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Nutrient Assimilation Services for Water Quality Credit Trading Programs

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RESOURCES FOR THE FUTURE

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Abstract

Water quality trading programs envision regulated point sources meeting discharge control requirements and then being allowed to increase their nutrient discharge if they secure nutrient reduction credits from other pollutant sources in the watershed. Reduction credits can be created when agricultural land managers implement best management practices and regulators predict that those practices will result in water quality conditions equivalent to controlling discharges at the regulated source. However, natural variability in runoff combines with model and data limitations to make predictions of water quality equivalence uncertain. Nutrient assimilation credits can be created by increasing the capacity of the ecosystem to assimilate nutrients through investments in aquatic plant biomass creation and harvest, shellfish aquaculture, stream restoration, and wetlands restoration and creation. Nutrient assimilation credits can provide greater certainty than agricultural best management practices that trading will result in equivalent water quality. Such credits should be an option in trading programs.

Key Words: water quality, trading, nutrient pollution, Clean Water Act, assimilation

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Contents

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I. Introduction

Elevated nutrient levels have been identified as one of the primary factors contributing to violations of water quality standards in coastal waters (NRC 2000). Water quality managers in the United States respond with proposed limits on allowable nutrient loads from different sources. In the United States, municipal wastewater treatment plants and industrial dischargers, called point sources, increasingly face legally enforceable nutrient discharge limits. Recently, some state and substate regulatory agencies have imposed regulatory limits on nutrient discharges from construction sites and existing municipal stormwater systems. Failure to reduce regulated loads to the limits can result in legal sanctions and fines. However, some sources, most notably agricultural "nonpoint" sources, are not subject to such regulation. Instead, these sources are encouraged to reduce loads through publicly funded cost-sharing for implementing nutrient control methods, called best management practices (BMPs), and the landowners are targeted through public education programs.

For some regulated dischargers, meeting nutrient limits at the source can be costly or technically difficult. In response, nutrient trading programs have been designed to give regulated point sources other options for complying with their load limits. Though varying in design, nutrient trading programs envision that regulated sources meet a portion of their mandated on-site discharge reduction by paying for nutrient reductions off-site at another source. The regulatory authorities are expected to certify that these off-site load reductions, called credits, have occurred and then authorize the purchase of credits as an acceptable way to meet the regulated entities' nutrient control requirements.

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Most trading programs allow regulated point sources not only to purchase load reduction credits from other regulated point sources but also to secure load reduction credits by paying for implementation of nutrient-reducing agricultural BMPs (e.g., no-till systems, cover crops, riparian buffers). Because trading programs must be protective of ambient water quality, regulators who allow point sources to discharge more than their regulatory limit must be certain that the off-site nonpoint source load reduction will yield similar or superior ambient water quality conditions. Without that assurance, allowing the trade will degrade water quality. Thus, point-nonpoint trading programs must ensure equivalent outcomes when controls take place at different nutrient sources and locations in the watershed (Stephenson et al 2009; King and Kuch 2003).

Government agencies have invested heavily in developing tools and procedures for determining when equivalent water quality outcomes can be realized from a trade. In recent years, point-nonpoint source trading has been proposed in several places across the United States (Woodward and Kaiser 2002; Shabman and Stephenson 2007; Selman et al. 2009; Greenhalgh and Selman 2012; Shortle 2013). The US Environmental Protection Agency (EPA) and the US Department of Agriculture (USDA) heavily promote point-nonpoint trading by issuing guidelines and manuals and by financing pilot trading projects (Willamette Partnership 2012; Conservation Technology Information Center 2006; USEPA 2004, 2007). In many cases the cost advantages of nonpoint source trades fail to materialize because of the high costs of addressing equivalence between point and nonpoint sources (Hoag and Hughes-Popp 1997; Stephenson et al. 2009; Ghosh et al. 2011; Ribaudo et al. 2014). This paper explores an alternative way for regulators to provide additional compliance options and ensure equivalent water quality outcomes from a trade.

In the next section we describe the alternative of increasing the receiving waters' capacity to assimilate nutrients, thereby creating "nutrient assimilation credits." The next section describes technologies and processes to increase the nutrient assimilative capacity of the ambient environment—what we call nutrient assimilation services. With this as background, the rest of the paper makes the argument for why and how nutrient assimilation services can be accepted as credits in trading programs, alongside agricultural nonpoint source credits. To make the argument, the paper will describe criteria for evaluating the equivalence of water quality outcomes and will use these criteria to compare water quality outcomes from nutrient assimilation credits with those from agricultural nonpoint source reduction credits. Our conclusion is that nutrient assimilation credits, relative to agricultural nonpoint source load reductions, can offer a greater assurance of equivalence for regulators. This paper's argument

and its conclusion will provide essential information for water quality managers who are interested in considering nutrient assimilation credits as an option in trading programs (Rose et al. 2010; Virginia Secretary of Natural Resources 2012).

II. Nutrient Assimilation Services

Investments to create or enhance the removal of nutrients (phosphorus and nitrogen) directly from ambient waters produce nutrient assimilation services. Nutrient assimilation services can be created or enhanced by managing chemical transformation, nutrient harvest, and/or nutrient storage. *Chemical transformation* refers to the conversion of nitrogen compounds into biologically unavailable, or less environmentally damaging, forms. The most common example of chemical transformation is the nitrification-denitrification process that converts organic and inorganic nitrogen compounds in ambient waters into forms unavailable for primary production (e.g., N_2 gas). Though it is commonly associated with wastewater treatment processes, a variety of managed systems can accelerate the rate of chemical transformation in the ambient environment (see discussion below). *Nutrient harvest* occurs when nutrients present in ambient waters foster the growth of managed aquatic plant or animal biomass production systems. Nutrients are sequestered in the biomass and then removed from the aquatic system as the organisms are harvested. Finally, *nutrient storage* involves removing nutrients from ambient waters by enhancing the sequestration of nutrients in soil or aquatic sediments (e.g., via burial or storage processes). These three processes and the possibility for creating or enhancing nutrient assimilation services are realized from investments in managed wetland systems, shellfish aquaculture, algal production facilities, and stream restoration.

Managed Wetland Systems

Wetlands' nutrient-cycling functions (primarily chemical processing and storage) can occur in natural wetlands, and active management can enhance these natural processes. Investments in constructed treatment wetlands are a well-recognized method to remove nutrients from stormwater runoff and from wastewater treatment plant effluent. Extending this concept, nutrient assimilation wetlands remove nutrients from ambient water; the difference in source water distinguishes treatment wetlands from nutrient assimilation wetlands. A managed wetlands system may be a naturally occurring wetland where actions are taken to increase nutrient assimilation potential. It might also be an area of constructed or restored wetlands. These nutrient assimilation services could be realized and enhanced by actively managing water flow through

the wetland (timing, duration, volume) and by selecting and managing wetlands vegetation (Wetlands Initiative n.d.).

A substantial literature addresses the nutrient removal efficiencies of various types of wetlands (Kadlec and Knight 1996; Mitsch and Gosselink 2015; Fisher and Acreman 2004; Kadlec 2006). Nutrient removal efficiencies for stormwater treatment wetlands range between 0 and 55 percent of total nitrogen and 15 to 75 percent of total phosphorus. Nutrient removal efficiencies, particularly for phosphorus, may decrease over time as the nutrient storage capacity of the wetland is used (unless the wetland is actively managed to remove accumulated plant mass and nutrient-saturated sediment) (Cappiella et al. 2008). Mitsch et al. (2000) found that midwestern wetlands remove 90 to 350 pounds of nitrogen annually (10 to 40 g-N/m^2), but nitrogen removal rates in constructed wetlands in similar geographic regions can be higher (Mitsch et al. 2001). Nutrient assimilation wetlands have been estimated to remove 274 pounds of nitrogen and 24 pounds of phosphorus per acre annually from large midwestern wetland systems with high nutrient inflows (Hey et al. 2005). Ranchers participating in the Florida Ranchlands Environmental Service Project divert water from public canals or rivers into private wetland treatment areas for the purpose of removing phosphorus (Lynch and Shabman 2011). Nutrient removal efficiencies as high as 90 percent have been realized in the early years of operation.

Denitrifying bioreactors perform similar services as managed wetlands. Extensively tested in the Midwest, bioreactors divert nutrient-rich farm runoff into subsurface treatment basins filled with carbon material to facilitate the denitrification process (Schipper et al. 2010; Christianson et al. 2012). Bioreactors, however, can also be used in an engineered approach to remove legacy nutrient loads in groundwater. For instance, bioreactors could be designed and sited to intercept and treat emergent springs high in nitrates (Collins and Gillies 2014).

Shellfish Aquaculture

Eutrophication is the process that ensues after a body of water acquires a high concentration of nutrients: the nutrients promote overgrowth of algae, and as the algae die, they are consumed by organisms that deplete the water of available oxygen. Enhanced shellfish production can reduce the effects of eutrophication (Rose et al. 2015). Nutrients provide the primary source of energy in phytoplankton production. Shellfish aquaculture requires no feed inputs, and so there is no importation of nutrients into the ambient system. When harvested, cultivated shellfish represent a new source of nutrient removal from ambient waters. The use of aquaculture shellfish production as a nutrient removal strategy has been piloted in several

locations (Landry 2002; Gifford et al. 2005; Lindahl et al. 2005; Long Island Sound Study 2013; Petersen et al. 2014; Hudson et al. 2014).

Oysters, for example, are filter feeders that graze on phytoplankton suspended in the water column. When oysters feed, a portion of the nutrients contained in the phytoplankton becomes stored in oyster tissue and shell (biosequestration). Oyster aquaculture operations represent biosequestration above and beyond what would be present in wild oyster stocks. Aquaculture oysters can be spawned in hatcheries, reared in upwellers, and then grown out in designated areas that do not displace wild oyster populations. Extensive studies have been conducted that estimate the nutrient content of various types of shellfish (Carmichael et al. 2012). Higgins et al. (2011) find that one million aquaculture Chesapeake Bay oysters *(Crassostrea virginica)* contain 92 to 657 pounds of nitrogen in oyster shell and tissue (the range depends on the size class of the oysters). Carmichael et al. (2012) estimate that harvest of oyster soft issue could remove as much as 15 percent of anthropogenic nitrogen loads in small estuaries in New England.

Researchers also hypothesize that oysters may improve water quality by accelerating the storage of nutrients and chemical transformation of nitrogen (Newell 2004; Newell et al. 2005; Bricker et al. 2014). Unlike many other shellfish, oysters filter constantly, even after energy needs for maintenance and growth have been satisfied. Oysters process phytoplankton and other suspended particles and deposit the digested and partially digested material (biodeposits in the form of feces and pseudofeces) onto aquatic sediments. A portion of the nutrients in the oyster biodeposits might be buried and stored in aquatic sediments. In addition, a portion of the oyster biodeposits may undergo a nitrification-denitrification process, thus removing organic and inorganic nitrogen from ambient waters by releasing N_2 gas into the atmosphere. Higgins et al. (2013), however, found little evidence of enhanced denitrification in floating raft culture in the Chesapeake Bay. Differences in denitrification rates appear to vary with site-specific conditions, with higher denitrification rates reported on restored oyster reefs and bottoms with similar structure (Piehler and Smith 2011; Kellogg et al. 2013). In addition, researchers acknowledge that relatively little is known about nutrient burial rates associated with enhanced oyster production (Kellogg et al. 2014).

Aquatic Plant Biomass Harvest

Managed aquatic plant systems (MAPS) remove nutrients primarily through sequestration and harvest of plant material. A variety of aquatic plant species, including multiple species of microalgae, macroalgae (“seaweed”), and aquatic plants have been investigated as

potential approaches to nutrient removal. MAPS production areas can be developed in either off-line or in situ (in-line) configurations. Off-line systems convey ambient water into an adjacent grow-out areas or production facilities. Aquatic plants take up the nutrients present in the ambient source water, and the water is returned to the original waterbody. In this approach, the vegetative treatment area does not occupy space within the source waterbody. In contrast, in situ systems designate specific vegetation production and harvest areas in the ambient aquatic environment for MAPS cultivation.

One type of algal production technology involves pumping ambient water into a production area that includes prepared flat surfaces covered with an engineered geomembrane (algal flow-way technology). Periphytic algae grow on the prepared surface and sequester nutrients during growth, and the algal biomass is periodically harvested. The water is then discharged back into the waterbody with lower nutrient concentrations (Adey et al. 1993, 1996; Hydromentia 2005). Large-scale pilot projects in Florida found that up to 1,300 kg/ha of nitrogen and 330 kg/ha of phosphorus could be removed annually by such facilities (Hydromentia 2005). Mulbry et al. (2010) removed an equivalent of 330 and 70 kg/ha/yr of nitrogen and phosphorus, respectively, from small-scale experimental algal scrubbers in the Chesapeake Bay.

Thousands of metric tons of nitrogen are estimated to be removed from ambient waters from the harvest of seaweed grown for food (Troell et al. 2003). The New York State Office of the Attorney General and the Long Island Sound Study have piloted the use of red seaweed *(Gracilaria)* as a nutrient removal strategy and report nitrogen removal rates over a 90 day growing period of 28 kg/ha^{-1} and 94 kg/ha^{-1} in Long Island Sound and the Bronx River Estuary, respectively (Kim et al. 2014). Floating aquatic plants have higher growth than submerged plants and may sequester more than 1,500 pounds of nitrogen per hectare annually (Reddy and DeBusk 1985). Others have explored the potential of adding aquatic plants to accelerate and enhance the nutrient removal in existing stormwater treatment ponds (Fox et al. 2008). Likewise, macroalgae have been actively cultivated and harvested to reduce the discharge of nutrients to ambient waters from nutrient-intensive finfish farms, a process known as integrated multitrophic aquaculture (Neori et al. 2004).

Stream Restoration

Urban stream restoration may also facilitate and enhance nitrogen processing and removal from ambient waters. Urban stream restoration may reduce nutrients present in receiving waters both by reducing sediment and nutrient loads (from preventing bank and

streambed erosion) and by enhancing in-stream nitrogen processing (Schueler et al. 2013; Filoso and Palmer 2011).

Researchers hypothesize that the hydrologic features characteristic of modified stream channels and streams altered by urban environments diminish riparian denitrification rates. Stream restoration activities that restore more naturally occurring stream features, such as river bends, pools, and riffles and stream-floodplain connections, can slow velocities and enhance retention times that enhance in-stream nitrogen processing (Kaushal et al. 2008; Bukaveckas 2007; Sivirichi et al. 2011). These studies focus on nitrogen cycling during base flow conditions, and nitrogen removal is thought to be positively related to restored stream length, connectivity to floodplains, water residence time, and diversity of stream flow characteristics (Schueler et al. 2013; Filoso and Palmer 2011; Lautz and Fanelli 2008). Other forms of urban stream restoration, such as daylighting, can also increase nitrate removal by more than 30 percent (Pennino et al. 2014).

Reduced velocities may also reduce channel and bank erosion, reducing sediment and nutrients contributions to the stream. Alterations to stream hydrology often cause significant erosion of streambed and bank materials, resulting in down cutting, mass wasting of stream banks, and significant sediment and nutrient export (Allmendinger et al. 2007; Farley et al. 2009). Nutrient reductions from reductions in bank sediment losses (0.075 and 0.068 lbs/ft/yr for nitrogen and phosphorus, respectively) have been established for the Chesapeake Bay region (Schueler et al. 2013).

III. Nutrient Assimilation Services for Regulatory Compliance

Clean Water Act Basics

The US Clean Water Act requires states to identify and then take actions to attain water quality standards. These water quality standards comprise state-assigned designated uses (e.g., swimming) for each waterbody and measurable criteria to represent each use (e.g., water clarity for swimming). In the case of eutrophication, the total maximum daily load (TMDL) planning process identifies the load (e.g., pounds) of nutrients that can be present in a defined area of a river, lake, or estuary (here called a waterbody) per unit of time. The load is based on the waterbody's capacity to assimilate nutrients, still meet the criterion (water clarity), and hence attain the designated use (swimming). If the criterion is not met, the regulatory authorities deem the waterbody to be impaired, in this case because nutrient loads exceed the TMDL.

If a waterbody is nutrient impaired, regulators have only one regulatory instrument available for limiting loads: they can issue National Pollution Discharge Elimination (NPDES) permits, but only to point sources. These point sources typically include industrial and municipal wastewater treatment plants, but over time other categories of dischargers, such as municipal stormwater systems, have been classified as point sources. NPDES permits may include specific numeric nutrient effluent limitations (expressed as a load, which may be separated into discharge volume and allowable concentration limits in the wastewater). In contrast, the Clean Water Act explicitly excludes runoff from all agricultural sources (excepting concentrated animal feeding operations) from the definition of a point source and from federal regulatory requirements to limit either loads or concentrations. Educational programs and financial subsidies to encourage on-farm nutrient controls (BMPs) are used to reduce agricultural discharges.

When faced with limiting effluent loads in impaired waters, regulators often limit allowable point source discharges to what can be attained if the point source installed control methods that were near the limit of the most advanced on-site nutrient removal technology. What is achievable with this technology is used to establish the nutrient load limit for each source (its wasteload allocation). Once established, the wasteload allocation for each source is typically not allowed to increase over time.

Most nutrient trading programs have been proposed where a waterbody is receiving nutrient loads from both point sources that face stringent wasteload allocations and nonpoint sources that face no limits. Proposed nutrient trading programs allow, with varying degrees of discretion, point sources to secure nutrient reductions with other sources when it becomes either technologically or cost prohibitive to maintain compliance with a stringent nutrient load limit using only on-site control technologies. In fact, several trading programs allow trading only to address growth in effluent flows (due to population or economic growth) and only after all available on-site point source controls to meet concentration limits have been implemented (Stephenson and Shabman 2011).

Nonpoint Source Credits

Regulatory authorities have emphasized one type of nutrient trading compliance option: point-nonpoint trading.[1] In this application, unregulated agricultural producers who implement

[1] Some authors describe programs in which buyers voluntarily purchase nonpoint source credits for publicity or general environmental "stewardship." This paper considers only trading programs that are used for regulatory compliance.

BMPs that are expected to reduce nutrient nonpoint loads below some reference level of discharge, called a baseline, create nonpoint source credits. These credits may be purchased by a point source as an alternative to on-site nutrient control at the point source. Permission to use credit purchases for NPDES compliance must be given by the regulatory authority and will be given if the regulatory authority is confident that the ambient water quality result of BMP implementation will be equivalent to load reduction at the point source.

Nutrient trading programs have procedures for determining when a nonpoint source credit will have a water quality improvement effect equivalent to the point source control it is replacing. A large literature has developed around assessing and evaluating program rules that can be implemented to address the equivalence of point-nonpoint trades (Horan and Shortle 2005, 2011; Malik et al. 1993), and regulatory agencies and nonprofit organizations have made significant investment in developing evaluation methods to quantify and verify outcomes to produce acceptable levels of equivalency. (Keller et al. 2014; Saleh et al. 2011).

Nutrient Assimilation Credits

Enhancing nutrient assimilation services could serve a role similar to that of agricultural BMPs in a nutrient trading program. Nutrient assimilation credits would be created when the effects of the nutrient assimilation service (nutrients removed from a waterbody) on water quality are approved and verified by water quality program officials. Within the confines of a nutrient trading program, such credits could potentially provide regulated point source dischargers an additional NPDES compliance option. The use of nutrient assimilation service credits in trading programs has been proposed (Heberling et al. 2007; Cherry et al. 2007; Shabman and Stephenson 2007; Newell 2004). Nutrient assimilation projects for the purpose of generating credits for use in a trading program have been piloted for wetlands (Hey et al. 2005), aquaculture shellfish harvest (Lindahl et al. 2005; Lindahl and Kollberg 2008; Rose et al. 2014), and algal harvest (Pizarro et al. 2006). In 2012 Virginia became the first US state to authorize in statute the use of nutrient assimilation service credits in a nutrient trading program. The Virginia law explicitly authorizes the development and use of nutrient assimilation service credits from stream restoration, wetlands enhancement, shellfish aquaculture, algal harvesting, and other “innovative methods of nutrient control or removal” (§10.1-603.15:2.B.1.a).

IV. Water Quality Outcomes: A Comparison of Agricultural Nonpoint Source Nutrient Assimilation Credits

Nutrient loads to a waterbody differ by the location, size, and timing and frequency of the discharge. Some sources are readily and accurately monitored, but for others, monitoring can be technically difficult or costly and prone to uncertainty. Nutrient trading programs must recognize this heterogeneity among nutrient sources when evaluating whether a trade can result in equivalent water quality (equivalence). Common criteria used for evaluating equivalence include load quantification certainty, temporal matching, spatial redistribution, additionality, and leakage (Stephenson et al. 2009).[2] Each criterion represents a different dimension to ensuring equivalence. This section will use these criteria to discuss how the strategies defined above (stream restoration, managed wetlands, aquatic biomass harvest) compare with agricultural nonpoint source credits. Nonpoint source credits are used for comparison because they have been approved for use in some nutrient trading programs.[3]

Quantifying Nutrient Loads

The nutrient credit is typically defined as a mass load reduction of a given nutrient, relative to a baseline, over a specific period of time (e.g., kilograms of nitrogen per year). Point sources typically quantify nutrient loads by direct measurement of flow and sampling of effluent concentrations. All other factors equal, nutrient trading program designers would prefer a similar level of certainty when quantifying load reductions that will be recognized as credits.

Nonpoint Source Credits

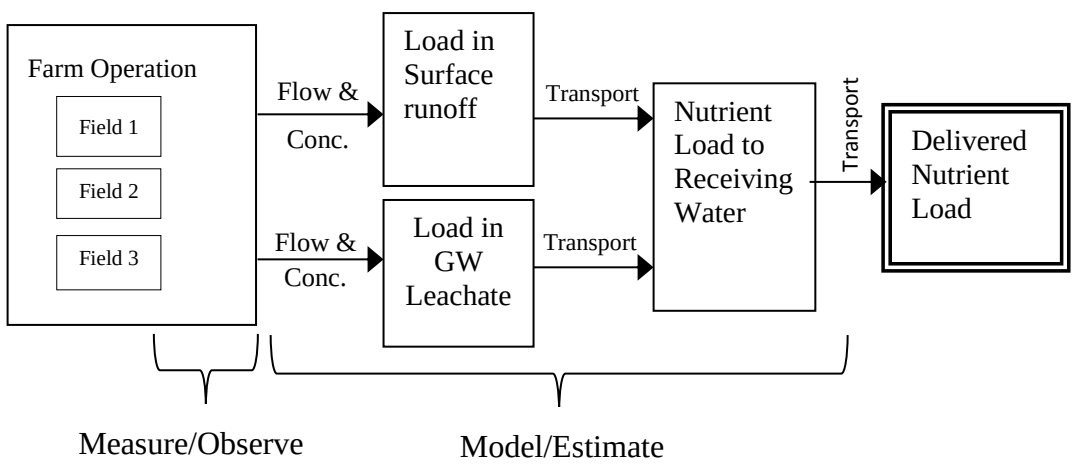
All US nutrient trading programs that recognize credits from agricultural nonpoint sources use computer models to translate an agricultural best management practice into an estimate of a reduced pollutant load (Figure 1) (Keller et al. 2014; Saleh et al. 2011). First, an agricultural nonpoint source BMP is entered into the model. Nutrient-reducing practices might include long-term land conversion (e.g., cropland to hayfield or forest) or annual field

[2] Since the goal of this analysis is to compare regulatory compliance options for regulated sources, the evaluative criteria focus exclusively on water quality. More expansive evaluative criteria, such as whether nutrient credit projects provide other ancillary benefits, could be considered. For example, in addition to reducing nutrient and sediment discharges, some nonpoint source reduction projects (e.g., conservation tillage, riparian buffers) provide other benefits, such as carbon sequestration and wildlife habitat. However, nutrient assimilation projects also provide a range of ancillary benefits, including aquatic habitat enhancements from stream restoration and wetland enhancements. In addition, shellfish aquaculture enhances some types of aquatic habitat.

[3] A review or evaluation of the cost-effectiveness of nutrient assimilation credits is beyond the scope of this paper. The relative cost of nutrient removal of nutrient assimilation services compared with point and nonpoint source reductions can be found elsewhere (e.g., Stephenson et al. 2010; Lentz et al. 2014).

management activities, such as planting of cover crops, conservation tillage, or reduced fertilizer applications. For any particular BMP, the model calculates how the BMP changes the water runoff from the farm field in the immediate area and the concentration of nutrients in the runoff; together, these determine the estimated change in load. Runoff transporting the nutrient load may then travel some distance from the edge of the field before entering a stream channel. Some nutrients will also be lost to groundwater leaching. Conceptually, the rate and timing by which the groundwater then is discharged to streams must also be estimated. Transport from field to stream necessitates estimating any change in nutrient load over that distance. If the stream receiving the runoff or groundwater discharge is not adjacent to the regulated source buying the credit (and increasing discharges), additional modeling is needed to estimate the portion of nutrients delivered to the area where equivalence to the point source discharge is to be evaluated (called the delivery or attenuation rate). Note that the only observation made in quantifying the credits during program implementation is in the field where the BMP's presence, operations, and maintenance might be documented.

Figure 1. Quantifying Nonpoint Source Nutrient Load



Given that changes in flow and concentration are not or cannot be feasibly measured directly, quantifying nonpoint source loads involves two sources of uncertainty (Ribaudo et al. 2010). These can be seen by making reference to Figure 1. First, there is uncertainty about the level of nonpoint control practice implementation, operation, and maintenance. Second, even if

the BMPS are implemented and maintained, model prediction uncertainty is a well-recognized challenge for quantification.

Quantification of nonpoint source credits from a BMP requires documenting the implementation and then the ongoing operation of the practice. Observing whether BMPs have been installed is a one-time activity, but checking their operation over the years can be costly and impractical, especially as new and widely dispersed BMPs are installed each year. Operation and maintenance are more easily observed and verified for some types of BMPs than for others. For instance, the implementation of streambank fencing (livestock exclusion) and cover crops can be relatively easily verified. In contrast, even though credits for nutrient management plans and animal waste storage practices assume a particular management and operational regime, the application of manure and fertilizer (application method, timing, and amount) is less easily observed and verified, and on-farm circumstances and logistical constraints can cause farmers to deviate from planned manure management behavior (Jackson-Smith et al. 2010). Sampling strategies for continuous observation can be used to target funds available for observation, but sample error will be present.

Also, translating BMP implementation and operation into credits (reduction in delivered load) is subject to model prediction uncertainty. Quantification of nutrient loads and changes in loads with a BMP depend on the chosen parameters and functional relationships used to build the model. Models are built using parameters and functions based on available laboratory and field-level studies. Such studies may be few, and their measurements to quantify and track nutrient movement and transformations in soil, water, and atmosphere will always be limited by time and budget. Not surprisingly, the literature reports wide variations in observed effectiveness in load reduction for the same BMP (Simpson and Weammert 2009). The reality of this uncertainty will continue.

Models assemble the conceptual understanding and empirical studies into structured mathematical representations of the system. Every model is a simplification of underlying processes that give rise to agricultural nutrient loads and BMP effects on those loads. In a review of intensive watershed studies of agricultural BMP implementation and performance, Osmond et al. (2012, 125A) found that, in general, 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 direct linkage between the implementation of BMPs and measured watershed outcomes. Such research establishes water quality monitoring

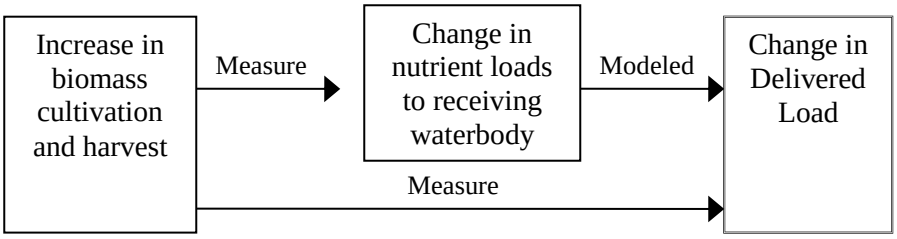
protocols in selected watersheds to identify any changes in ambient water quality from concentrated agricultural conservation efforts. Despite considerable implementation, in many cases it has been challenging to link the level of BMP implementation to improvements in water quality (Inamdar et al. 2001; Osmond et al. 2012). In short, the observational and modeling uncertainty in quantifying delivered loads through the process represented in Figure 1 is unavoidable and can be significant.

Designers of nutrient trading programs typically address the uncertainty in the quantification of nonpoint source loads by assigning an "uncertainty ratio" to point-nonpoint trades (USEPA 2014a). An uncertainty ratio requires more estimated nonpoint source load reductions to be achieved for every unit of point source discharge increase. For example, a 2:1 ratio is common and would require a point source to purchase two units of nonpoint source reduction to offset every unit of point source discharge. Uncertainty ratios are generally set based on convention or expert opinion rather than empirical evidence or analysis (USEPA 2014a).

Nutrient Assimilation Credits

In many instances, nutrient assimilation projects can offer greater certainty when quantifying nutrient reduction than agricultural nonpoint sources (Figure 2). First, nutrient assimilation technologies reduce the number of processes that must be modeled or measured to quantify credits because nutrient removal can be directly measured within receiving waters. For example, the location of the nutrient assimilation project can be chosen such that there is no need to model overland flow and transport. Second, nutrient assimilation processes within the waterbody can often be measured directly, through sampling and observation. For instance, nutrient removal through harvest of cultivated algae, seaweed, or aquaculture oysters can be directly quantified by recording the total harvested cultivated biomass (e.g., dry weight) and sampling its percentage of total nitrogen and total phosphorus. If this biomass was cultivated in the waterbody (or off-stream, using ambient water) at the location where equivalence must be met, no further quantification is needed to measure the removal of nutrients from the water (see Figure 2). If the biomass harvest occurs upstream of the waterbody of concern, model estimates (via delivery or attenuation ratios) would still be needed to translate upstream removal into downstream load reductions.

Figure 2. Quantifying Nutrient Removal via Cultivated Biomass Harvest



In addition, measurement costs can be reduced if field results demonstrate that elements of the nutrient calculation procedure exhibit minimal variance over time. For instance, the total nitrogen and total phosphorus content of algae has been found to be relatively stable across samples at a particular site (Mulbry et al. 2010; Kim et al. 2014). Biomass harvest is readily measured and can be multiplied by a fixed coefficient (expressed in nutrients per unit of algal mass) to quantify estimates of nutrients removed. In the case of aquaculture oysters in the Chesapeake Bay, the sequestered nitrogen and phosphorus are directly and closely related to the size of the harvested oysters, measured by shell length (Higgins et al. 2011). In this case nitrogen and phosphorus removal can be quantified by measuring the harvest of different-size aquaculture oysters. Other nutrient assimilation strategies also may be directly observed and measured. For instance, the nutrient concentrations of water moving through the inlets and outlets of nutrient assimilation wetland can be regularly sampled and the total volume of water measured in much the same way that point source loads are monitored (Hey et al. 2005; Cherry et al. 2007).

Some nutrient assimilation processes, however, may be technically difficult or costly to measure directly. Direct measurement of changes in nutrient load from stream restoration may be technically difficult to isolate, prompting one recent study to conclude that there is insufficient evidence that stream restoration can lead to sustained higher levels of nutrient cycling (Bernhardt et al. 2008). Similarly, the nutrient removal of nutrients via nutrient burial and denitrification of biodeposits is difficult to measure directly, and removal estimates are often highly uncertain (Kellogg et al. 2014). The timing and duration of nutrient burial in sediments are also uncertain. In these cases, the level of scientific and model uncertainty of nutrient assimilation services would need to be compared with the level of uncertainty being accepted for approved nonpoint source reduction credits. As for nonpoint source credits, the application of uncertainty ratios could be used to address uncertainty associated with the modeled nutrient removal effectiveness

of nutrient assimilation projects. A case-by-case evaluation would be necessary to determine whether modeled nutrient assimilation services would provide more measurement certainty than nonpoint source credits. However, direct measurement of nutrient removal outcomes reduces uncertainty of nutrient removal estimates compared with modeled outcomes. Nutrient assimilation credit projects that directly measure nutrient removal performance could be recognized and encouraged with lower uncertainty trading ratios.

Temporal Matching

Temporal matching means that the timing of the load reduction from the credit is the same as the timing of the load reduction from the point source the credit is replacing. When the timing is the same, there is no risk of an adverse effect on water quality conditions as a result of the trade. TMDLs define the load limit that will meet the water quality criterion for a specific time period. Nutrient load limits are typically for a year or season of the year (summer). Therefore the NPDES permit will expect regulated dischargers to be in compliance within a specified time period. As a result, point-nonpoint nutrient trading programs aspire to define credits in terms of the same timing: that is, the credit ideally is defined as the reduction in pounds of nutrient per year or reduction per season, depending on the time period used to define the point source NPDES load limit.

Nonpoint Source Credits

Point source discharges occur with regularity, and point source regulatory load limits specify time-referenced discharge conditions. However, nonpoint source loadings are stochastic, depending on the timing, duration, and amount of rainfall, and so too is the load reduction achieved by a BMP. This weather dependency means that temporal matching is a design challenge for point-nonpoint trading programs (Shortle and Horan 2008; Horan and Shortle 2011). In practice, point-nonpoint trading programs abstract from the actual timing of nonpoint loads by quantifying (through modeling) nonpoint source loads and reductions from BMPs based on average rainfall and runoff. Nonpoint source nitrogen loss pathways, particularly via leaching to groundwater, also introduce a time lag between a change in BMP implementation and realized changes in nonpoint source loads to surface water (see Figure 1). Nitrate leached through soils into groundwater may take decades to eventually be discharged to surface waters. In the Chesapeake Bay region, groundwater being discharged into surface waters can be less than a year to more than 50 years old (Phillips and Lindsey 2003; Meals et al. 2010; Sanford and Pope 2007). These processes are highly uncertain and site specific, so here, too, models of delivered load are based on averages, making temporal matching uncertain.

Both the stochastic nature of runoff and the uncertainty about groundwater pathways make it difficult to temporally match nonpoint source credits to point source load reduction requirements. In a wet year, nonpoint source load reduction, depending on the BMP, might equal or even exceed the credits modeled for the average year. In abnormally dry years, there will be little runoff and hence no credits available, but the model will suggest that credits are generated. The extent to which water quality may be impaired if credits do not temporally align with the point source discharge will depend on how sensitive water quality conditions are to the variability in loads. As with load quantification, temporal uncertainty also tends to be addressed with a single uncertainty trading ratio.

Nutrient Assimilation Credits

Nutrient assimilation credits may offer opportunities to better match the timing of nutrient load reductions with the increased load discharge from the point source credit buyer. Aquatic biomass harvest can be operated to provide nutrient removal within specifically scheduled time periods. Nutrient assimilation wetlands and engineered bioreactors can be designed to treat nutrients emerging from groundwater (springs). If springs produce relatively stable outflows across years, such treatment would also provide relatively stable and predictable levels of nutrient removal. Stream restoration projects would provide nitrogen cycling via denitirification of nutrient removal during normal (base) flow periods. These examples are not intended to argue that nutrient assimilation technologies are independent of weather or that there are no other sources of variability in removal results. For instance, biomass harvest can be influenced by differential growth, disease, or predation rates. The focus here is to identify whether credits created through nutrient assimilation technologies are more likely than nonpoint source BMPS to temporally match the point discharge that will be above the NPDES load limit as part of a trading program.

Spatial Redistribution

Nutrient credit trading spatially redistributes nutrient load reduction actions across a watershed. Where the credits are created in relation to the location of the delivered load that is the water quality concern needs to be a consideration when ensuring that a trade has equivalent water quality outcomes. Note, however, that trading program provisions would prohibit transactions that would impair local water quality along the delivery route.

Nonpoint Source Credits

In some nutrient trading programs, nutrient loads and credits are defined for the load *delivered* (not released at the end-of-pipe or edge-of-stream) to a specific location in a waterbody. In the modeling process (Figure 1), attenuation ratios convert end-of-pipe or edge-of-stream loads to delivered load. A point source load effect on water quality depends on the proportion of the discharged load that is ultimately transported to a specific location, after accounting for processing and attenuation during travel time to that location. A trading program may allow the point source to buy credits from a nonpoint source regardless of location as long as "delivered loads" are the same between buyer and seller. In fact, a point source could buy credits from either an upstream or a downstream source, although the number of credits required for NPDES compliance would differ. For example, consider a new point source, located in the headwaters of a watershed, that must offset its nutrient load. Assume the point source discharges 100 kg per year, but because of attenuation, only 75 kg is delivered to a location in a downstream impaired estuary. The 75 kg becomes the regulatory requirement and the point source can meet the regulatory requirement by buying 75 kg of nonpoint source credits next to the estuary or 100 kg of nonpoint source credits near the point source discharge.

Other trading programs may address spatial redistribution by referencing the point of the buyer's discharge rather than the location of the impairment (Keller et al. 2014). In this program design, a point source buyer could buy nonpoint source credits only upstream of the point source discharge location. Given in-stream attenuation, the upstream credit producer would need to produce reductions in excess of the increase in point source loads so that the delivered reductions would equal the point source loads at the point source outfall. Using the same hypothetical example as above, the new point source seeking to offset 100 kg of nutrient load would be required to purchase more than 100 kgs of nonpoint source reductions upstream, enough to offset the new load at the point of discharge.

Nutrient Assimilation Credits

A concern sometimes voiced about nutrient assimilation services is that water quality might be compromised if dischargers are allowed to increase loads to ambient waters, only to have them removed elsewhere. Yet regulatory authorities have already established the precedent that point source loads can be increased in one part of the watershed if nonpoint source loads are reduced in another location. From a water quality equivalence perspective, nutrient assimilation credits function like nonpoint source credits, since nutrient assimilation service enhancement can be located in the same areas of the watershed as nonpoint source controls. Nutrient assimilation

service enhancements can be placed in upstream headwaters or in the impaired waterbody itself (delivering direct nutrient load reductions). Thus, nutrient assimilation credits could be used in either of the spatial program rules described for nonpoint credits.

Additionality

Nutrient trading programs may have unintended consequences on water quality if they do not provide "additionality." Additionality means that a credit will not be given for a nutrient reduction or removal service that would have occurred in absence of the trade (Stephenson et al. 2009; Miller and Duke 2014). 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 any new offsetting reductions.

Nonpoint Source Credits

An agricultural operator may receive some private production benefit from the implementation of a BMP and so may implement that practice without the financial incentive provided through a trading program (Claassen et al. 2014). In this case, the BMP implementation is unaffected by the payment through trading; the BMP is nonadditional. In evaluating farm conservation subsidy programs, Mezzatesta et al. (2013) found that nonadditionality varied significantly across BMPs in southern Ohio. For farmers receiving a conservation cost-share payment, roughly 90 percent of their adoption of filter strips and cover crops could be attributed to the financial cost-share payment, while only 20 percent of conservation tillage acres was additional and due to the incentive payment. Similarly, Claassen et al. (2014) estimate that cost-shared annual nonpoint source control practices produce less additional gain than payments made to implement more permanent structural control practices.

Nutrient trading program designers often use credit baselines as a way to address additionality concerns. To ensure that nutrient reduction actions are additional, a baseline would require prediction of what nonpoint source loads would have been without a trade (Gillenwater 2012). Credits can be created only when trading creates load reductions above that baseline. Proposed and operating nutrient trading programs have variously defined nonpoint source baselines to reduce the potential for crediting nonadditional reductions. For instance, a time-referenced baseline would establish the baseline as the level of discharge existing at specific point in time, typically the current time period (existing level of discharge) or some historical reference point. Perhaps more common, nonpoint source credits are defined with respect to a specific level of performance (performance-based baseline). In the Chesapeake Bay watershed,

all nutrient trading programs must establish nonpoint source baselines consistent with the level of nutrient discharge needed to meet the agricultural load expectations identified in the TMDL (USEPA 2014b).

Baseline definitions, however, can generate different sets of behaviors from credit suppliers, but rarely eliminates concerns about nonadditionality. For example, Duke et al. (2014) reported that the Maryland nutrient trading program rules for nonpoint sources would place nearly 40 percent of existing agricultural fields below the baseline. The authors outline several opportunities for farmers with fields under the baseline to claim nonpoint source reduction credits without providing any new nutrient control efforts.

Nutrient Assimilation Credits

The possibility of nonadditionality for nutrient assimilation projects would vary depending on type of project. In some cases, nutrient assimilation credit suppliers face no or little financial incentive to provide the service enhancement without a direct payment for nutrient removal. For example, algal and seaweed biomass producers in the United States have few viable market opportunities beyond nutrient remediation. In such situations, baselines would be straightforward to establish, since credit providers have no market for their services beyond nutrient removal and face no regulatory requirement to remove nutrients. The baseline would simply be zero, and any nutrients removed could be credited as an additional removal from the ambient environment.

With commercially viable coproducts, however, nonadditionality can be a concern for nutrient assimilation service credit projects. For example, shellfish aquaculture operations provide highly quantifiable nutrient removal services via harvest. Credits for nutrient assimilation services could give shellfish aquaculture businesses incentives to expand operations. However, existing shellfish operations that rely solely on the sale of shellfish products might then say they are already providing nutrient credits. A time-referenced baseline could reduce the opportunity for existing firms to claim credits for past investments. Once such time-referenced baselines are established, expansions of nutrient credit services (e.g., new nutrient farm wetlands, expanded shellfish aquaculture production) beyond the referenced date could be counted as new, additional services and credited. However, such baselines do not eliminate the chance for shellfish growers to receive nonadditional credits, since some of the expansion might have occurred without any nutrient assimilation service payments if market demand for shellfish warranted expansion. If future growth is expected in an industry absent any nutrient assimilation service payment, then forecast growth might be required to establish a baseline.

Nutrient assimilation wetlands and stream restoration projects raise different additionality concerns. Under water quality policy, nutrient assimilation credit suppliers have little reason to construct these types of projects in absence of the opportunity to sell nutrient or sediment removal services. Absent any other financial incentives or regulatory requirements, all stream restoration and wetland enhancement projects would be undertaken only in response to nutrient credit market opportunities. However, other market opportunities exist for these projects, including wetland and stream restoration credits for offsetting impacts from development activities (permitted under Section 404 of the Clean Water Act) and for compensatory mitigation for natural resource damages from oil and hazardous waste spills. Federal and state governments also provide various financial incentive payments for farmers to restore previously drained wetlands. The policy question becomes whether credits produced from a wetland or stream restoration project can be sold for multiple purposes. Such credit "stacking" creates additionality concerns when a landowner or credit provider delivers the services under one program and then sells the credits from the same project in other programs (Cooley and Olander 2012; Lentz et al. 2014). In such cases, no new services have been provided. Stacking, and the additionality concerns associated with it, is not unique to these nutrient assimilation technologies; it also confronts agricultural nonpoint source control practices that seek to claim credits for carbon, habitat, and development rights.

Leakage

Leakage occurs when a nutrient credit trade produces another form of unaccounted-for changes in nutrient loads. Nonpoint source credit trades quantify a reduction in nutrient loads for the implementation of nutrient controls at a specific place. The same trade, however, may directly or indirectly induce an increase in nutrient loads in another place, and the net effect of the nutrient load or assimilation project is not recognized.

Nonpoint Source Credits

Leakage can be primary (direct) or secondary (indirect) (Aukland et al. 2003). Primary leakage occurs when a nonpoint credit producer takes other actions that increase loads to the same waterbody, but in a different location. For example, the installation of forested buffers may take highly productive bottomland out of production, prompting the farmer to bring additional upland acres under intensive cultivation. If the intensified upland use increases nutrient loads and this induced load change is not part of a credit calculation procedure, leakage occurs. Secondary leakage can occur when credit-generating activities create changes in market conditions that might induce increased loads. For instance, if land conversion (for nutrient reduction) reduces

local vegetable production, the price of local produce may increase. Higher vegetable prices may then encourage additional vegetable cultivation elsewhere. Thus, new sources of nutrient loads are created indirectly through the new (higher) relative market price, but these induced load changes are unaccounted for in the trading system.

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 on the BMP installed on a portion of the farmer's land. As a result, nutrient trading programs need to calculate changes in nonpoint source loads based only on the land where the practice is installed, implicitly assuming that all other activities and loads on the agricultural operation or watershed remain constant. Bonham et al. (2006) found that incentives exist to create direct leakage on farms required to adopt riparian buffers or phosphorus-based nutrient management plans. Faced with certain nutrient requirements, dairy farmers shifted some land out of alfalfa production and into more nutrient-intensive corn. In such cases, the higher loads from land-use change completely overrode the per acre nutrient reductions. The study also reported that nutrients removed by installing riparian buffers were also partially offset by higher nutrient loads upstream from induced cropping intensification. Evidence of secondary leakage has been reported in federal land retirement programs (Wu 2000; Fleming 2010). However, given the limited number of acres affected by any nutrient trading program, secondary leakage is not likely to be significant.

Nutrient Assimilation Credits

Leakage can be a possibility with certain types of nutrient assimilation credit-generating activities. For example, shellfish aquaculture facilities may be expanded in one area to generate assimilation credits. The increase, however, could stimulate a reduction in cultivation activities elsewhere in the watershed by directly shifting production inputs from existing operations to the expanded (credited) areas. Secondary leakage issues may occur if expanded shellfish production induced by the additional revenue from nutrient credit sales eventually depresses the price of shellfish, reducing the supply and associated assimilation services that were present before the trade. Leakage appears to a relatively minor water quality concern for other types of nutrient assimilation service projects, including noncommercial bioharvest, nutrient assimilation wetlands, and stream restoration projects.

Primary leakage can be reduced for both nonpoint source reduction and nutrient assimilation services by relatively straightforward policies. For instance, nutrient accounting could be expanded from the practice level (e.g., project operation) to the entity level (e.g., entire

farm, firm) to help avoid unanticipated load increases from activity shifting within the management unit. More comprehensive firm-level accounting of loads, however, would increase the complexity and administrative cost of generating credits.

IV. Conclusion

Table 1 compares the likelihood that equivalent water quality outcomes will be secured though nutrient assimilation credits versus nonpoint source credits.[4] It lists the five strategies for producing nutrient assimilation credits—algal harvest, seaweed and other aquatic plant biomass harvest, shellfish aquaculture, stream restoration, and nutrient assimilation wetlands—and provides a qualitative assessment of the five criteria for ensuring equivalent water quality outcomes with a point source trading partner. For comparative purposes, Table 1 also lists three general classes of nonpoint source BMPs commonly proposed for nutrient trading programs: agricultural structural practices (riparian buffers, grass filter strips), agricultural management practices (cover crops, tillage practices, nutrient management), and land conversion.

What is clear is that many nutrient assimilation strategies are more likely to secure equivalence than nonpoint sources. Nutrient harvest technologies, particularly for algae and aquatic plants, provide greater measurement certainty (quantification), better temporal matching, and lower nonadditionality and leakage risks than agricultural nonpoint source projects. Across the five criteria, agricultural best management practices provide the greatest challenges to produce equivalent water quality outcomes in a trade with a point source. Agricultural BMPs are characterized by uncertain measurement, temporal mismatching of loads, leakage, and additionality concerns. Spatially, nutrient assimilation technologies could be located anywhere in the watershed and do not present any unique spatial challenges relative to the nonpoint source alternative. In no instances do nutrient assimilation strategies present special water quality concerns beyond those currently addressed in nonpoint source credit trading. Although nutrient loads from stream restoration and nutrient assimilation wetlands must be estimated, as with BMPS, these projects are less likely to provide nonadditional load reduction or create leakage.

[4] Although a more detailed characterization of the level of certainty for different crediting strategies would be warranted, the conceptual framework and a qualitative evaluation nutrient credit alternative do provide a first-cut insight into the comparative strengths of the nutrient assimilation alternatives.

Table 1. Summary of Water Quality Equivalence of Nutrient Credit Trading Options

	Quantification of outcomes	*Temporal matching*	*Spatial redistribution*	*Additionality*	*Leakage*
Nonpoint source credits					
Structural agricultural BMPs	Observed behavior Modeled outcomes	Stochastic loads, load averaging across time	Requires delivery attenuation estimates	Some nonadditionality likely	Some leakage potential
Management agricultural BMPs	Observed or reported behavior Modeled outcomes	Stochastic loads, load averaging across time	Requires delivery attenuation estimates	Some potentially significant nonadditionality	Some leakage potential
Land conversion	Observed behavior Modeled outcomes	Stochastic loads, load averaging across time	Requires delivery attenuation estimates	Some nonadditionality likely	Some leakage potential
Nutrient assimilation credits					
Nutrient assimilation wetlands	Measure or Modeled outcomes	Potentially stochastic loads, load averaging across time	Requires delivery attenuation estimates	Some nonadditionality likely, depending on stacking policy	Minimal
Shellfish aquaculture	Biomass Harvest: Measure Burial/denitrification: Model	Temporal matching of load reductions with buyers	Requires delivery attenuation estimates	Some nonadditionality likely	Some leakage potential
Algal harvest	Measure outcomes	Temporal matching of load reductions with buyers	May require delivery attenuation estimates	Nonadditionality not likely	Minimal
Seaweed and aquatic plant harvest	Measure outcomes	Temporal matching of load reductions with buyers	May require delivery attenuation estimates	Nonadditionality not likely	Minimal
Stream restoration	Model outcomes	Partially stochastic loads, load averaging across time	Requires delivery attenuation estimates	Some nonadditionality likely, depending on stacking policy	Minimal

Nutrient trading program designers recognize the uncertainty surrounding equivalence issues with point and nonpoint source trading programs. Regulators typically impose trading rules and procedures to address uncertainties between point and nonpoint sources and concerns about additionality and leakage (USEPA 2014a). These tools are not unique or specific to

nonpoint sources, however, and could be adapted to address equivalence issues for nutrient assimilation services. Nutrient assimilation credits hold potential to increase both the quantity and the quality of credits used by regulated point sources to achieve compliance. If nutrient assimilation credits can provide more certain water quality outcomes, then a strong case can be made for their inclusion in nutrient trading programs. For this reason, the possibility of allowing a point source to purchase nutrient assimilation service credits in a trading program is currently under consideration in Virginia and other places.

As with BMPs, rules will increase the likelihood of equivalence if a trade is permitted. Those rules may affect the relative cost of the two sources of credits, but that should not be a consideration for the regulator, whose responsibility is to ensure that water quality goals are not compromised by trading. If the rules for all forms of credits ensure equivalence, then the regulator can step back, and credit suppliers can compete to offer the lowest-cost credits that provide equivalence. The regulated point source is the appropriate entity to consider cost, or other factors, when determining whether to control on-site or to buy credits, and from whom. The regulators will have done their job by ensuring water quality equivalence.

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