lie somewhere in between these two scenarios.

As stated earlier, the purpose of a trading ratio greater than one is to account for phosphorus reduction uncertainty and ensure that there is an overall increase in water quality. According to the simulation results, this was the case. With a 2:1 trading ratio, each unit of increased point source loadings is offset by a 2-pound reduction in expected loading by point sources, resulting in net environmental gains equal to the height of the shaded bars. For example, simulation 1 under a 2:1 trading ratio resulted in 18,163 credits traded. Because of the 2:1 trading ratio, nonpoint sources reduced loading by a total of 36,326 pounds, resulting in a net expected loading reduction of 18,163 pounds of phosphorus. So, the introduction of a trading ratio greater than 1:1 did result in a net environmental improvement as predicted by the theory.

As also predicted by the theory, this net environmental improvement does come at a cost. The cost of this extra loading reduction is the main factor in evaluating the trading ratio. Comparing simulation 1 under a 2:1 and 1:1 trading ratio, raising the trading ratio to 2:1 increased costs by \$3,458,022 - \$3,069,144 = \$388,878 (table 1). Thus, the average cost of the 18,163 pounds of net phosphorus reduction was \$388,878/18,163 = \$21.41 per pound. It is possible that this reduction could have been achieved by a more cost effective approach. For example, the average control cost of achieving the 1 mg/L phosphorus limit through treatment upgrades (the command and control policy) for the 30 WWTPs was \$14.40 per pound of phosphorus reduced. Assuming that the WWTPs faced constant marginal control costs, it would have been more cost effective to lower the TMDL limit by 18,163 pounds and then allow trading with a 1:1 trading ratio.

The trading ratio appears to play an important role in determining the cost savings from trading. As Figure 4 shows, different trading ratios produce completely different curves. The 1:1 trading ratio simulation 1 results in greater marginal savings than the 2:1 trading ratio simulation 1 for all corresponding trade amounts. The 1:1 trading ratio also has the potential to nearly double the cost savings of the 1:1 market, if all possible trades were executed.

Figure 4 Effect of trading ratio on marginal savings



Conclusions

The simulations of this model suggested that water quality trading is an efficient way to regulate phosphorus in surface water. Research has shown that point sources face much greater costs in treatment upgrades relative to nonpoint sources. The difference between these costs represents the potential gains from trading. A wider gap in costs leads to greater possible gains. This study found that the small WWTPs would benefit the most from a water quality trading program. The smaller WWTPs have relatively high control costs, due to their low volume of treatment. Larger WWTP have lower average control costs, due to economies of scale.

Smaller towns have smaller operating budgets than their large municipal counterparts. This would give them more incentive to trade rather than bear the cost of a technology upgrade. Also, many farmers can probably relate to the needs of a small town better than to a large city. So they would have more interest in helping the small towns reduce their costs.

Farmers could benefit greatly from a water quality trading market as well. Simulation results indicated that a farmer could make over $500/acre on a grass filter strip. Comparing this value with the $14.75/acre average return from 1998-2002 on nonirrigated corn (KFMA Profitcenter Summary 2003), this represents a 33-fold increase in net returns. So, it is plain to see the potential benefits of trading for the farmer.

One very important policy implication found in this study deals with the incorporation of trading ratios. Many existing trading programs (e.g., Kalamazoo River and Chesapeake Bay) have imposed 2:1 trading ratios on all point-nonpoint source trades. The purpose of this ratio is to account for uncertainty and assure that there is an overall increase the environmental benefits. The findings of this study show this to be the case, but that these benefits come at a great cost. These same environmental benefits could be achieved by a more cost effective approach. Also, imposing a 2:1 trading ratio prohibits many trades from occurring, thus lowering the effectiveness of the market.

There is no reason why results such as these could not potentially be seen in the real world. The data is realistic for northeast Kansas and all the assumptions made in this model are based on previous research. The basic principle behind water quality trading is to allow polluters with high control costs to pay polluters with lower control costs to reduce their pollutant load. That is exactly what this model simulates, and the results show the potential benefits from such a market.

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