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Can Water Quality Trading Fix the Agricultural Nonpoint Source Problem?

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Abstract

Policy analysts and government agencies promote a particular form of what they term water quality trading as a means to address the most vexing obstacle to meeting water quality standards: reducing nutrient pollutants from agricultural nonpoint sources. However, agricultural nonpoint sources' participation in water quality trading programs will only make limited contributions to lowering overall pollutant loads. We argue that economists need to more clearly articulate the limitations of current and proposed water quality trading programs as a water quality management strategy. A new generation of market-like incentive policies will be necessary to make significant progress in reducing agricultural nonpoint source loads.

1. INTRODUCTION

In the course of less than a generation, the environmental economics field has witnessed a remarkable reversal of policy influence. Since the publication by Dales (1968), environmental economists have proposed the use of transferable discharge (called emissions in the air context) rights as a market-like policy mechanism to achieve environmental goals. Through the 1970s and 1980s, academic interest was generally met with policy indifference or skepticism. Beginning with Title IV amendments of the Clean Air Act in 1990 in the United States, policy support for the use of emission rights trading began to grow and spread nationally and internationally. Emissions trading now stands at the center of policy efforts to combat climate change (Newell et al. 2014).

Interest in trading has spread to water quality policy as government agencies, consultants, and nongovernmental organizations now promote what is called water quality trading. Since the first published trading guidelines (EPA 1996a), US government agencies have devoted considerable resources to implementing pilot water quality trading programs (EPRI 2015, Selman et al. 2009, USDA 2015), developing technical guidance (EPA 2004; Sanneman et al. 2014; Willamette Partnersh. 2012, 2013; Willamette Partnersh. et al. 2015), and building agency expertise (EPA 2007b; USDA 2013, 2015). The number of water quality trading programs being studied, piloted, or implemented is exploding (Breetz et al. 2004, Greenhalgh & Selman 2012, Selman et al. 2009).

Advocates assert that water quality trading will both reduce costs to control pollutant discharges and secure attainment of water quality standards. In particular, they argue that water quality trading can reduce agricultural runoff of nutrients such as nitrogen and phosphorus, called nonpoint source pollution and often the single largest obstacle to achieving water quality objectives. Meanwhile, technical papers that consider comparative costs regularly report that total pollutant control costs can be significantly lowered by water quality trading. However, water quality trading programs involving agriculture, as currently designed and implemented, will make limited contributions to lowering loads or pollutant control costs. We argue that economists need to clearly articulate the limitations of current and proposed water quality trading programs and refine, test, and promote a new generation of market-like policy alternatives to make progress toward reducing agricultural nonpoint source loads and meeting water quality standards.

2. WATER QUALITY POLICY AND CHALLENGES IN THE UNITED STATES

In the United States, policies and programs to reduce pollutants to meet water quality standards are mostly governed by the legal requirements and derivative regulations of the federal Clean Water Act (CWA). Enacted in 1972, the CWA focused on addressing the most visible water quality challenges of that time: pollutants from industrial and municipal wastewater treatment facilities, otherwise known as point sources. A point source is one where it is technically and financially feasible to unambiguously identify a place of discharge or in some way trace a pollutant back to a particular originating location. The US Environmental Protection Agency (EPA) was tasked with developing individual point source limits and describing the amount of a conventional pollutant (e.g., biological oxygen demand, pH, total suspended solids, and fecal coliform) and toxic compounds that may be present in the effluent from a point source. These are technology-based effluent limits (TBELs) because the limit is determined by the ability of the best available technology to remove pollutants from wastewater.

The TBEL is specified in a National Pollutant Discharge Elimination System (NPDES) permit for each point source for each pollutant. The permit specifies the concentration of pollutant in the effluent, maximum allowable effluent flow from the source, effluent load limit (concentration times flow), and in some cases, the pollutant removal technology to be used. Industrial and municipal wastewater treatment permits also require the point source to measure and report the effluent load (flow and effluent concentrations).

Other pollutant sources include stormwater runoff from urban development and agricultural operations, including livestock feeding operations, cropland, and pastures. These are generally known as nonpoint (or diffuse) sources. A nonpoint source is characterized by the lack of technical capacity or by high costs for tracking pollutants entering water bodies to their original source. Nonpoint source discharge is largely stochastic, typically discharging pollutants only during episodic rainfall events and varying with rainfall intensity and duration.

Under the CWA, a nonpoint source is, by default, any source not otherwise described as a point source. This means that the legal definition of a point source is elastic enough to allow sources that were at one time nonpoint and then later reclassified as point sources. For example, federal permitting requirements have expanded to include stormwater runoff from urban areas as a point source. Although stormwater permits do not typically impose numeric limits, the permits require specific actions and processes to be implemented to manage urban stormwater runoff. Agricultural stormwater runoff from fields, however, is the only source explicitly granted an exemption from being defined as a point source under federal law [Section 502(14) of the CWA]. Federal permits, however, have been expanded to cover runoff at the site of large confined animal feeding operations, but these tend to be a small portion of overall agricultural loads.

The CWA also requires attainment of ambient water quality standards. These are comprised of state-assigned designated uses (e.g., swimming, fishing) for each water body and the measurable criteria used to represent the uses (e.g., water clarity, oxygen levels). If the criteria are exceeded, the water is listed as impaired. An impaired listing triggers a planning process, called total maximum daily load (TMDL), designed to identify the cause of the impairment and then determine the load (in pounds) of a pollutant (e.g., nitrogen) that can be present in the water per unit of time based on the watershed's capacity to assimilate waste and still meet the criterion (e.g., water clarity). In effect, the ambient load limit is the result of a social apportioning of the rights to the water between those who benefit from water supply, recreation, aesthetics, or intrinsic values and those who value the waste assimilation service. Then the allowable load is divided into a waste load allocation (WLA) for all the point sources and load allocation (LA) for all the nonpoint sources. If the discharge of pollutants does not exceed the sum of the WLA and LA, with a margin of safety, the water will meet its water quality standard.

If a waterbody is impaired, regulators responsible for implementing the CWA can impose effluent limitations more stringent than the TBEL on point sources, which are called water quality–based effluent limits (WQBELs). A WQBEL can be one that approaches the limit of treatment technology (LOT). These point source limits can be imposed for any pollutant responsible for the impairment, including those such as nutrients that are not identified as a conventional pollutant in the CWA.

Regulators will identify the levels of nonpoint source loads needed to achieve water quality criteria (such as LA), but they have no federal authority to require load reductions from most agricultural sources. Conceptually, state governments could mandate nonpoint source controls, and in some instances, they will require a few select control practices (e.g., vegetated buffers or conditions on manure applications) (Craig & Roberts 2015, ELI 1997, Kling 2013). Far more typically, state and federal efforts to reduce agricultural loads rely on US Department of Agriculture (USDA) and state programs that subsidize the voluntary installation of government-approved effluent load-reducing best management practices (BMPs) from agricultural sources (Ribaudo 2001). These programs face funding limitations and have achieved limited effectiveness in reducing nonpoint source loads sufficiently to improve water quality (NRCS 2011, Osmond et al. 2012, Shortle et al. 2012).

During the first two decades after passage of the CWA in 1972, the water quality standard and TMDL processes remained largely dormant until a series of successful lawsuits in the 1990s accelerated implementation. Today, the TMDL process highlights the reality that discharges from unregulated nonpoint sources are now the primary cause for failure to achieve water quality standards (EPA 1996b, 2007a). Based on the most recent national water quality assessment reports, nonpoint sources represent the largest cause of water quality impairments in the United States (EPA 2016). Based on the rivers and streams that have been assessed, bacteria, sediment, and nutrients are the primary causes of impairment, and agriculture is the most probable source of impairment. For lakes and reservoirs, mercury, nutrients, and polychlorinated biphenyls represent the largest causes of impairment. Atmospheric deposition and agriculture are the top two ranking probable sources of water quality impairment in lakes and reservoirs.

During this time, nutrient (nitrogen and phosphorus) enrichment has also emerged as a major barrier to meeting ambient standards. Excessive nutrient loads are associated with eutrophication, particularly for coastal waters (Howarth 2008, Howarth et al. 2002, NRC 2000). Nutrient loads are a primary cause of poor water quality conditions for many major water bodies, including the Gulf of Mexico, Lake Erie, Chesapeake Bay (primarily Maryland, Pennsylvania, Virginia), the Albemarle-Pamlico Estuary (North Carolina), and Long Island Sound (primarily Connecticut and New York). These watersheds alone represent almost 64% of the total area in the continental United States.

Agriculture, not point sources, is generally the primary source of nutrient loads into most of these receiving waters (Boesch et al. 2001, Carpenter et al. 1998, EPA 2011, Ohio EPA 2010). Agricultural nutrient discharge arises from the large-scale importation of nutrients into a watershed in the forms of fertilizer and animal feed, the latter of which produces manure. For example, agriculture is responsible for the largest share of nutrients within the largest-scale eutrophication challenge in the United States: the Gulf of Mexico (Goolsby et al. 1999; NRC 2008, 2009). The Mississippi River watershed, which represents the vast majority of flow from the United States, drains 1.245 billion square miles and includes all or part of 31 states. Alexander et al. (2008) estimate that agriculture contributes 71% of all nitrogen and 80% of all phosphorus reaching the Gulf of Mexico. By comparison, urban and industrial sources contribute an estimated 9% and 12% of nitrogen and phosphorus, respectively, reaching the Gulf of Mexico.

3. ECONOMIC THEORY OF TRADING AND THE REALITY OF WATER QUALITY TRADING PROGRAMS

It is in this context that advocates promote water quality trading as a solution to contemporary water quality management challenges. Support for water quality trading largely originates from the desire to address agricultural nonpoint source loads, particularly for nutrients. Trading advocates base their support on three arguments. First, agricultural nonpoint sources are the lowest-cost way to reduce effluent loads, making them an attractive potential seller of abatement. Second, financial payments from trading will incentivize agricultural producers to implement agricultural conservation practices. Traditional federal and state funding for cost share subsidies is limited, and trading is viewed as the next generation of agricultural funding for agricultural nonpoint source control (USDA 2013, Willamette Partnersh. 2012). Finally, advocates often argue that water quality trading programs will improve water quality by addressing agricultural nonpoint sources (Blooming horrible 2012, EPA 2008, Perez et al. 2013, Schary & Fisher-Vanden 2004, USDA 2013). Trading proponents often refer to economists' case for cap and trade as a basis for claiming these benefits.

3.1. Cap and Trade

Economists have long argued that meeting socially determined environmental goals can be met in a static and dynamically cost-effective way through markets for discharge rights (Dales 1968). This market-like system, commonly called cap and trade, begins with a social apportioning process that allocates the services of the environment between waste disposal and consumptive and nonconsumptive uses of the water body.[1] With this allocation made, the waste disposal service is allocated to dischargers when the regulatory authority defines a limited number of waste discharge rights. These rights, sometimes called discharge allowances, are time-limited government authorizations to discharge a fixed quantity of a pollutant. Similar to any market system, the rights must be well specified and enforceable. For pollution control policy, discharge allowances must clearly specify the terms under which pollutants can be discharged and grant dischargers the discretion to choose waste control strategies (Shabman et al. 2002). The right must be measurable (e.g., quantity of pollutant discharged), and discharge must be monitored (observed) for compliance. Dischargers who are assigned the legal responsibility to limit effluent load must hold sufficient discharge rights to cover effluent load or face penalties for noncompliance.

The discharge cap is the sum of all discharge rights issued in the system. Conceptually, if every party discharging waste must acquire and hold allowances, then the system is fully capped. In a fully capped system, if the number of allowances issued equals the total allowable discharge, then achievement of ambient water quality objectives is assured. Rights must also be initially allocated to dischargers, either through an administrative process or a bidding process. Any new entrant must first secure allowances before legally discharging.

Discharge sources must also be granted the authorization to transfer rights between users (across space) and across time periods with low transaction costs. Trading of discharge rights effectively allows users to shift pollutant control obligations between users to jointly lower compliance costs of trading participants. Because trades alter the distribution and timing of discharge, trading could impact the achievement of desired environmental objectives. For well-mixed pollutants with no localized damages, trading does raise this risk. When such conditions do not hold, rights definition and exchange conditions must be defined to ensure that trades produce equivalent environmental outcomes. For instance, trade conditions, such as trading ratios, may need to be devised to ensure that trades between sources at different locations or with different effluent characteristics may produce similar outcomes without producing significant adverse third-party impacts (Baumol & Oates 1988).

If such conditions hold, economists expect cap-and-trade systems to produce both desirable environmental and economic outcomes. Discharger discretion on how to manage their own waste stream promotes technical cost efficiencies by allowing dischargers to select and operate effluent control strategies that minimize the cost of achieving any level of abatement. Decentralized allowance trade achieves allocative cost efficiencies by achieving a least-cost allocation of pollution control among all dischargers (equalizing marginal control costs across all dischargers). Though applied economists often focus on static cost effectiveness, the ultimate benefit of such a policy is the ability to achieve social environmental objectives. Fully capped and nonattenuated trading systems ensure achievement of environmental goals by accounting for all effluent loads in the system and providing a mechanism to account for economic and population growth. Price incentives and decentralization of waste control decision-making drive technological innovations in waste

[1]Some economists express interest in the efficiency issues that arise from setting overall levels of waste discharge relative to other uses of the water body. This review assumes the legitimacy of a social apportioning process and does not review the efficiency literature associated with balancing costs and benefits of cap setting.

management, putting downward pressure on both effluent control costs and allowance prices (dynamic cost effectiveness) and making room for new economic activity under an environmental constraint.

3.2. Water Quality Trading in Practice

In practice, trading programs applied in the water quality context represent a vast assortment of program designs, most of which bear little resemblance to what economists would recognize as a cap-and-trade program (King & Kuch 2003, Shabman et al. 2002, Shortle 2013, Stephenson & Shabman 2011). The divergence between the cap-and-trade concept and water quality trading programs is a result of both the nature of managing pollutant loads in a water context (Horan & Shortle 2011, Shortle & Horan 2008) and the institutional conditions and framework imposed by the CWA and its supporting regulatory programs (Jones & Vossler 2014, Shabman & Stephenson 2007, Stephenson et al. 1999). The reasons for the divergence between reality and practice largely explain why most water quality trading programs are poorly suited to addressing agricultural nonpoint pollution. Therefore, the advantages of cap and trade have proven challenging to transfer to current water quality program design and will not address agricultural nonpoint sources.

As evidence for our argument, we review a comprehensive list of existing water quality trading programs. The programs were identified through published surveys and papers and our personal knowledge about water quality trading (EPRI 2013, Fisher-Vanden & Olmstead 2013, Greenhalgh & Selman 2012, Selman et al. 2009, Willamette Partnersh. 2012). This process produced 26 active programs (see **Table 1**). The list excludes a large number of efforts that have been formally studied, suspended (piloted but never implemented), or discontinued (implemented but closed).

Of these active programs, we classify 18 as rule based: These include programs that implement enforceable discharge limits on some set of discharge sources and also include a system of predefined trading rules that determine when and how those sources may pay for reductions from other sources. Permit modifications are another class of programs that the literature also considers to be water quality trading. Permit modifications are one-off agreements between the regulator and an NPDES permittee that allow the permittee to meet a portion of its waste load reduction obligations off-site of the permitted discharge. This is typically done by paying a nonpoint source to make reductions it would not otherwise make (Fang et al. 2005, Shabman et al. 2002, Woodward & Kaiser 2002). **Table 1** includes six examples of NPDES permit modifications. It also includes two well-funded and high-profile demonstration projects in the Ohio River Basin that target agricultural nonpoint sources and are also included in the literature as water quality trading (Keiser & McCarthy 2015, Newburn & Woodward 2011). These two demonstration efforts operate without any mandatory caps on any source. Instead, the funds used for making the payments are from research grants and donations (EPRI 2013, Stephenson & Shabman 2011).

3.3. Water Quality Trading Programs Do Not Bring Agricultural Sources Under a Cap

No active water quality trading programs cap agricultural source loads. Of the 18 rule-based trading programs identified, 14 establish mandatory numeric limits on municipal and industrial wastewater dischargers to control nutrients (nitrogen and/or phosphorus). However, note that in 11 of these 14 programs, point sources are not the dominant source of nutrient loads, so most of the load is outside of the cap (see **Table 1**).

A nonpoint source is not necessarily one that escapes NPDES permitting. In fact, six rule-based trading programs place control requirements on urban nonpoint sources. These programs then

Table 1 Operational water quality trading programs in the United States

Trading program	State	Pollutant	Regulated party	Regulated load (%)
Rule-based programs				
Bear Creek	CO	P	Point	20–35
Chatfield Reservoir	CO	P	Point	29
Connecticut Long Island Sound	CT	N	Point	73
Dillion Reservoir	CO	P	Point	Unknown
District of Columbia Stormwater	DC	Stormwater volume	New urban development	NA
Lower St. Johns River Basin Trading	FL	N, P	Point	47 N, 47 P
Maryland Chesapeake Bay Nutrient Trading	MD	N, P	Point	26 N, 23 P
Minnesota River Basin Trading	MN	P	Point	65
Neuse River Falls Lake	NC	N, P	Point, new and existing urban development	24 N, 37 P
Neuse River Jordan Lake	NC	N, P	Point, new and existing urban development	32 N, 16 P
Neuse River Point Source Association	NC	N	Point	34
Neuse River Stormwater Offsets	NC	N, P	New urban development	NA
Pennsylvania Chesapeake Bay	PA	N, P	Point	11 N, 25 P
Red Cedar River Nutrient Trading	WI	P	Point	7
Tar Pamlico	NC	N	Point	8
Virginia Stormwater Offsets	VA	P	New urban development	NA
Virginia Chesapeake Bay, Point	VA	N, P	Point	27 N, 18 P
Virginia Chesapeake Bay, MS4	VA	N, P	Existing urban stormwater	11 N, 8 P
Permit modifications				
Alpine Cheese (Sugar Creek)	OH	P	Point	Unknown
Clean Water Services, Tualatin	OR	Temperature	Point	6
Delaware Inland Bay	DE	N, P	Point	6 N, 30 P
Medford City, Rogue River	OR	Temperature	Point	Unknown
Rahr Malting	MN	CBOD5	Point	Unknown
Southern MN Beet Sugar Coop.	MN	P	Point	10 N, 37 P
Demonstration trading programs				
Great Miami River	OH	N, P	Point	Unknown
Ohio River Basin Trading	OH	N, P	Point	Unknown

Abbreviations: CBOD5, carbonaceous biochemical oxygen demand; N, nitrogen; NA, not applicable; P, phosphorus.

allow those sources some flexibility to pay other unpermitted sources to reduce their loads by an equivalent amount (see **Table 1**). Most of these programs require urban land developers to meet limitations, either as the volume of stormwater discharge or the concentration of nutrients in the discharge, when the runoff is from lands being converted to buildings and roads. These programs are often called offsets because the regulators require new sources of discharge to offset loads. Virginia and North Carolina, however, are implementing programs that aim to cap nutrient loads from all existing urban sources. These programs establish numerical nutrient limits for municipalities managing urban stormwater drainage systems, called municipal separate storm sewer systems (MS4s).

Note that, whereas the measurement of nonpoint source loads is difficult, regulations still impose load limits. This means that in these urban nonpoint source trading programs, the load of pollutants in the stormwater runoff is not measured directly but estimated with models that assign pollutant loads to different land uses (e.g., pounds/acre for lawn, forest, pavement). Regulators identify a variety of control technologies, or BMPs, that may be used by the regulated party and are predicted to reduce pollutant loads. The modeling process assigns removal efficiency estimates for each control technology (percent removal effectiveness). Multiplying land-use load estimates by removal efficiencies of installed practices produces a load reduction estimate. The stochastic nature of actual discharge is typically reduced to average load estimate, or the standard is written to meet an effluent limitation from a specific rain event (e.g., the two-year storm event). Monitoring and enforcement are based on maintaining and verifying the functioning of control structures/technologies. No sampling of runoff is required to demonstrate control technology performance.

Given that urban nonpoint sources are being capped and load limits are imposed, what explains the absence of load limits on agriculture? Although agriculture loads are large in aggregate, individual contributions to the total can be small, dispersed over a large area, and can arise from multiple parties. Loads can be estimated using models, but the transaction costs of reporting and verifying actions from numerous small sources with multiple and complex production systems are high. Within the urban stormwater context, the number of sources is relatively small. In the case of MS4s, one permittee is solely responsible for loads within a large area, and the MS4s already track stormwater control structures (BMPs) under their jurisdiction. Furthermore, monitoring behavior can be more difficult with agricultural producers because some agricultural management practices, such as fertilizer or manure application methods and rates, are more difficult to monitor than the presence of a structural control practice (urban stormwater practices mostly involve physical control structures).

Although these challenges can be overcome in some situations (see discussion below), there are also legal and political reasons for no caps on agricultural runoff. As noted above, the CWA explicitly exempts agriculture from federal law, and states have generally been unwilling to fill the federal CWA void and impose requirements on agriculture. Furthermore, agricultural groups have been politically successful in opposing major new regulatory efforts (Craig & Roberts 2015).

Given the relative contribution of agricultural nonpoint source loads and the lack of legal requirements to limit discharge, the extent to which water quality improvements can be made by regulating or capping municipal and industrial wastewater or urban stormwater sources is limited. These partially capped programs can only make limited progress toward achieving water quality objectives because the regulated sector usually represents a relatively small share of total pollutant loads, particularly for nutrients.

The Chesapeake Bay provides a useful illustration. In the mid-1980s, state and federal officials began a concerted effort to reduce nutrient (nitrogen, phosphorus) loads to the bay. To date, the Chesapeake Bay water quality program is the most expansive regulatory effort to manage a regional water quality issue in the United States. The Chesapeake Bay watershed encompasses both large urban population centers (Baltimore, Washington, DC, and Richmond) as well as agricultural production areas that include high concentrations of confined animal operations. In 2015, 45% and 55% of all the nitrogen and phosphorus, respectively, reaching the Chesapeake Bay came from agricultural sources (**Table 2**). Approximately one quarter of the nutrient discharge comes from municipal/industrial point sources and MS4s (**Table 3**).

Table 2 Distribution of nutrient loads in the Chesapeake Bay[a]

Source sector	Nutrient load distribution, 2015		TMDL nutrient reduction goals, 1985–2025		Additional reductions needed to meet TMDL (1,000s of pounds/year)[b]	
	N (%)	P (%)	N (%)	P (%)	N	P
Point sources	15	15	57	70	−954.7	−590.3
Agriculture	45	55	49	35	36,347.5	1,328.1
Forest	18	10	0	1	1,399.0	−55.2
MS4 stormwater	10	9	11	26	6,883.6	306.6
Nonregulated urban stormwater	7	8	22	29	5,214.1	297.3
Septic	4	0	22	NA	2,386.6	NA
Other	2	1	79	20	1,082.3	15.0

[a]Data accessed from the US Environmental Protection Agency's Chesapeake Bay TMDL tracking database, October, 2016 (**https://ofmpub.epa.gov/waters10/attains_index.home**).
[b]Negative numbers indicate that the source sector total loads meet or exceed the 2025 reduction goals.
Abbreviations: MS4, municipal separate storm sewer system; N, nitrogen; NA, not applicable; P, phosphorus; TMDL, total maximum daily load.

In the 2000s, the EPA developed the nation's largest TMDL. The Chesapeake Bay TMDL identified the nutrient reduction targets believed necessary to achieve water quality standards across the bay by 2025. Consistent with the philosophy of the CWA, federal and state regulators required industrial and municipal point sources to achieve the largest reductions in nitrogen and phosphorus mass loads (57% and 70% reduction in loads, respectively, since 1985) (see **Table 2**). Though point sources have collectively achieved this aggregate reduction, other source sectors have not. Agriculture remains by far the single biggest impediment to achieving the Chesapeake Bay's nutrient reduction targets. Of the nearly 50 million pounds of nitrogen reduction still needed to meet TMDL targets, agriculture needs to reduce nitrogen loads by 36 million pounds. Clearly, partial caps on regulated sources are insufficient to achieve water quality objectives in the bay.

The role of agricultural sources in nutrient-related water quality impairments is even more pronounced in the Mississippi River drainage basin. EPA estimates that a 45% reduction in overall nutrient loads will be needed to adequately address the hypoxia issues in the Northern Gulf of Mexico (EPA 2015). Although regulatory agencies have yet to implement a TMDL or establish mandatory nutrient caps on any sources in the Mississippi River watershed, even draconian regulatory requirements on nutrient loads from urban regulated sources that represent less than 15% of the total nutrient discharge will make only a marginal contribution to meeting nutrient reduction goals for the Gulf of Mexico.

3.4. Point–Nonpoint Trading

Given the lack of caps on agriculture, the question becomes: Can water quality trading programs address agricultural nonpoint sources? The form of water quality trading that generates the most interest in water policy is called point–nonpoint trading. In point–nonpoint trading programs, regulated sources, such as municipal and industrial point sources, face enforceable effluent limits or caps. These sources are then allowed meet a portion of their regulatory obligations by purchasing pollutant reduction credits from uncapped agricultural nonpoint sources. Of the 26 water quality trading programs identified, 24 incorporate nonpoint sources, and most of these involve

Table 3 Operational water quality trading programs and pollutant source(s) in the United States

Trading program	Largest pollutant source	Potential sellers	NPS actions	Ag NPS trades
Rule-based programs				
Bear Creek	Unspecified NPS	PS, NPS	Restoration	Yes
Chatfield Reservoir	Unspecified NPS	PS, NPS	Ag BMPs	No
Connecticut Long Island Sound	PS	PS	None	No
Dillion Reservoir	Unspecified NPS	NPS	Septic retirement	No
District of Columbia stormwater	Urban development	Urban NPS	Stormwater retention	No
Lower St Johns River trading	PS	PS, NPS	Ag BMPs, restoration	No
Maryland Nutrient Trading	Ag NPS	NPS	Ag BMPs	No
Minnesota River Basin Trading	PS	PS	None	No
Neuse River Falls Lake	Ag NPS	PS, NPS	Land restoration	Yes
Neuse River Jordan Lake	Unspecified NPS	PS, NPS	Land restoration	Yes
Neuse River Point Source Association	Ag NPS	PS, NPS	Land restoration, Ag BMPs	No
Neuse River Stormwater offsets	Ag NPS	NPS	Land conversion (buffers)	Yes
Pennsylvania Chesapeake Bay	Ag NPS	PS, NPS	Ag BMPs	Yes
Red Cedar River nutrient trading	Ag NPS	NPS	Ag BMPs	Yes
Tar Pamlico	Ag NPS	PS, NPS	Ag BMPs	No
Virginia stormwater offsets		NPS	Land conversion	Yes
Virginia Chesapeake Bay, point	Ag NPS	PS, NPS	Ag BMPs, land conversion	No
Virginia Chesapeake Bay, MS4	Ag NPS	PS, NPS	Ag BMPs, land conversion	No
Permit modifications				
Alpine Cheese (Sugar Creek)	Ag NPS	NPS	Ag BMPs	Yes
Clean Water Services, Tualatin	Rural NPS	NPS	Land conversion	Yes
Delaware Inland Bay	Ag NPS	NPS	Land conversion, Ag BMPs	Yes
Medford City, Rogue River	Rural NPS	NPS	Land conversion	Yes
Rahr Malting	Unknown	NPS	Ag BMPs, land conversion	Yes
Southern MN Sugar Beet Coop.	Ag NPS	NPS	Ag BMPs	Yes
Demonstration programs				
Great Miami River	Ag NPS	NPS	Ag BMPs	NA
Ohio River Basin Trading	Ag NPS	NPS	Ag BMPs	NA

Abbreviations: Ag, agricultural; BMP, best management practice; NA, not applicable; NPS, nonpoint source; PS, point source.

agricultural nonpoint sources (see **Table 3**). These programs allow regulated sources to trade with sources outside of a cap. Two programs, Connecticut Long Island Sound and Minnesota River, only allow trades between regulated point sources under a cap.

But could point–nonpoint trades help meet water quality standards by producing net reductions in pollutant loads? A regulated point source that bought agricultural nonpoint source credits would only purchase enough agricultural reductions to match the allowed increase in point source loads. Although such a trade may reduce point source compliance costs, overall pollutant loads remain unchanged. Therefore, to achieve net reductions in pollutants through this form of trading, hope is pinned on two approaches that, in effect, tax cap (i.e., NPDES permitted) sources and use the revenues to pay for more than equivalent compliance. The first approach requires net nonpoint source reductions for every trade. The second one imposes requirements on regulated sources that are technologically unachievable at the source.

To better appreciate how such net reductions in total load can occur, it is necessary to describe the basics of how point–nonpoint source trading occurs. Trade with sources outside of a cap creates challenges in defining a transferable asset for the uncapped source. Because agricultural nonpoint sources are not assigned responsibility to limit discharge, no predefined right to discharge exists. To create a transferable asset, called a reduction credit, regulatory authorities must define a reference point, called a baseline, from which the nonpoint source can begin counting reductions in pollutant loads. The credit (defined in mass load terms, pounds/year) is the difference between the quantity of effluent released and the baseline quantity. In point–nonpoint trading programs, the nonpoint source baseline and discharge are quantified using models (similar to measuring urban nonpoint source loads discussed above) (Saleh et al. 2011). Unlike a cap-and-trade system where the asset to be traded is defined a priori by the government, nonpoint source credits are created at the discretion of the party wishing to claim and then sell a reduction in pollutant load.

Designers of water quality trading programs can produce net pollutant reductions from a nonpoint credit trade in several ways. Regulators may require an explicit retirement ratio on all trades. A retirement ratio requires the regulated source to purchase more reductions than is required to meet the point source's discharge control obligation. Virginia, for instance, requires that 5% of nutrient credits be retired in every trade.

Similar outcomes can also be achieved by manipulating the nonpoint source credit baseline (Ribaudo et al. 2014). For instance, nonpoint source baselines could be set below existing levels of discharge. Under such a baseline policy, agricultural credit suppliers would first need to reduce effluent discharge to baseline before credits are awarded (baselines may be set to reflect nonpoint source load reduction goals in a TMDL). Thus, a nonpoint trade generates two nonpoint source reductions: one level of reduction to meet baseline and the second reduction to generate credits for sale. Ribaudo et al. (2014) found that total additional reductions generated by meeting baseline vary with the stringency of the baseline and may increase with less stringent baselines.

Some argue that point–nonpoint trade could also produce net reductions in nonpoint source loads through the imposition of uncertainty trading ratios (Perez et al. 2013). Most trading programs impose a point–nonpoint trading ratio to account for the uncertainty surrounding nonpoint source loads (Fisher-Vanden & Olmstead 2013, Shortle & Horan 2008). Nonpoint source loads are quantified through models and verified through observations of on-farm structural and management practices. Both are subject to considerable and unknown error. Temporal variations in discharges due to stochastic weather patterns are largely ignored. Regulators often require regulated sources with measurable loads to purchase additional estimated nonpoint credits to account for this uncertainty. The common 2:1 trading ratio requires an estimated 2 pounds of estimated nonpoint source reduction for every measured 1 pound of measured point source load. If the trading ratio does indeed account for uncertainty, however, it appears to cast doubt on the legitimacy of claiming net reductions from the application of an uncertainty ratio.

The second avenue to obtain net reductions is to set effluent limitations or caps low enough that trades are required for compliance. Under the Chesapeake Bay TMDL, the EPA (2009) has stated that a state's failure to make adequate progress in reducing nonpoint source loads could trigger federal actions that require point sources to fund reductions at other sources in the watershed. One option, called a net improvement offset, would require new and expanding point sources to more than offset any new loads (e.g., a 100-unit increase in loads would require a 150-unit reduction in the watershed). The EPA also threatened to lower mass load caps on point sources. Caps are already set at near limits of technology in most Chesapeake Bay states. Of course, the explicit motivation for trading in these situations is not to reduce compliance costs for regulated sources but to generate revenue to finance nonpoint source reductions (Stephenson & Shabman 2011).[2]

3.5. Point–Nonpoint Trading Will Not Secure Net Reductions in Pollutant Loads

The distribution of pollutant loads between regulated point sources and nonpoint sources makes it unlikely that point–nonpoint trading can generate enough net reductions to achieve water quality standards (see **Table 2**). However, point–nonpoint trading could potentially make modest contributions to reducing net agricultural nonpoint loads if specific rules were in place and vigorous trading activity occurred. Multiple factors make achieving these modest reductions highly improbable.

Empirical studies consistently report the potential for vigorous trading activity between point sources and agricultural nonpoint sources based on regulated source incentives to reduce compliance costs (Faeth 2000, Fang et al. 2005, Hanson & McConnell 2008, Jones et al. 2010, Perez et al. 2013, Ribaudo et al. 2005, Shortle et al. 2014, Van Houtven et al. 2012, Wainger et al. 2013). Empirical studies estimate that agricultural nonpoint sources can achieve pollutant reductions at a low marginal cost. Nonpoint source credit supply (agricultural producers' minimum willingness to sell pollutant reduction credits) is modeled as the nonpoint source marginal pollutant abatement cost function. The potential gains from trade occur because analysts estimate that point source control costs are higher. The point source credit demand (maximum willingness to pay for nonpoint source credits) is typically assumed to be the cost function of point sources' marginal pollutant abatement. Cost-minimizing solutions suggest positive credit prices (where marginal control costs across sources are equalized) and significant reallocation of loads between point and nonpoint sources through trading.

These empirical studies, however, just as consistently fail to reflect the level of point–nonpoint trading that actually occurs with program implementation. Despite large public investments in the development of trading infrastructure and pilot programs, the reality is that point–nonpoint trading programs have produced very little trading activity with agricultural nonpoint sources (EPA 2008, Fisher-Vanden & Olmstead 2013, King 2005).

Reviewing the evidence for existing trading programs shows that rule-based trading programs for municipal and industrial wastewater sources (traditional point sources) rarely produce even a single trade with agricultural sources (see **Table 3**). The trading activity that does occur generally happens in two other situations. In rule-based programs, nonpoint source trading involving agriculture is largely confined to situations concerning stormwater runoff from new urban developments (e.g., North Carolina and Virginia programs). In these programs, developers can avoid some on-site urban stormwater controls by purchasing agricultural credits generated from land conversion activities (e.g., converting agricultural land to forest) or landscape restoration activities (e.g., stream restoration or riparian buffer expansion). Thus, these programs generate credits by permanently taking land out of agricultural production. The other situation in which nonpoint source trades occurs is for isolated individual permit modifications. On a watershed scale, these volumes represent small quantities relative to overall agricultural loads.

Economists and policy analysts have examined many potential explanations for the lack of trading activity between regulated dischargers and agricultural nonpoint sources. Analysts tend to focus attention on agricultural nonpoint sources and the barriers to agricultural producer

[2] Such systems appear to be on questionable legal grounds. Under US law, administrative agencies such as the EPA do not have the legal authority to impose a tax.

participation. However, increasing evidence suggests that the challenges confronting point–nonpoint source trading programs come from the inability or unwillingness of regulated sources to buy agricultural nonpoint source credits.

3.5.1. Nonpoint source credit supply will be limited. One well-recognized challenge confronting the supply of nonpoint source credits is the conditions put in place to address uncertainty. Uncertainty trading ratios, for example, raise the cost of nonpoint source credits. The typical 2:1 trading ratio doubles nonpoint source credit cost. Yet this alone does not explain the lack of trade because such requirements are easily accounted for in empirical cost effectiveness studies. Baseline policies can also have a substantial impact on the cost of producing nonpoint source credit (Ghosh et al. 2011, Motallebi et al. 2017, Ribaudo & Gottlieb 2011, Ribaudo et al. 2014, Stephenson et al. 2010).

Beyond program rules, agricultural nonpoint source credits may have high transaction costs (Motallebi et al. 2017). Beyond the opportunity costs of installation, the transaction costs of producing a nonpoint source credit include evaluating credit generating alternatives, developing and renewing contracts, and monitoring and verifying contracts/practice adoption. Many pollutant-reducing agricultural practices with low implementation costs identified in the literature may have high transaction costs. For instance, low implementation cost agricultural BMPs tend to be management practices on working lands (e.g., tillage practices, cropping practices such as cover crops, nutrient application practices). Yet Deboe & Stephenson (2016) estimate that the transaction costs may be three to six times higher for these practices than more expensive and long-term reduction options, such as converting agricultural land to forest or implementing forested buffers.

Some researchers speculate that agricultural producers may be leery about entering into contracts with regulated sources. As a result, farmers may require a premium above control costs before supplying credits (King & Kuch 2003, Wainger & Shortle 2013). A recent empirical study estimating farmers' premiums required to produce a nonpoint source credit could more than double nonpoint source credit prices (Motallebi et al. 2016). Breetz et al. (2005) suggest that agricultural participation can be enhanced by coupling nonpoint source trading systems within existing and trusted communication and social networks.

Finally, the supply of nonpoint source credits can be limited by restricted choices for BMPs that are accepted for crediting (Ribaudo & Gottlieb 2011). Nonpoint source trading programs quantify nonpoint source loads and credits through the use of models. Given the challenges of modeling complex production and physical systems, these models include a limited number of preselected BMPs. Agricultural producers can only produce a credit from a practice included in the model. Sometimes trading program administrators restrict BMP choices to match the characteristics of the impact. For example, stormwater offset programs allow developers to purchase credits to offset loads from permanent changes in the landscape (e.g., buildings). Consequently, regulators in Virginia and North Carolina require nonpoint source credits to be produced by permanent changes in the landscape, such as permanent land conversion or restoration. Limiting the control options for agricultural sources restricts alternatives and increases costs.

3.5.2. No demand for nonpoint source credits. The demand side challenges that confront point–nonpoint trading programs are generally acknowledged but not as thoroughly characterized. Some researchers investigate whether the lack of demand may be attributed to trading areas that are too small or too thinly populated with regulated sources to generate a sufficient number of potential buyers (Greenhalgh & Selman 2012, Ribaudo & Nickerson 2009). Yet most programs listed in **Tables 1** and **3** have multiple potential nonpoint source credit buyers. In areas with sufficient buyers, the lack of nonpoint credit trades has been attributed to an unwillingness of regulators to impose stringent enough load reduction requirements that would drive up point source marginal control costs, frequently referred to as regulatory drivers (King 2005, Ribaudo & Gottlieb 2011). In the TMDL context, point sources typically face very aggressive permit requirements (e.g., Chesapeake Bay). In the face of water quality impairments, regulators have both the incentive and ability to achieve as much pollutant control as possible through the sources over which they have permitting authority: point sources.

Rather, weak demand for agricultural nonpoint credits is complexly tied to a significant degree to the structure of trading rules and institutional structure of the CWA and derivative regulations that limit choices and influence the preferences of regulated sources. The disincentives and conditions emerging from a complex permitting structure and multiple regulatory conditions can radically dampen the willingness and ability of regulated sources to pay for nonpoint source credits (Stephenson & Shabman 2011, 2017b). These factors are often related to CWA regulatory programs and include (*a*) direct regulatory requirements that limit trade opportunities with nonpoint sources, (*b*) complex overlapping regulatory requirements that diminish the incentive to trade, and (*c*) regulatory compliance preferences of dischargers.

Permitting programs under the CWA actively and consistently follow a regulatory sequencing process that first aims to reduce the on-site impacts of any discharge activity (Hodge & Cutter 2012, Shabman & Scodari 2005, Stephenson & Shabman 2011). The explicit goal of the CWA is the elimination of pollutant discharge into US waters, and regulators are instructed to devise and progressively lower TBELs on regulated sources to achieve that goal. Furthermore, the CWA requires that once regulators establish TBELs, dischargers can never be permitted to exceed the limitations at the discharge source (called antibacksliding). Some argue that strict adherence to on-site effluent limits also applies to WQBELs (Corrigan 2015). This philosophy is reflected in regulatory rules and executive orders. For example, the Obama Administration (White House 2015) recently issued a memorandum promoting the use of regulatory credit trading programs but only after the avoidance and minimization of impacts.

This sequencing logic is pervasive in all types of water quality trading programs and significantly limits discharger choices for any off-site compliance option by design (Stephenson & Shabman 2011). Maryland, for example, requires every wastewater point source to meet the same LOT nutrient concentration limit at the facility. Maryland point sources are only allowed to purchase nonpoint source credits to offset unavoidable new growth in wastewater flows. Virginia funds a capital grant program for wastewater plants installing nutrient removal technologies. Once installed, Virginia issues permits with nontradable numeric nutrient concentration limits. The wastewater facility must meet these limits regardless of the cost advantages of having another source do equivalent levels of control (Stephenson & Shabman 2017b). Stormwater permitting programs in Virginia and North Carolina all require specific levels of controls that must be met on-site. The CWA requires that MS4s maximize the installation of stormwater controls to the maximum extent practicable.

In fact, the overriding objective of many trading programs, including point–nonpoint trading, is not to allocate pollutant control responsibility among capped sources, but rather to help regulators transition to more stringent effluent limitations for regulated sources (typically for nutrients). Connecticut's nitrogen trading program for Long Island Sound is a useful illustration. A TMDL required point sources to achieve a nearly 58% reduction in nitrogen loads across 70 municipal wastewater plants. The state agreed to help finance the necessary capital upgrades but needed a way to keep plants compliant with uniform reduction requirements as construction upgrades were phased in. The trading program has been held up as a success for producing trades, but the trading revolves around trading construction schedules for nitrogen effluent limitations at the point sources (EPA 2008).

In addition, regulated dischargers also face a suite of regulatory obligations that may override trading options for a single pollutant. For example, MS4s often face local water impairments because of adverse impacts associated with urban runoff (e.g., pathogens, aquatic life support due to stream erosion). MS4 efforts to meet local water quality standards involve implementing technologies to treat and reduce the volumes of urban runoff. Most of these same technologies also address downstream nutrient-related impairments. Given the joint production of pollutant control outcomes, multiple regulatory requirements can reduce an MS4's willingness to purchase agricultural nonpoint sources outside its jurisdiction (Stephenson & Shabman 2017b).

Research and experience also find evidence that dischargers are willing to pay a premium to achieve compliance with technologies and control practices under their direct control. This general preference is observed under the most favorable trading conditions, such as low credit prices and low transaction cost trades with other point sources.

Under CWA permitting, regulatory risks of noncompliance create a premium for managing pollutants under the permittee's control. Unlike the Clean Air Act, the CWA does not explicitly authorize the use of trading for compliance purposes. The lack of explicit statutory authorization also opens up the permittee to legal challenges (Corrigan 2015). Under the CWA's five-year NPDES permits, pollutant control responsibility cannot be transferred to another party (Stephenson et al. 1999). Thus, if a federal CWA permittee buys credits, the permittee is still legally responsible for the reductions being undertaken by the credit seller. Thus, engaging in a trade requires that the permittee relinquish some control over permit compliance to a third party. Note, however, that this risk does not apply to permittees under most urban stormwater offset trading programs. The permit for construction activities is a one-time temporary permit. Thus, when a developer purchases a nonpoint source offset, the responsibility for maintaining that phosphorus reduction is transferred to a third party. The ability to transfer legal responsibility may partly explain why nonpoint source credit demand in Virginia and North Carolina comes largely from developer demand for stormwater nutrient offsets.

Experimental research supports these observed patterns of compliance behavior. The permit obligations of wastewater point sources and municipal MS4s are long term and ongoing. The technologies necessary to meet these obligations by the permittee are irreversible, with high up-front costs. The useful life of pollution control equipment and structural urban stormwater practices typically spans 20–30 years. Under these conditions, experimental research finds that dischargers tend to overinvest in the high-cost capital-intensive technology (Jones & Vossler 2014, Suter et al. 2013). Jones & Vossler (2014) also found that how the transferable commodity is defined (versus an allowance) would also dampen point source incentives to use trading as a compliance option.

Point sources also face transaction costs of using agricultural nonpoint credits. Agricultural nonpoint source practices generally do not match well with the scope and duration of the compliance needs of many NPDES permittees. Industrial and municipal wastewater permittees face long-term obligations for relatively large volumes of wastewater. Many agricultural BMPs are short-term management practices and generate a relatively small number of credits per acre. Thus, to achieve permit compliance through agricultural nonpoint source credits, the permittee with a modest plant upgrade would require multiple contracts with farmers/landowners covering thousands of acres with frequent renewals (Stephenson et al. 2010). The transaction and coordination costs for such practices would not be faced with other types of compliance alternatives.

3.6. Nonpoint Source Trades: Uncertainties in Achieving Expected Outcomes

Finally, if a point–nonpoint trade actually occurs, will it produce the expected water quality outcome? Point–nonpoint trading programs face multiple sources of uncertainty in attempts to ensure water quality equivalency between point and nonpoint discharges. Trading programs include general policies such as uncertainty ratios to ensure that changes in point and nonpoint loads produce the same water quality impact. However, in practice, the level and types of uncertainty are not well characterized.

Quantifying nonpoint source loads involves uncertainty about the level of nonpoint control practice implementation, operation, as well as maintenance and modeling uncertainty about the fate and transport of nutrient loads and runoff volumes (Ribaudo et al. 2010). Quantification of nonpoint source credits from a BMP requires documenting the implementation of the practice. Operation and maintenance are more easily observed and verified for some types of BMPs than for others. For instance, the implementation of streambank fencing (for livestock exclusion) and cover crops can be relatively easily verified. In contrast, changes in nutrient application rates from nutrient management plans and animal waste storage practices are common on farms but less easily observed and verified (Jackson-Smith et al. 2010).

How well models predict actual loads is also subject to uncertainty. Water quality models tend to be deterministic, and sources of uncertainty are frequently not quantified. In a review of intensive watershed studies of agricultural BMP implementation and performance, Osmond et al. (2012, p. 125A) found that the "complexity and nonlinear nature of watershed processes overwhelm the capacity of existing modeling tools to reveal water quality impacts of conservation practices." Some studies have attempted to identify a direct linkage between BMP implementation and measured watershed outcomes. Even in instances involving a considerable level of BMP adoption, it has been challenging to link the level of BMP implementation to improvements in water quality (Inamdar et al. 2001, Osmond et al. 2012).

Trading with nonpoint sources involves other sources of uncertainty (Stephenson & Shabman 2017a, Stephenson et al. 2009). Credit trading outside a cap creates a number of accounting and right attenuation issues that can produce net increases in effluent discharges. Risks exist regardless of whether credits produce additional effluent reductions (additionality) (Duke et al. 2014, Miller & Duke 2012, Ribaudo & Savage 2014, Woodward et al. 2016). If credits are awarded to activities that have already occurred or that will occur without the trade (nonadditional), then the credit buyer will be allowed to increase loads without achieving any new offsetting reductions. Trades with uncapped credit systems create incentives for credit generators who are already below baseline to claim credits without undertaking any new actions to reduce effluent loads.

Leakage is the induced and unaccounted for increases in load due to transaction (Stephenson & Shabman 2017a). Leakage is a concern with nonpoint source credit trading because there is no comprehensive physical and legal accounting for nonpoint source loads. In most trading programs, program administrators award nonpoint source credits based only on the acres treated by the BMP. This requirement simplifies credit calculations but implicitly assumes that all other activities and loads on remaining agricultural lands remain constant. The installation of forested buffers may take productive bottomland out of production, prompting the farmer to bring additional upland acres under cultivation. If the intensified upland use increases nutrient loads, and this induced load change is not part of a credit calculation procedure, leakage occurs. Bonham et al. (2006) found that incentives exist to create leakage on farms required to adopt riparian buffers or phosphorus-based nutrient management plans.

4. DISCUSSION: PROSPECTS AND ALTERNATIVES TO WATER QUALITY TRADING

As currently implemented, water quality trading programs will not make an appreciable impact in addressing agricultural nonpoint source loads. Water quality trading programs are designed around mandatory caps for sources that contribute a relatively small share of pollutant loads. The obstacles confronting point–nonpoint trading will hinder the achievement of even modest net reductions in aggregate pollutant loads.

Economists interested in enhanced programs for water quality management can offer many alternatives to point–nonpoint trading to water quality managers who must secure reductions in agricultural nonpoint source loads. There is no dearth of conceptual ideas. Economists have produced extensive reviews on general classes of policy instruments to address nonpoint source pollution (Dosi & Tomasi 1994; Kling 2011; Segerson 2013a,b; Shortle & Horan 2001, 2013; Shortle et al. 2012; Xepapadeas 2011).

The challenge, however, is putting these ideas into practice. We conclude with some illustrative examples of policy alternatives that rely on the principles of market-like designs: the creation of incentives for producing measurable outputs and delegation of decision-making authority to the sources facing the incentives.

We begin with the observation that there is no single agriculture. Agricultural nonpoint source pollution originates from extremely diverse agricultural production systems. These production systems can contribute nutrients and other pollutants in different intensities and different compositions (including different species of nitrogen and phosphorus). The industrial organization of agricultural production systems differs at both the firm- and market-structure levels. These characteristics will be important in tailoring the design of market-like policy alternatives that can make significant contributions to reducing agricultural pollutants and that can be plausibly implemented.

Opportunities exist within agriculture to make both a significant and positive impact on water quality with market-like incentive policies. Plausible implementation requires addressing how outcomes will be measured and identifying the appropriate management entity. Economists have explored the conceptual possibility of using cooperative organizations to achieve ambient outcomes (Segerson 1998, Taylor et al. 2004). Variations of this basic idea have been implemented or piloted. North Carolina requires counties in nutrient-impaired watersheds to work with agricultural producers to meet county-wide agricultural reduction goals. Although compliance is based on modeled outcomes, the policy is backstopped by mandatory technology standards, such as riparian buffers. Maille et al. (2009) piloted a program that incentivized a voluntary association of landowners to reduce observed (measured) nitrogen levels at the outlet of a small watershed.

In other cases, modeling capabilities render the incorporation of agricultural sources under a sector cap technically possible (Kling 2011). Similar to some emerging stormwater programs, agricultural controls and compliance would be based on the implementation of observable BMPs rather than measured outcomes. Trading elements could also be incorporated. Such programs would trade off lower monitoring and measurement costs with less certainty in pollutant outcomes and less discharge discretion regarding the choice of abatement options.

Payments for ecosystem services (PES) strive to move voluntary incentive programs away from the installation of practices to achievement of outcomes. PES programs involve the following fundamental features. First, they identify environmental services (e.g., reduced nitrogen and phosphorus loads) valued by buyers willing and able to pay for them, including federal and state governments. Second, because buyers want to purchase environmental results, not just land and BMPs, they define performance goals and evaluate practices in relation to those goals. Third, because they are designed to encourage innovation, PES offer participants' discretion in the practices undertaken to meet a performance goal. Fourth, PES mechanisms allow buyers and sellers to negotiate a price and then enter into contracts governing the terms and conditions under which payments will be made; payments are made after documenting the quantity of the services produced. PES programs with these features have been implemented for large-scale cattle operations in Florida (Shabman et al. 2013).

This Florida PES experience, which is based on monitoring outflows at tile drains, can inform the design of policies elsewhere. For example, in large areas of the US Midwest, landowners have installed ditches and underground drains to keep lowland fields dry, and these artificially drained lands are particularly susceptible to nutrient losses (Randall et al. 1997, Sims et al. 1997). These areas are often served by drainage districts with revenue-generating capacity and management responsibilities over the drainage system. The drainage districts could also provide management oversight and coordination to lower administrative costs and coordinate nutrient management efforts. Tailoring policies to these artificially drained systems offers potentially fruitful opportunities for market-like policy advancements because of the existence of a large-scale management entity, technologies to treat or retain nutrients, and opportunity to observe flow and/or concentrations.

Animal waste management offers another potential area for policy innovation. Significant portions of the livestock industry (poultry and pork in particular) are vertically integrated and concentrated in geographic areas where the importation of nutrient exceeds local assimilative capacity. These situations are associated with high rates of nutrient loss (Beegle 2013). Although land application of animal manure has agronomic benefits, the characteristics of manure can contribute to high nutrient losses because its nutrient content is variable and does not match crop needs (e.g., manure tends to be relatively high in phosphorus), and manure is costly to transport. Currently, farmers who contract with a vertically integrated company typically do not own the animals being raised, but the farmers do own all of the manure produced by the animals. The farmer can land apply the waste, but they may find it challenging to do so at acceptable agronomic rates given animal densities in the region.

One policy alternative for animal agriculture would be to reassign ownership rights to the manure along with the nutrient requirements for its disposal to the company. The vertically integrated company has the management capacity and access to capital unavailable in the current system to develop system-wide alternatives that can lower nutrient losses. Vertically integrated companies have the potential to lower costs due to the availability of treatment technologies, such as waste-to-energy facilities and manure treatment/conversion, with considerable economies of scale. These technologies can transform manure into other higher-valued products and make export of nutrients out of the system more cost effective.

These examples are just illustrative. A new generation of market-like policy innovations for agricultural nonpoint sources will need to be situational, creative, and grounded in legal, scientific, and physical realities to make noticeable progress toward achieving water quality standards. Economists have an important role to play in helping policy makers match policies to physical and institutional realities in ways that can make progress in cost-effectively reducing agricultural nonpoint source pollution. But sometimes we must deliver the message that the water quality manager's preferred policy is not such a good match, including policies as conceptually appealing as water quality trading.

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LITERATURE CITED

Alexander RB, Smith R, Schwarz G, Boyer E, Nolan J, Brakebill J. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. *Environ. Sci. Technol.* 42(3):822–30

Baumol WJ, Oates WE. 1988. *The Theory and Practice of Environmental Policy*. Cambridge, UK: Cambridge Univ. Press

Beegle D. 2013. Nutrient management and the Chesapeake Bay. *J. Contemp. Water Res. Educ.* 151(1):3–8
Blooming horrible. 2012. *Economist*, June 23. **http://www.economist.com/node/21557365**
Boesch DF, Brinsfield RB, Magnien RE. 2001. Chesapeake Bay eutrophication: scientific understanding, ecosystem restoration, and challenges for agriculture. *J. Environ. Qual.* 30:303–20
Bonham JG, Bosch DJ, Pease JW. 2006. Cost-effectiveness of nutrient management and buffers: comparisons of two spatial scenarios. *J. Agric. Appl. Econ.* 38:17–32
Breetz H, Fisher-Vanden K, Garzon L, Jacobs H, Kroetz K, Terry R. 2004. *Water quality trading and offset initiatives in the U.S.: a comprehensive survey*. Work. Pap., Dartmouth Coll., Hanover, NH
Breetz H, Fisher-Vanden K, Jacobs H, Schary C. 2005. Trust and communication: mechanism for increasing farmers' participation in water quality trading. *Land Econ*. 81(2):170–90
Carpenter SR, Caraco NF, Correll DL, Howarth RW, Sharpley AN, Smith VH. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecol. Appl.* 8(3):559–68
Corrigan Z. 2015. The case against water quality trading. *Nat. Resour. Environ.* 30(2):1–4
Craig RK, Roberts AM. 2015. When will governments regulate nonpoint source pollution? A comparative perspective. *Boston Coll. Environ. Aff. Law Rev.* 42(1):1–64
Dales JH. 1968. *Pollution, Property, and Prices*. Toronto: Univ. Toronto Press
Deboe G, Stephenson K. 2016. Transaction costs of expanding nutrient trading to agricultural working lands: a Virginia case study. *Ecol. Econ.* 130:176–85
Dosi C, Tomasi T, eds. 1994. *Nonpoint Source Pollution Regulation: Issues and Analysis*. Dordrecht, Neth.: Kluwer Academic
Duke JM, McGrath JM, Fiorellino NM, Monteith TS, Rosso E. 2014. *Additionality in water quality trading: evidence from Maryland's nutrient offset program*. Work. Pap. APEC RR14–06, Dep. Econ. Stat., Univ. Del., Newark
Electr. Power Res. Inst. (EPRI). 2013. *Case studies of water quality trading being used for compliance with national pollutant discharge elimination system permits*. EPRI Tech. Rep. 3002001454, Electr. Power Res. Inst., Palo Alto, Calif.
Electr. Power Res. Inst. (EPRI). 2015. *EPRI awarded $2 million for water quality trading project*. News Release, Oct. 27
Environ. Law Inst. (ELI). 1997. *Enforceable state mechanisms for control of nonpoint source water pollution*. Project Rep. 970300, Environ. Law Inst., Washington, DC
Environ. Prot. Agency (EPA). 1996a. *Draft framework for watershed-based trading*. Rep. 800-R-96–001, Off. Water, EPA, Washington, DC
Environ. Prot. Agency (EPA). 1996b. *Nonpoint source pollution: the nation's largest water quality problem*. Rep. EPA841-F-96–004A, Off. Water, EPA, Washington, DC
Environ. Prot. Agency (EPA). 2004. *Water quality trading assessment handbook: can water quality trading advance your watershed goals*? Rep. 841-B-04-001, EPA, Washington, DC
Environ. Prot. Agency (EPA). 2007a. *National water quality inventory: report to Congress*. Rep. 841-R-07-001, EPA, Washington, DC
Environ. Prot. Agency (EPA). 2007b. *Water quality trading toolkit for permit writers*. Rep. 833-R-07-004, Off. Wastewater Manag., EPA, Washington, DC
Environ. Prot. Agency (EPA). 2008. *Water quality trading evaluation: final report*. Rep., EPA, Washington, DC
Environ. Prot. Agency (EPA). 2009. *Letter to Virginia Secretary of Natural Resources Preston Bryant from Shawn Garvin, EPA Region 3 Administrator*. EPA, Washington, DC
Environ. Prot. Agency (EPA). 2011. *Reactive nitrogen in the United States: analysis of inputs, flows, consequences, and management options*. Rep. EPA-SAB-11-01, Off. Admin., EPA, Washington, DC
Environ. Prot. Agency (EPA). 2015. *States develop new strategies to reduce nutrient levels in Mississippi River, Gulf of Mexico*. News Release, Dec. 12
Environ. Prot. Agency (EPA). 2016. *Water quality assessment and TMDL information*. EPA database, retrieved Sept. 27, 2016. **https://ofmpub.epa.gov/waters10/attains_index.home**
Faeth P. 2000. *Fertile Ground: Nutrient Trading's Potential to Cost-Effectively Improve Water Quality*. Washington, DC: World Res. Inst.
Fang F, Easter W, Brezonik PL. 2005. Point-nonpoint source water quality trading: a case study in the Minnesota River Basin. *J. Am. Water Resour. Assoc.* 41(3):645–57

Fisher-Vanden K, Olmstead S. 2013. Moving pollution trading from air to water: potential, problems, and prognosis. *J. Econ. Perspect.* 27(1):147–72

Ghosh G, Ribaudo M, Shortle J. 2011. Baseline requirements can hinder trades in water quality trading programs: evidence from the Conestoga watershed. *J. Environ. Manag.* 92(8):2076–84

Goolsby DA, Battaglin WA, Lawrence GB, Artz RS, Aulenbach BT, et al. 1999. *Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin. Topic 3 Report.* Natl. Ocean. Atmos. Admin. Coastal Ocean Prog. Decis. Anal. Ser. 17, Silver Spring, Md. **http://ny.water.usgs.gov/pubs/jrn/Lawrence.1999.CENRreport.pdf**

Greenhalgh S, Selman M. 2012. Comparing water quality trading programs: What lessons are there to learn? *J. Reg. Anal. Policy* 42(2):104–25

Hanson JC, McConnell KE. 2008. Simulated trading for Maryland's nitrogen loadings in the Chesapeake Bay. *Agric. Resour. Econ. Rev.* 37:211–26

Hodge C, Cutter WB. 2012. In-lieu fees: steps toward stormwater treatment cost-effectiveness. In *Economic Incentives for Stormwater Control*, ed. HW Thurston, pp. 193–210. Boca Raton, FL: CRC Press

Horan RD, Shortle J. 2011. Economic and ecological rules for water quality trading. *J. Am. Water Resour. Assoc.* 47:59–69

Howarth RW. 2008. Coastal nitrogen pollution: a review of sources and trends globally and regionally. *Harmful Algae* 8:14–20

Howarth RW, Sharpley A, Walker D. 2002. Sources of nutrient pollution to coastal waters in the United States: implications for achieving coastal water quality goals. *Estuaries* 25(4):656–76

Inamdar SP, Mostaghimi S, McClellan PW, Brannan KM. 2001. BMP impacts on sediment and nutrient yields from an agricultural watershed in the Coastal Plain region. *Trans. ASAE* 44(5):1191–200

Jackson-Smith DB, Halling M, de la Hoz E, McEvoy JP, Horsburgh JS. 2010. Measuring conservation best management practice implementation and maintenance at the watershed scale. *J. Soil Water Conserv.* 65(6):413–23

Jones C, Branosky E, Selman M, Perez M. 2010. *How nutrient trading could help restore the Chesapeake Ba*y. Work. Pap., World Res. Inst., Washington, DC

Jones LR, Vossler C. 2014. Experimental tests of water quality trading markets. *J. Environ. Econ. Manag.* 68:449–62

Keiser MS, McCarthy JL. 2015. Water quality trading in Ohio. In *Use of Economic Instruments in Water Policy*, eds. M Lago, J Mysiak, CM Gomez, G Delacamara, A Maziotis, pp. 209–22. Heidelberg, Ger.: Springer

King DM. 2005. Crunch time for water quality trading. *Choices* 20(1):71–74

King DM, Kuch PJ. 2003. Will nutrient credit trading ever work? An assessment of supply and demand problems and institutional obstacles. *Environ. Law Rep.* 33(5):10352–68

Kling CL. 2011. Economic incentives to improve water quality in agricultural landscapes: some new variations on old ideas. *Am. J. Agric. Econ.* 93(2):297–309

Kling CL. 2013. State level efforts to regulate agricultural sources of water quality impairment. *Choices* 28(3):1–4

Maille P, Collins AR, Gillies N. 2009. Performance-based payments for water quality: experiences from a field experiment. *J. Soil Water Conserv.* 64(3):85A–87A

Miller K, Duke JM. 2012. Additionality and water quality trading: institutional analysis of nutrient trading in the Chesapeake Bay watershed. *Georgetown Int. Environ. Law Rev.* 25:521

Motallebi M, Hoag DL, Tasdighi A, Arabi M, Osmond DL. 2017. An economic inquisition of water quality trading programs, with a case study of Jordan Lake, NC. *J. Environ. Manag.* 193(15):483–90

Motallebi M, O'Connell C, Hoag DL, Osmond DL. 2016. Role of conservation adoption premiums on participation in water quality trading programs. *Water* 8(6):245

Nat. Res. Conserv. Serv. (NRCS). 2011. *Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Chesapeake Bay Region*. Washington, DC: US Dep. Agric.

Natl. Res. Counc. (NRC). 2000. *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*. Washington, DC: Natl. Acad. Press

Natl. Res. Counc. (NRC). 2008. *Mississippi River Water Quality and Clean Water Act: Progress, Challenges and Opportunities*. Washington, DC: Natl. Acad. Press

Natl. Res. Counc. (NRC). 2009. *Nutrient Control Actions for Improving Water Quality in the Mississippi River Basin and Northern Gulf of Mexico*. Washington, DC: Natl. Acad. Press

Newburn DA, Woodward RT. 2011. An ex post evaluation of Ohio's great Miami Water Quality Trading Program. *J. Am. Water Resour. Assoc.* 48(1):156–69

Newell RG, Pizer WA, Raimi D. 2014. Carbon markets: past, present and future. *Annu. Rev. Resour. Econ.* 6:191–215

Ohio Environ. Prot. Agency (Ohio EPA). 2010. *Ohio Lake Erie phosphorus tax force final report*. Rep., Div. Surf. Water, Ohio Environ. Prot. Agency, Columbus, OH

Osmond D, Meals D, Hoag D, Arabi M, Luloff A, et al. 2012. Improving conservation practices program to protect water quality in agricultural watersheds: lessons learned from the National Institute of Food and Agriculture–Conservation Effects Assessment Project. *J. Soil Water Conserv.* 67(5):122A–27A

Perez M, Walker S, Jones C. 2013. *Nutrient Trading in the MRB: A Feasibility Study Using Large-Scale Interstate Nutrient Trading in the Mississippi River Basin to Help Address Hypoxia in the Gulf of Mexico*. Washington, DC: World Res. Inst.

Randall GW, Huggins DR, Russelle MP, Fuchs DJ, Nelson WW, Anderson JL. 1997. Nitrate losses through subsurface tile drainage in conservation reserve program, alfalfa, and row crop systems. *J. Environ. Qual.* 26:1240–47

Ribaudo MO. 2001. Nonpoint source pollution control policy in the USA. In *Environmental Policies for Agricultural Pollution Control*, ed. J Shortle, D Abler, pp. 123–50. Oxfordshire, UK: CAB Int.

Ribaudo MO, Gottlieb J. 2011. Point nonpoint trading: Can it work? *J. Am. Water Resour. Assoc.* 47:5–14

Ribaudo MO, Greene C, Hansen L, Hellerstein D. 2010. Ecosystem services from agriculture: steps for expanding markets. *Ecol. Econ.* 69(11):2085–92

Ribaudo MO, Heimlich R, Peters M. 2005. Nitrogen sources and gulf hypoxia: potential for environmental credit trading. *Ecol. Econ.* 52:159–68

Ribaudo MO, Nickerson CJ. 2009. Agriculture and water quality trading: exploring the possibilities. *J. Soil Water Conserv.* 64(1):1–7

Ribaudo MO, Savage J. 2014. Controlling non-additional credits from nutrient management in water quality trading programs through eligibility baseline stringency. *Ecol. Econ.* 105:233–39

Ribaudo MO, Savage J, Talberth J. 2014. Encouraging reductions in nonpoint source pollution through point-nonpoint trading: the roles of baseline choice and practice subsidies. *Appl. Econ. Perspect. Policy* 36:560–76

Saleh A, Gallego O, Osei E, Lal H, Gross C, et al. 2011. Nutrient tracking tool: a user-friendly tool for calculating nutrient reductions for water quality trading. *J. Soil Water Conserv.* 66(6):400–10

Sanneman C, Culliney S, Cochran B. 2014. *Verification in markets for water quality and habitat*. Rep., Willamette Partnersh., Portland, Or.

Schary C, Fisher-Vanden K. 2004. A new approach to water quality trading: applying lessons from the acid rain program to the Lower Boise River watershed. *Environ. Pract.* 6:281–95

Segerson K. 1998. Uncertainty and incentives for nonpoint pollution control. *J. Environ. Econ. Manag.* 15:87–98

Segerson K. 2013a. Voluntary approaches to environmental protection and resource management. *Annu. Rev. Resour. Econ.* 5:161–80

Segerson K. 2013b. When is reliance on voluntary approaches in agriculture likely to be effective? *Appl. Econ. Perspect. Policy* 35(4):1–28

Selman M, Greenhalgh S, Branosky E, Jones C, Guiling J. 2009. *Water quality trading programs: an international overview*. WRI Issue Brief, World Res. Inst., Washington, DC

Shabman L, Lynch S, Boughton E. 2013. Acquiring water services from Northern Everglades ranchlands: assuring buyers that that they get what they pay for. *Rangelands* 35(5):88–92

Shabman L, Scodari P. 2005. The future of wetlands mitigation banking. *Choices* 20(1):65–70

Shabman L, Stephenson K. 2007. Achieving nutrient water quality goals: bringing market-like principles to water quality management. *J. Am. Water Resour. Assoc.* 43(4):1076–89

Shabman L, Stephenson K, Shobe W. 2002. Trading programs for environmental management: reflections on the air and water experiences. *Environ. Pract.* 4:153–62

Shortle J. 2013. Economics and environmental markets: lessons from water-quality trading. *Agric. Resour. Econ. Rev.* 42(1):57–74

Shortle J, Horan RD. 2001. The economics of nonpoint pollution control. *J. Econ. Surv.* 15(3):255–89

Shortle JS, Horan RD. 2008. The economics of water quality trading. *Int. Rev. Environ. Resour. Econ.* 2:101–33

Shortle J, Horan RD. 2013. Policy instruments for water quality protection. *Annu. Rev. Resour. Econ.* 5:111–38

Shortle J, Kaufman Z, Abler D, Harper J, Hamlett J, Royer M. 2014. *The costs to agriculture of the Chesapeake Bay TMDL*. Rep., Envir. Nat. Res. Inst., Pa. State Univ., State Coll., Pa.

Shortle JS, Ribaudo M, Horan RD, Blandford D. 2012. Reforming agricultural nonpoint pollution policy in an increasingly budget-constrained environment. *Environ. Sci. Technol.* 46:1316–25

Sims JT, Simard RR, Joern BC. 1997. Phosphorus loss in agricultural drainage: historical perspective and current research. *J. Environ. Qual.* 27(2):277–93

Stephenson K, Aultman S, Metcalf T, Miller A. 2010. An evaluation of nutrient nonpoint offset trading in Virginia: A role for agricultural nonpoint sources? *Water Resour. Res.* 46:W04519

Stephenson K, Parker D, Abdalla C, Shabman L, Shortle J, et al. 2009. *Evaluation framework for water quality trading programs in the Chesapeake Bay watershed*. Rep., Chesapeake Bay Prog. Sci. Tech. Advis. Comm., Edgewater, Md.

Stephenson K, Shabman L. 2011. Rhetoric and reality of water quality trading and the potential for market-like reform. *J. Am. Water Resour. Assoc.* 47(1):15–28

Stephenson K, Shabman L. 2017a. Nutrient assimilation services for water quality credit trading programs: a comparative analysis with nonpoint source credits. *Coastal Manag*. 45(1):24–43

Stephenson K, Shabman L. 2017b. Where did the agricultural nonpoint source trades go? Lessons from Virginia water quality trading programs. *J. Am. Water Resour. Assoc.* In press

Stephenson K, Shabman L, Geyer LL. 1999. Watershed-like effluent allowance trading: identifying the statutory and regulatory barriers to implementation. *Environ. Lawyer* 5(3):775–815

Suter JF, Spraggon JM, Poe GL. 2013. Thin and lumpy: an experimental investigation of water quality trading. *Water Resour. Econ.* 1:36–60

Taylor MA, Sohngen B, Randall A, Pushkarskaya H. 2004. Group contracts for voluntary nonpoint source pollution reductions: evidence from experimental auctions. *Am. J. Agric. Econ.* 86(5):1196–202

US Dep. Agric. (USDA). 2013. *USDA, EPA partnership supports water quality trading to benefit environment, economy*. News Release 0226.13, Dec. 3

US Dep. Agric. (USDA). 2015. *USDA partners with EPA, offers new resources to support water quality trading*. News Release 0260.15, Sept. 17

Van Houtven G, Loomis R, Baker J, Beach R, Casey S. 2012. *Nutrient Credit Trading for the Chesapeake Bay: An Economic Study*. Annapolis, Md.: Chesapeake Bay Comm.

Wainger L, Shortle J. 2013. Local innovations in water protection: experiments with economic incentives. *Choices* 28(3):1–6

Wainger L, Van Houtven G, Loomis R, Messer J, Beach R, Deerhake M. 2013. Tradeoffs among ecosystem services, performance certainty, and cost-efficiency in implementation of the Chesapeake Bay total maximum daily load. *Agric. Resour. Econ. Rev.* 421:196–224

White House. 2015. *Presidential Memorandum: Mitigating Impacts on Natural Resources from Development and Encouraging Related Private Sector Investment*. Washington, DC: Off. Pres.

Willamette Partnersh. 2012. *In it together: a how-to reference for building point-nonpoint water quality trading programs*. Rep., Willamette Partnersh., Hillsboro, Or.

Willamette Partnersh. 2013. *General crediting protocol version 2.0*. Rep., Willamette Partnersh., Portland, Or.

Willamette Partnersh., World Res. Inst., Natl. Netw. Water Qual. Trading. 2015. *Building a water quality trading program: options and considerations*. Rep., Willamette Partnersh., World Res. Inst., Natl. Netw. Water Qual. Trading, Portland, Or. **https://www.usda.gov/oce/environmental_markets/files/BuildingaWQTProgram-NNWQT.pdf**

Woodward RT, Kaiser RA. 2002. Market structures for US water quality trading. *Rev. Agric. Econ.* 24(2):366–83

Woodward RT, Newburn DA, Mezzatesta M. 2016. Additionality and reverse crowding out of pollution offsets in water quality trading. *Ecol. Econ.* 128:224–31

Xepapadeas A. 2011. Economics of non-point-source pollution. *Annu. Rev. Resour. Econ.* 3:355–73