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Research papers

A smart market for nutrient credit trading to incentivize wetland construction

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ABSTRACT

Nutrient trading and constructed wetlands are widely discussed solutions to reduce nutrient pollution. Nutrient markets usually include agricultural nonpoint sources and municipal and industrial point sources, but these markets rarely include investors who construct wetlands to sell nutrient reduction credits. We propose a new market design for trading nutrient credits, with both point source and non-point source traders, explicitly incorporating the option of landowners to build nutrient removal wetlands. The proposed trading program is designed as a smart market with centralized clearing, done with an optimization. The market design addresses the varying impacts of runoff over space and time, and the lumpiness of wetland investments.

We simulated the market for the Big Bureau Creek watershed in north-central Illinois. We found that the proposed smart market would incentivize wetland construction by assuring reasonable payments for the ecosystem services provided. The proposed market mechanism selects wetland locations strategically taking into account both the cost and nutrient removal efficiencies. The centralized market produces locational prices that would incentivize farmers to reduce nutrients, which is voluntary. As we illustrate, wetland builders' participation in nutrient trading would enable the point sources and environmental organizations to buy low cost nutrient credits.

1. Introduction – Nutrient trading and wetlands

Water quality trading (WQT) is widely viewed as the most economical and efficient mechanism for controlling excess nutrient runoff loads in waterways. Nutrient runoff can be reduced cost-effectively using wetlands which also improve ecological sustainability. Recent research has pointed out the viability of WQT with wetlands as a supplier of nutrient credits (Heberling et al., 2010; US EPA, 2007a). Though the capability of wetlands in removing nutrients is well established (Crumpton et al., 2006; Kadlec and Knight, 1996; Kadlec and Wallace, 2008; Reddy et al., 1999, 2005), only a few studies like Heberling et al. (2010), Ng (2007) and US EPA (2007a) have investigated the role of wetlands as credit suppliers in nutrient trading. US EPA (2007a) conducted a detailed analysis of the technical, economic, and regulatory aspects of WQT with wetlands, illustrating the need for further research into the integration of wetlands into WQT programs.

WQT, especially with wetlands, requires careful market design. Technical difficulties arise from nutrient transport dynamics of the watershed, spatial and temporal heterogeneity in the impacts of nutrient loading and uptake, and the uncertainty involved in nutrient transport and removal. From an economic standpoint, wetland construction requires lumpy investments and long-term land use commitments. Once constructed, a wetland would supply a seasonally-varying series of nutrient reduction credits over a long time period, whereas the demand for nutrient reduction credits from point sources is relatively constant throughout a year. Wetlands remove various nutrients, such as nitrate-nitrogen and phosphorus, at different rates. In addition to the removal of excess nutrients, wetlands offer other ecosystem services or benefits, such as increasing wildlife habitat, improving biodiversity, and reducing flood damage. Ideally, the present value of a wetland should be determined by considering all these ecological services. Nutrient trading with wetlands should therefore accommodate multiple commodities such as nitrogen reduction, phosphorus reduction, and flood reduction.

Such complexities impede opportunities for efficient and fair trading in nutrient credits generated by wetlands. Trading mecha-

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nisms should be designed to encourage the voluntary participation of wetland builders. Unless the potential investors perceive wetland construction as a profitable long-term investment, they would not make the long-term financial and land use commitments required for wetlands.

WQT in the U.S. dates back at least to the 1980s (Eheart et al., 1987; O'Neil et al., 1983; Shortle, 2012), and has extensive literature covering market designs (Horan et al., 2002a; Hung and Shaw, 2005; Morgan et al., 2000), market simulations (Horan et al., 2002b; Leston, 1992; Nguyen et al., 2013), case studies (Breetz et al., 2005; Fang et al., 2005), critical reviews (David, 2003; King and Kuch, 2003; Kochtcheeva, 2009; Stephenson and Shabman, 2011), and detailed surveys (Environomics, 1999; Morgan and Wolverton, 2005; US EPA, 2007b, 2008). Nitrogen and phosphorus are the most commonly traded nutrient pollutants in the U.S. Nutrient trading gained more attention as scientists identified the impacts of nutrients pollution, mainly algal blooms, hypoxia, and dead zones. At present, the U.S. has several watershed level nutrient trading programs in operation (Selman et al., 2009; Shortle, 2012; US EPA, 2008) targeting both point-point and point-nonpoint source trades. Though some WQT programs in the US facilitate the use of wetlands; only a few trades have actually taken place (Stephenson and Shabman, 2011; US EPA, 2007a).

To date, U.S. nutrient trading has experienced both successes and failures, but failures dominate (Stephenson and Shabman, 2011). The main reasons for failure are insufficient demand and supply caused by over-restrictive trading rules, few participants, and high transaction costs (David, 2003; Faeth, 2000; Hoag and Hughes-Popp, 1997; King and Kuch, 2003; McGartland, 1988). The transaction costs arise because would-be buyers must find willing sellers, the physics of the proposed trade has to be appropriate, and the parties must usually obtain government approval.

Regarding the physics of the trade, most U.S. nutrient trading systems use *trading ratios* to manage the uncertainty in nonpoint source reductions (US EPA, 2007b) and to account for the spatial differences in the impacts of point and nonpoint source reductions (Selman et al., 2009; Shortle, 2013). These ratios are usually conservative, requiring a higher amount of nutrient reduction from nonpoint sources to offset point source discharges. Conservative trading ratios have been identified as a factor that impedes nutrient trading (US EPA, 2007a). Some trading programs apply the same trading ratios for each trade between point and nonpoint sources, but fixed trading ratios do not accurately account for the spatial heterogeneity of nonpoint source impacts. Administrative cost rise when trading ratios are calculated separately for each trade. With trading ratios, a trade can occur through bilateral negotiations or through a third party (clearinghouse). While bilateral trading incurs high transaction costs, clearinghouses may incur higher administrative costs. Though several studies have focused on designing trading ratios (Shortle, 2013), relevant scientific information has not been used in deciding trading ratios for real-time trades (Selman et al., 2009).

Besides trading ratio systems, various market designs applicable for nutrients have also been proposed. Zonal permit systems allow trades across time to account for the time lags in pollutant transport (Environmental Protection Authority, 2003; Lock and Kerr, 2008). Centralized auctions (Morgan et al., 2000) connect traders and an auctioneer through electronic media, use hydrogeological models to evaluate the impacts of trade, and attempt to find market equilibrium by adjusting prices iteratively. Smart markets (Prabodanie et al., 2014) use centralized clearing, various watershed hydrogeological models, and in particular, linear optimization algorithms to find market clearing prices, but smart market designs have not been tested for nutrient trading with wetlands. A detailed literature review on various nutrient trading systems is available in TWI (2014).

In this paper, we report on part of a major study done for the U. S. Environmental Protection Agency (US EPA) (TWI, 2014), which explores the feasibility of using wetlands in a nutrient credit market. This project assessed whether the environmental, economic, and social factors could support a nitrogen and phosphorus credit trading market in the Big Bureau Creek (BBC) watershed, a sub-watershed of the priority Lower Illinois River–Lake Senachwine watershed. The project comprised (1) a full literature review, (2) an assessment for wastewater treatment plant demand and potential wetland site supply, (3) an economic analysis of a market, (4) development of a "smart market" proposal and simulation, (5) an assessment of the social readiness of stakeholders, and (6) specific proposals for administration of the market. Some of these sections have been published (Tomer et al., 2013; Lentz et al., 2013). This paper presents the design and simulation of the smart market (part 4) which we call "MarshWren." Our market design would assure economically justifiable payments for wetland builders, that the conservative ratio based trading has failed to accomplish.

A smart market is a periodic auction cleared with the help of mathematical optimization (Carlson et al., 2012; McCabe et al., 1991; Rothkopf et al., 1998). Owing to the use of an optimization model to clear the market (i.e., to determine the prices and quantities to be traded), smart markets are a viable trading mechanism that can account for complex physical interactions relevant to trade in common-pool commodities such as groundwater, electricity and pollution (Alvey et al., 1998; Hogan et al., 1996; Prabodanie et al., 2014; Raffensperger et al., 2008). As in a clearinghouse (Woodward et al., 2002), participants buy from or sell to a centralized auction manager rather than from or to each other. The auction manager aggregates all buyer bids and seller offers that become part of the optimization model. The optimization model chooses which bids and offers to accept while ensuring that required load constraints are satisfied at the minimum cost. After solving the optimization, the auction manager informs traders of the accepted quantities, collects money from buyers, and pays sellers based on prices obtained from the dual prices of the optimization. Under modest assumptions of competitiveness, the prices obtained from such an optimization model are expected to be efficient (Gabriel et al., 2005; Hobbs, 2001; Samuelson, 1952).

The smart markets, through the use of optimization models, can handle a range of complications that arise in nutrient trade with wetlands, including multiple types of commodities (nitrate and phosphorus), different attenuation rates in stream segments and wetlands, and multiple environmental constraints, while taking advantage of relevant scientific data that affect nutrient loads (e.g., precipitation, temperature, catchment area, and stream channel attenuation). Furthermore, the proposed smart market accounts for the lumpiness of wetland investments (i.e., the return does not linearly or continuously increase with the investment). The transaction costs of trading are likely to be low, so participants could trade easily and often, possibly online, at least once per season.

This point about transaction costs is an important one. Researchers often use optimization to simulate markets under the assumption of low transaction costs, resulting in wide participation, with predictably positive results. Assuming low transaction costs, a "perfect" market would find the optimum predicted by the optimization. Our simulation has this weakness, but to a much lesser extent than previous such simulations. Previous such studies simulate markets that are or would be cleared using ordinary bilateral exchanges, with high transaction costs. Our market design would be cleared with the same optimization used in our market simulation. The optimization matches supply and demand in many-to-many fashion, simultaneously with all participants. This design would reduce transaction costs, because users do not have