The Use of Nutrient Assimilation Services in Performance-based Water Quality Incentive Programs

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Selected paper prepared for presentation at the Southern Agricultural Economics Association Annual Meetings, Orlando, FL, February 2-5, 2013

Partial funding and support for this research was provided by the United States Environmental Protection Agency's Ecosystem Services Research Program. The opinions and ideas expressed in this paper are the authors' and may not necessarily reflect the views of EPA.

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Introduction

Elevated nutrient levels have been identified as one of the primary factors contributing to variety of adverse water quality impacts in coastal waters (NRC 2000). Water quality managers typically respond by implementing a variety of regulatory requirements and financial inducements aimed at reducing nutrient loads at the source. In the United States, regulators will impose legally enforceable individual nutrient discharge limits on those sources (commonly referred to as "point" sources) over which they have permitting authority. For sources not subject to regulatory requirements ("nonpoint" sources such as from agriculture), water quality programs attempt reduce source loads through publicly-funded education campaigns and by partially financing the cost to install nutrient control technologies, frequently called best management practices (BMPs).

Given the scope of the nutrient enrichment issue, achieving socially desired levels of water quality has proven costly and challenging. Despite signs of progress, long standing nutrient control programs for the Chesapeake Bay and Long Island Sound still must achieve additional reductions before coastal water quality goals are achieved. Furthermore, reductions will need to be achieved by sources that are expensive, technically challenging to control, or beyond the scope of most regulatory programs. Extensive and costly investments in municipal and industrial point source nutrient control technologies have produced substantial reductions in nutrient loads. Reductions in other sources have proven more difficult. In Long Island Sound, nonpoint nitrogen loads have not decreased in 20 years (Long Island Sound Study 2013).

Another means to reducing nutrient loads in coastal waters is to implement a variety of technologies and processes that can increase the nutrient assimilative capacity of the ambient environment (enhancing nutrient sinks). Active human intervention to enhance the removal of nutrient loads directly from ambient waters is called nutrient assimilation services. Through expanding these services, water quality can be improved beyond what can be achieved by source load reductions alone. To date, water quality programs have devoted little attention and resources to exploring and developing technologies and programs to enhancing this nutrient removal pathway.

The objective of this paper highlight the variety of possible means nutrient assimilation services can be provided and to discuss the requirements, opportunities, and challenges to enhancing these services within existing water quality management programs in the United States. The paper begins by summarizing the removal pathways and technologies that can increase nutrient assimilation services. Areas where these efforts have been used explicitly and directly to remove nutrients from ambient waters are noted. Next, we describe how nutrient assimilation services can be enhanced through performance-based incentive programs such as water quality credit trading and payment for environmental services (PES). The final section provides a discussion of the policy opportunities and challenges of incorporating these activities in water quality management programs. We compare nutrient assimilation credits with nonpoint source reduction credits based on the extent to each achieves public water quality objectives.

Nutrient Assimilation Processes

Nutrient assimilation services are the result of actions to enhance the capacity of the aquatic environment to act as a nutrient sink. In general, nutrient assimilation services can be created or enhanced by managing one or more of the following processes: chemical transformation, nutrient harvest, and nutrient storage. Chemical transformation refers to the conversion of nutrients (particularly nitrogen) into biologically unavailable 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). Nutrient harvest occurs when nutrients present in ambient waters foster the growth of cultivated aquatic plants or animal biomass, so that the nutrients are sequestered in biomass and then removed from the aquatic system as the organisms are harvested (Rose et al 2010). Finally, nutrients may be removed from ambient waters by enhancing the sequestering nutrients in soil or aquatic sediments (e.g. via burial/storage processes).

These processes are present in four general strategies for creating or enhancing nutrient assimilation services: managed wetland systems, shellfish aquaculture, algal production facilities, and stream restoration.

Managed Wetlands

Wetlands have long been recognized for the nutrient cycling functions they provide (primarily chemical processing and storage). Wetlands provide these nutrient storage and chemical reduction processes naturally, but active human management can create and enhance these services. Constructed treatment wetlands are a common method to treat stormwater runoff. Wetlands have also been constructed to treat effluent wastewater. Unlike constructed treatment wetland systems designed to treat wastewater flows, nutrient assimilation wetlands remove nutrients from ambient source water. The type of source water is an essential difference between "treatment wetlands" and wetlands that provide assimilation services. Nutrient assimilation in managed wetland systems could be further enhanced by actively managing water flow through the wetland (timing, duration, magnitudes) and by the selection and management of wetland vegetation (Wetlands Initiative 2010).

A substantial literature exists summarizing the nutrient removal efficiencies of various Knight, 1996; Mitsch and Gosselink, 2000; Fisher and Acreman, 2004). Nutrient removal efficiency of emergent stormwater treatment wetlands ranges between 0 and 55% for total nitrogen and 15 to 75% of total phosphorus. Nutrient removal efficiencies, particularly for phosphorus, could be expected to 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). Nutrient assimilation wetlands have been estimated to remove 274 pounds of nitrogen and 24 pounds of phosphorus per acre from large Midwestern wetland systems with high nutrient inflows (Hey et al., 2005). In the Florida, ranchers participating in the Florida Ranchlands Environmental Service Project (FRESP) divert water from public canals or rivers into private wetland treatment areas for the purpose of removing phosphorus (Lynch and Shabman 2011).

Shellfish Aquaculture Enhancement

Oysters are productive filter feeders that graze on phytoplankton suspended in the water column. Nutrients in the water column are the primary source of energy in phytoplankton production. When oysters feed, a portion of the nutrients contained in the phytoplankton are converted into oyster tissue and shell (biosequestration). For this reason, enhanced oyster aquaculture operations, adding to the wild stock and current aquaculture production, can be a new source of nutrient removal from ambient waters. Aquaculture oysters (shellfish in general) require no feed inputs (no importation of nutrients into the system). Further, aquaculture oysters are exclusively the product of human intervention and the associated water quality improvements would not occur in the absence of that investment. Aquaculture oysters are spawned in hatcheries, reared in upwellers, and then grown out in designated areas that do not displace wild oyster populations.

Nutrients sequestered in oyster biomass are removed when harvested. Higgins et al. (2011) found that one million aquaculture Chesapeake Bay (*Crassostrea virginica*) oysters contain between 92 and 657 pounds of nitrogen in oyster shell and tissue (range depends on the size class of the oysters). 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).

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). Unlike many other shellfish, oysters filter constantly, even after the oyster has satisfied energy needs for maintenance and growth. 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. The extent of oyster aquaculture induced denitrification, however, is still open to scientific uncertainty (Higgins et al 2013). Although not often described as oyster aquaculture, establishment and maintenance of artificial oyster reefs may also provide nutrient assimilation services through this nitrogen removal pathway, even if the oysters are not harvested for sale.

Aquatic Plant Biomass Harvest

The active cultivation and management of aquatic plants is a long recognized means to improve water quality through the removal of nutrients from ambient waters. Managed aquatic plant systems (MAPS) have been the subject of considerable research. In the case of MAPS, all nutrient removal is achieved largely through sequestration and harvest of plant material.

A variety of aquatic plant species, including multiple species of microalgae, macro algae ("seaweed"), and aquatic plants (e.g. water hyacinths) have been investigated as potential nutrient removal pathways. MAPS production areas can be developed in either an offline or in-situ (inline) configuration. Offline systems divert ambient water into an adjacent grow-out areas or production facilities. Nutrients present in the ambient source water are used for plant growth but the vegetative treatment area does not occupy space within the source waterbody. After plant uptake of nutrients, water is returned to receiving water. In-situ systems designate specific vegetation production/harvest areas in the ambient aquatic environment for MAPS cultivation.

Research and interest in algae production facilities is expanding rapidly. One type of algal production technology involves pumping ambient water into a production area that includes prepared flat surfaces covered with an engineered geomembrane (called algal turf scrubbers). Periphytic algae grow on the prepared surface and sequester nutrients during growth. The algal biomass is then periodically harvested. The water is then discharged back into the water body with lower nutrient concentrations (Adey et al., 1993; Adey et al., 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 can be removed 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 scrubbers in the Chesapeake Bay.

In addition, a variety of macro algae (seaweed) can be actively cultivated and harvested and has been actively used as a means to mitigate the impact of nutrient-intensive finfish aquaculture (Neori et al., 2004). 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). In the United States, the Long Island Sound program is piloting the use of red seaweed (*Gracilaria)* as a nutrient removal strategy (Long Island Sound Study 2013). Floating aquatic plants (e.g., water hyacinth) 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).

Stream Restoration

Recently more attention has been given to the possibility that stream restoration can also facilitate and enhance nitrogen removal from ambient waters (Bukaveckas, 2007; Kaushal et al., 2008). Researchers hypothesize that the hydrologic features characteristic of modified stream channels and streams altered by urban environments diminish riparian denitrification rates. Stream stabilization and restoration activities that restore more naturally occurring stream features such as river bends and pool/riffle structures slow water velocities and stabilize stream channels/banks which may, in turn, enhance instream nitrogen processing (Kaushal et al., 2008). Reduced velocities may also reduce channel and bank erosion, reducing sediment and nutrients contributions to the stream. Alterations to stream hydrology often result in significant erosion of stream bed and bank materials, resulting in downcutting, mass wasting of stream banks, and significant sediment and nutrient export. Restorative approaches that reduce erosion and improve instream nutrient processing holds potential to solve urban drainage issues and generate nutrient reductions.

Policies to Expand Nutrient Assimilation Services

Most nutrient management water quality programs focus on restraining sources, through either mandatory or voluntary means, from discharging nutrients into a waterbody. With few exceptions, water quality programs rarely devote effort or resources to explicitly expanding nutrient assimilation services to achieve coastal water quality goals. Since nutrient assimilation services represent an enhancement or benefit to water quality, regulatory requirements cannot be imposed on service providers to expand water quality services since regulations are, by design, a restraining action. If water quality managers wish to utilize nutrient assimilation services to help achieve water quality goals, financial incentives for the provision of these services must be created. Nutrient assimilation services of interest here are specifically defined in terms of performance-based outcomes: the mass load quantity of nitrogen and/or phosphorus removed from given waterbody per unit of time (kg/year). Properly designed, performance-based incentive systems create motivations to search and secure low cost combinations of various nutrient reduction and nutrient removal technologies.

Performance-based payment for services programs differ from many other types water quality financial payment programs in how payments are made. Performance-based programs tie the level of payment with the quantity of the service provided (pounds of nutrient removed). In contrast, many public efforts to induce voluntary reductions in nonpoint sources make financial payments based on costs to install a technology or practice.

At a fundamental level, the creation of performance-based incentive programs requires the presence of buyers; organizations or people who are both willing and able to pay for nutrient removal. In general we focus attention on two general types of buyers, regulated dischargers and public agencies/nonprofit organizations.

First, buyers may be regulated dischargers who face mandatory nutrient control requirements. Many mature estuary restoration programs have created nutrient trading programs as a way to help provide compliance options to sources facing mandatory requirements to limit the total amount of nutrients nutrient discharged into a waterbody (Shabman and Stephenson 2007; Greenhalgh and Selman 2012; Selman et al 2009; Breetz et al. 2004). Nutrient trading programs are now part of many major coastal water quality improvement programs along the eastern United States including the Long Island Sound (Connecticut and New York), Chesapeake Bay (Maryland, Pennsylvania, and Virginia), Tar-Pamlico Estuary (North Carolina), and St. Johns River (Florida). While each trading program differs widely in design and operation, generally dischargers are granted varying degrees of discretion to meet a portion of their regulatory obligations by sponsoring nutrient reductions or removal from another party located offsite of the regulated discharge activity. Depending on the program, regulated sources may be able to sponsor quantified and verified nutrient load reductions, called credits, from other regulated point sources or from unregulated nonpoint sources.

In concept, regulated point sources participating in a trading program could also be allowed to offset excess nutrient loads (loads above assigned limits) by enhancing the level of nutrient assimilation services (Heberling, Thurston, and Mikota, 2007; Cherry et al., 2007; Stephenson and Shabman 2007; Newell 2004). Nutrient assimilation projects for the purpose of generating credits for use in a trading program have been piloted for nutrient removal wetlands (Hey et al., 2005), aquaculture shellfish harvest (Lindahl et al., 2005), and algal harvest (Pizarro et al., 2006). Some local programs, particularly for stormwater, have approved offsets that involve stream restoration (Henrico County, Virginia fee in lieu program) and removal of nutrients through temporary instream retention (Hanover County, Virginia). In 2012 Virginia was the first state in the U.S. to explicitly authorize the use of nutrient assimilation credits in a nutrient trading program.[1]

A second class of buyers include are agencies, organizations or individuals with a general interest in improving water quality. Unlike the first class of buyers, these agencies and organizations face no legal requirements to limit nutrient loads and are not offsetting reductions with increases in loads elsewhere. The buyer pays for water quality improvements outside of a regulatory program. These buyers participate in what generally can be called Payment for Environmental Services (PES) programs. Buyers in PES programs might include government agencies with a programmatic goal of improving water quality or nonprofit organizations with the organizational goals and resources to make water quality improvement investments.

While buyer motivations differ across the different classes of buyers, all buyers share a common interest in securing the most of the service possible, in this case nutrient reductions, per dollar spent. Like all exchange situations, buyers are interested in securing a documentable level of service. In the case of nutrient assimilation services, the service being provided is mass load of nutrients removed from the relevant ambient waterbody per unit of time. This requires that the transacting parties be able to measure the change in nutrient loads. The loads are then quantified into a transferable unit, called a credit. In exchange for payment, the buyer also requires assurances that the specified level of service (credit) is actually being provided. This includes verification of performance and specified actions in the case of nonperformance (compliance contracts).

Buyers in PES systems have a direct interest in ensuring that payments result in ensuring performance (that the service is delivered). In the case of trading programs, regulated parties participating as buyers may not have a direct stake in ensuring that claimed services are actually delivered. The buyers in a trading program may not be concerned that maintaining compliance with their permitted obligations and that the credits purchased for compliance are certified by the regulatory agency, The regulatory agency, acting as a proxy for the buyer, has the primary interest in ensuring water quality improvement actions produce the desired water quality performance.

[1] The Virginia law authorizes "certifying credits that may be generated from agricultural and urban stormwater best management practices, use or management of manures, managed turf, land use conversion, stream or wetlands projects, shellfish aquaculture, algal harvesting, and other established or innovative methods of nutrient control or removal, as appropriate." (§10.1-603.15:2.B.1.a)

The Policy Efficiency of Nutrient Assimilation Services: A Comparative Analysis

Investments in nutrient assimilation services can add another means to combat eutrophication of coastal waters and incentive-based programs can encourage the provision of this service, but the question remains as to whether pursuing such programs investments should be pursued or encouraged. A critical element in evaluating the efficacy of any nutrient management policy is to compare the certainty that alternative public or private nutrient control investments will deliver the desired water quality outcome.

A number of criteria can be used to evaluate and compare nutrient control alternatives, including quantification of performance, performance verification, baseline/additionality, and leakage (Stephenson et al., 2009). The following discussion will briefly describe general water quality evaluative criteria and then compare nutrient assimilation service investments with nonpoint source reduction projects. Nonpoint source reductions are selected as a point of comparison because we assume that regulated (point) source controls are already in place. We will compare nutrient assimilation services with nonpoint source reductions since both are most likely to be managed through voluntary, financial inducement type of programs. Thus, the overall question being considered is: “Can nutrient assimilation credits provide buyers and the public with levels of water quality assurances equal to or greater than nonpoint source credits?”

Quantifying Performance (Outcomes)

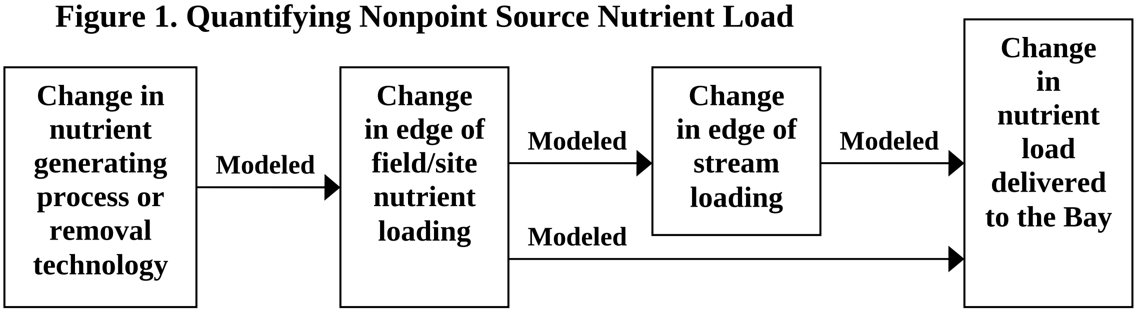
Nutrient management programs to combat eutrophication in coastal waters must be able to translate spatial, temporal, and source heterogeneity of nutrient loads into equivalent water quality results. Defining equivalence in water quality outcomes allows water quality managers to determine how different types of nutrient control efforts in different locations within the watershed will translate into changes in estuary water quality.

In a payment for service program, determining the credits expected from an action requires measuring either the reduction in nutrient discharge from a particular load reduction action and then delivered to the receiving water, or the expected removal of nutrients from receiving water. The realized change in nutrient reduction or removal can be estimated using either models or direct measurements, or combinations of both. Often the measured change in nutrient levels at a particular location in the watershed must then be translated into the change in load delivered to the target coastal water. Different quantification approaches will provide buyers with different levels of assurances that estimated reductions actually occur.

Quantifying changes in nonpoint source loads produced by a particular nutrient reducing action involves a number of steps (see Figure 1). Starting with the adoption of some technology or behavioral change (ex BMP implementation), models are used to estimate the change in flow and concentration of runoff from a field or site. Runoff may then travel, either through overland runoff or subsurface flow, some distance before entering a stream channel, necessitating the need to estimate changes in transport and loss of nutrients in the process. If the area upstream from the coastal water of interest, additional modeling is needed to estimate the portion of nutrients transported through miles of streams that reach the target coastal water (called attenuation). Weather also has obvious impacts on the timing of the reductions achieved. The timing and magnitude of rainfall will influence the actual load reductions achieved in a given time period. Performance-based nonpoint source incentive payment programs estimate changes in nonpoint source loads through the use models. To estimate nonpoint source credits in a nutrient trading program, both Pennsylvania and Maryland both use a model to estimate field level changes (edge of stream) in nutrient loads from the implementation of specific agricultural best management practices (BMPs). Virginia calculates nutrient load changes for a more limited set of agricultural BMPs and publishes the changes in the form of “look-up” tables that are derived from model results. Emerging urban stormwater management programs also quantify load changes from modeled load estimates. Virginia, for example, uses a spreadsheet model that estimates phosphorus and nitrogen loads given the application of stormwater control practices on three general categories of land cover (impervious surface, urban turf, and forest). In all cases actual nutrient removal performance is assumed to reflect modeled outcomes.

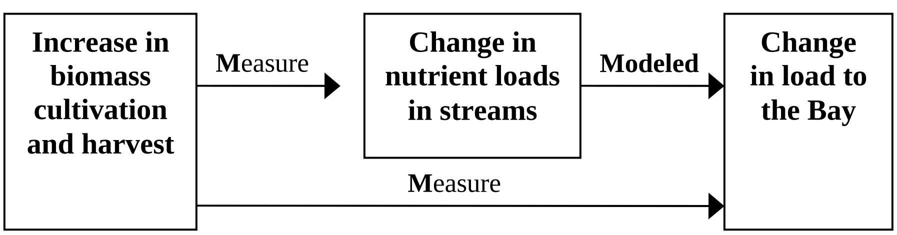
Models, obviously, vary significantly in terms of their sophistication to reflect the spatial and temporal variability. Some quantification protocols may not account for specifically for the spatial factors that influence nonpoint source loads (slope, soil type, proximity to surface waters) but will estimate load changes for individual projects based on spatial averages. Typically, modeled changes in nonpoint source loads are calculated based on average rainfall patterns and quantified reductions do not vary across years. Quantifying the time lags in change in nutrient loads associated with subsurface and groundwater flows represents another challenging issue in quantifying load changes. Regardless of the sophistication of the model, varying degrees of uncertainty will exist between estimated and actual loads at each stage in Figure 1.

Figure 1. Quantifying Nonpoint Source Nutrient Load



In contrast, the amount of nutrient removed through the use of nutrient assimilation projects can, in many instances, be quantified by direct measurement. For instance, nutrient removal via cultivated biomass harvest (e.g., algal, seaweed, aquaculture oysters) can be directly quantified by recording total harvested cultivated biomass (e.g., dry weight) and sampling the percent TN and TP composition of that biomass. If this biomass cultivation activity occurs in coastal water (or off-stream using estuary water), no further quantification is needed to measure the removal of nutrients (bottom arrow in Figure 2). If the biomass harvest occurs within upstream freshwater systems, model estimates (via delivery or attenuation ratios) would still be needed to translate measured nutrient removal into delivered removal to the downstream coastal water.

Figure 2. Quantifying Nutrient Removal via Cultivated Biomass Harvest



Measurement costs can be reduced if field results demonstrate that elements of the nutrient calculation procedure exhibit minimal variance over time. For instance, the TN and TP content of macroalgae (expressed in nutrients per unit of algal mass) has been found to be relatively stable across samples, time and location (Mulbry et al., 2010). If this is the case, then biomass harvesters might only need to measure the mass quantity harvested in order to generate accurate estimates of nutrients removed. In the case of aquaculture oysters in the Chesapeake Bay, nitrogen and phosphorus sequestered in harvested aquaculture oysters is directly and closely related to oyster size (measured by shell length) (Higgins et al., 2011). In this case quantifying nitrogen and phosphorus removal can be measured by the harvest of different size classes of aquaculture oysters.

Other nutrient assimilation processes may also 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 point source loads are monitored (Hey et al., 2005; Cherry et al., 2007). Nutrient removal of the wetland can be measured as the difference in calculated reductions in nutrient load between inflow and outflows.

Some nutrient assimilation processes, however, may be either too technically difficult or costly to measure directly. Measuring 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). Yet, some local stormwater programs now use stream restoration as an offset mechanism for increased nutrient loads from development activity. Measured changes in outcomes were based on the predicted removal derived from existing literature rather than measured, observed changes in ambient stream conditions. Multiple methods exist to quantify nutrient loads from stream restoration (Beisch 2011). Of course, this measurement practice is similar to how nonpoint load reductions are now measured. Similarly, the nutrient removal of nutrients from ambient water from the in situ water filtering of aquaculture oysters (via nutrient burial and denitrification of oyster biodeposits) is difficult to measure directly. The timing and duration of nutrient burial in sediments is also uncertain. Nutrient removal estimates would need to be developed through scientifically defensible modeled estimates.

Thus, nutrient assimilation projects provide similar or higher levels of certainty in quantifying changes in nutrient loads than nonpoint source reduction efforts. In many instances, changes in nutrient removal can be measured directly. Furthermore, the causal chain between action and change in nutrient loads in coastal waters are often shorter and more direct for nutrient assimilation projects than nonpoint source control practices.

Verification of Implementation, Operation and Maintenance of Actions

Protocols may also be necessary for buyers to verify that the modeled or measured load changes were produced from nutrient control activities. The type and certainty of verification will differ between various nonpoint source and nutrient assimilation credit technologies/processes.

As illustrated in Figure 1, nonpoint source reduction projects begin with the application of a nonpoint source BMPs. Agricultural nonpoint source reduction activities range from long term land conversion (ex. cropland to hay or forest), the installation of a control structure (ex. manure storage facility, infiltration basins) or annual activities such as planting of cover crops, conservation tillage, or reduced fertilizer applications. Since changes in loads from such activities are not measured directly, verification of credit-generating performance occurs by documenting and confirming the implementation and operation of practices. If verified to be installed and operated correctly, performance (as predicted by model estimates) is assumed to occur. The cost and certainty of verification of behavioral change differs across practices. While it might be relatively easy to verify land conversion activities through visual inspection and satellite imaging, verification of the timing of cover crop planting or the changes in fertilizer application rates must be accomplished indirectly through self-reporting.

Verification of performance for nutrient assimilation credits will differ across various nutrient assimilation approaches. Unlike nonpoint sources, many nutrient assimilation process focus on verification of outcomes. For example, verification of biomass harvest projects would focus on protocols to document mass weight of biomass harvested and perhaps sampling procedures to document the nutrient content of the biomass. Some types of biomass harvest activities might also require biomass source verification protocols. Cultivated biomass harvest represents new nutrient assimilation services to the aquatic ecosystem that do not diminish naturally occurring processes. Verification may be necessary to verify that the biomass harvested is the product of managed cultivation and not from the diminishment of wild, beneficial biomass. For instance, oysters grown in an aquaculture operation may not be easily distinguishable by sight inspection from wild caught oysters. In such cases, verification protocols beyond simple biomass measurement might be required. Such verification could be provided by documentation of the use of inputs necessary to produce aquaculture oysters (e.g., oyster seed purchases, private leases, grow-out permits, grow-out structures deployed). This type of verification is analogous to the approach needed to verify some nonpoint source BMP implementation (e.g., reduced fertilizer inputs, cover crop timing). Conversely, verification of the harvest of algal biomass in an algae production facility could be accomplished by the measurement of algal biomass produced since there is no concern about the harvest of "wild" algae.

Baselines and Additionality

In order to translate the quantified changes in service flow and the transferable credit, a starting or reference point for measuring the change in the level of service provision must be identified, called "baseline". The difference between the baseline level of performance and the level of nutrients achieved with the project is equal to the credits generated by the project. Establishing baselines are also critical in assuring that buyers also receive new nutrient reduction or removal services from their purchase, called "additionality". Additionality is the incremental increase in water quality services that would not have been achieved in absence of the incentive payment. Both nutrient assimilation and nonpoint source reduction both face challenges in defining baselines and ensuring additionality.

For nonpoint sources, the selection of a specific baseline has no precise analytical solution. Baseline definition involves issues of equity (fairness related to what levels of pollutant control responsibility assigned to different source sectors) and the level of buyer (public or private) assurance that equivalent water quality results will be achieved when trading occurs (additionality). Conceptually, nonpoint source baselines can be defined in a number of ways (Stephenson et al 2009; Ghosh, Ribaudo, and Shortle 2011). Baselines could be defined as the estimated load being discharge at a particular point in time. Credits are then calculated as the reduction in nutrient loads achieved after that date. A time-referenced baseline may be defined as a fixed point in time (for example at the beginning of a program) or the date in which a particular project or technology was installed. Alternatively, a baseline can be defined by referencing a specific level of performance. Nonpoint source performance baselines may be expressed as an estimated load that much be achieved (ex. nitrogen load discharged per acre) or as a minimum set of conservation practices that must be implemented before being eligible to count reductions.

Most trading programs stipulate performance baselines for nonpoint sources. Defining a performance baseline raises the question as to what level of performance? Typically performance baselines are established lower than typical levels of performance achieved by the nonpoint source. For instance, if the typical crop farm discharges 10 pounds of nitrogen per acre per year, a baseline of 8 pounds per acre might be established. If nonpoint source efforts reduce estimated loads to 5 pounds per acre, the farmer would receive 3 credits per acre (assuming a credit equals one pound). An stringent baseline helps ensure that a nonpoint source must under take new or "additional" nutrient reduction activities in order to receive credits. Such a baseline, however, also drives up the cost of generating a credit since many sources would need to make investments to make reductions to just achieve the baseline. Conversely, if less stringent performance baselines are established, nonpoint sources may generate credits without achieving additional reductions. Modifying the previous example, a 12 lbs/acre baseline would allow the average farm to generate 2 nonpoint source reduction credits without providing any new nutrient reduction services. Thus, performance baselines present a trade off between the cost of generating a credit and assurances that new nutrient reduction services are being provided.

Time-referenced nonpoint source baselines face principal-agent challenges. A time referenced baseline, for instance, could allow a nonpoint source the opportunity to manipulate current activities to increasing discharges before selling credits. Due to these challenges, some nonpoint source reduction credit programs establish a fixed date for a time-referenced baseline. For example, Virginia allows land owners to generate nonpoint source reduction credits by converting agricultural land to less nutrient intensive uses after a particular date (example January 1, 2005). Since land use change is continuous and ongoing, the question arises as to when land conversion (or other nonpoint source BMPs) can be counted as credit-generating activity.

In some respects, nutrient assimilation credit suppliers do not face the same baseline/additionality challenges as nonpoint source reduction activities. For example, nutrient assimilation credit suppliers face no nutrient removal performance expectations. Any new private investments to remove nutrients through the provisioning of nutrient assimilation services are above and beyond state and federal requirements or expectations. Similar to nonpoint source credits, some nutrient assimilation credits would require the establishment of baseline dates. For instance, wetland mitigation banking firms and oyster aquaculture firms provide services other than nutrient removal. The opportunity to participate in a performance-based incentive program would provide incentives to expand operations in order to provide new nutrient removal services. However, a time referenced benchmark would appear necessary in order to prevent an existing firm to claim credits for past investments. Once such time-referenced baselines are established, expansions of nutrient credit services (new nutrient farm wetlands, expanded oyster aquaculture production, etc. beyond the referenced date) could be counted as new (additional) services and credited. However, in practice it is impossible to demonstrate whether such investments would have occurred in absence of a PES payment.

Leakage

A related accounting challenge, called leakage, occurs from incomplete load accounting of nutrient reducing/removal activities. Leakage is the induced, but unaccounted for, increase in nutrient loadings that result from a nutrient credit purchase. Leakage is a potential concern for both nonpoint source and nutrient assimilation credit projects.

For nonpoint source reduction projects, an agricultural operation could generate nonpoint credits by installing BMPs such as riparian buffers on a portion of its land. Holding all other farming activities constant, the riparian buffer would reduce nutrient loads leaving the farm and nonpoint source credits could be generated (assuming baselines are met). The installation of forested buffers may take highly productive bottomland out of production, prompting the farmer to bring additional upland acres under active cultivation. If the intensified upland land use increases unaccounted nutrient loads, primary leakage occurs. Research suggests that farm operations do have such incentives and leakage is a potential concern with agricultural BMPs (Bonham et al., 2006). Similarly, a landowner who rents land to a farmer may elect to convert the land to forest and place in a conservation easement. The landowner could receive nonpoint source reduction for this activity, but this might prompt the farmer renting the land to bring new land under cultivation elsewhere.

The type of leakage just described occurs when the credit generator undertakes other actions that increase unaccounted for loads, called primary leakage. Another type of leakage, called secondary leakage, can occur when credit-generating activities create changes in market conditions that tend to increase pollutant discharges (Aukland et al., 2003). For instance, if land conversion (for nutrient reduction) reduces local vegetable production, the price of local produce may increase. Higher produce prices may then induce additional intensive vegetable cultivation elsewhere. Thus new sources of nutrient loads are created indirectly through trade activity but are unaccounted for in the trading system.

Leakage is also a potential issue for certain types of nutrient assimilation credit-generating activities. For instance, biomass harvesting activities may be shifted from location to location. Oyster aquaculture facilities may be expanded in one area in order to generate credits. The increase, however, could stimulate a reduction in cultivation activities elsewhere in the watershed. Leakage issues may be less likely for noncommercial bioharvest and creation of nutrient removal wetlands.

Primary leakage can be reduced for both nonpoint source reduction and nutrient assimilation services by relatively straight-forward policies. For instance, expanding nutrient accounting from the project level (e.g. project operation) to the entity level (e.g., entire farm, firm) would help avoid unanticipated load increases from activity shifting.

Other Policy Issues: Nutrient Removal versus Source Reductions

In some dimensions, nutrient assimilation service credits may provide buyers with greater assurances than nonpoint credits that water quality improvements are successfully secured. A question remains, however, as to whether nutrient management programs and efforts should include nutrient assimilation services as part of a portfolio of measures to achieve and maintain water quality standards.

In situations where the buyer is a regulated permitted source, there is some uncertainty whether it is legal to purchase nutrient assimilation services as a way to secure water quality objectives under U.S. law. The federal Clean Water Act (CWA) requires regulated (NPDES permitted) point sources to implement technology based effluent limits (TBEL) before granting a permit to discharge. TBEL are established for specific industries and pollutants and are based on specific reduction technologies at the load source. If water quality standards are not met, water quality-based effluent limits (WQBEL) are to be imposed. Early during the implementation of the CWA, EPA determined that instream treatment measures (ex. instream aerators, etc) could not be implemented in lieu of implementing end-of-pipe controls (TBEL or WQBEL) even if equivalent water quality outcomes (DO levels, for example) could be achieved (ex: EPA Memo from Deputy Assistant Administrator for Water Enforcement May 2, 1977). In short, enhancing the aquatic environment's sink capacity should not be used in lieu of source (point) effluent reduction.

In a contemporary context, nutrient assimilation services may not be considered instream treatment under U.S. federal law because regulated point source reductions are typically required in all major large scale nutrient reduction programs, thus nutrient assimilation service projects are not being proposed as a substitute for end-of-pipe treatment at NPDES regulated sources. Most nutrient management programs within the Chesapeake Bay do not allow regulated point sources to avoid advanced ("on-site") nutrient treatment. Both Virginia and Maryland require regulated dischargers to follow a well-defined sequencing logic that prioritizes the minimization of source nutrient discharge before trading is allowed. As the example, Virginia requires a new permitted point source to implement advanced nutrient treatment before being granted the authority to discharge. These stringent treatment requirements cannot be avoided through purchase of credit offsets. Regulatory programs only allow point-nonpoint source offsets to address growth in (uncontrollable) point wastewater flows and in instances where additional source reduction is technically difficult to achieve.

Shifting the discussion to PES programs, it might be argued that nonpoint source reductions should be prioritized over nutrient assimilation services. One argument is that water quality policy would be improved if nutrients never reach the receiving water in the first instance. This might be less of a concern based on two related observations. First, nutrient assimilation services can be positioned in the watershed to target areas of concern. For instance nutrient assimilation wetlands or biomass harvest projects might be placed upstream of coastal waters and adjacent to nutrient sources. Such a positioning would not only provide nutrient removal benefits from lower loads delivered to estuaries but also reduce nutrient levels in freshwater stream reaches. The difference in local water quality impacts between a landowner installing nonpoint control practices on a field adjacent to a stream and a nutrient assimilation service provider removing nutrients in the stream adjacent to field is likely to be negligible. Second, coastal nutrient control programs already recognize and rely on the fact that instream attenuation reduces that amount of nutrients delivered to coastal waters. A water quality manager electing to focus limited resources on nonpoint source control efforts near coastal waters would be similar to locating nutrient assimilation projects in the same location.

Prospective buyers of nutrient control services would ultimately need to decide if these differences are important. However, buyers will have strong incentives to consider the how much nutrients can be removed with their limited financial resources. If nutrient assimilation credits offer more water quality assurances and more nutrients removed from the target water body per dollar spent, then concerns over how nutrients are removed might not seem as important. In this context, it can be argued that recognition and use of nutrient assimilation service credits as part of an overall water quality management program is consistent with the U.S. Environmental Protection Agency's (EPA's) watershed approach that promotes multiple means to achieve water quality standards.

Cost Effectiveness

The cost to achieve nutrient reduction/removal would be an important consideration to buyers in either type of performance-based incentive program. In absence of an actual performance-based program, however, gaining reliable information on the cost per pound to reduce nutrients through agricultural nonpoint source reductions or remove nutrient through nutrient assimilation services is challenging. The cost estimates that do exist suggests that nutrient assimilation investments can remove nutrients at costs similar to nonpoint source removal.

Estimates of unit nonpoint source reduction costs exhibit considerable range. Early trades within the Pennsylvania nutrient trading program report nitrogen removal costs between around $5/lb/yr for conservation tillage. Costs are sensitive to baseline definitions. Virginia has more stringent baseline requirements than Pennsylvania and nonpoint source reductions from cover crops, fertilizer reductions, and land conversion could range from $4 to over $100 of N/lb/yr (Stephenson et al 2010). Others have reported nonpoint costs ranging from $3 to $30/lb/N (Jones et al. 2009).

Like nonpoint source nutrient removal costs, nutrient removal costs from nutrient assimilation wetlands vary widely. Removal costs in the mid-Atlantic region have been estimated to be between $8 and $200 of N/lb/yr, depending nitrogen removal rates (Stephenson et al 2010). Cost studies in the upper Mississippi River basin claim nutrient reductions using restored wetlands can be achieved at much lower costs, approaching approximately $1 per pound of nitrogen (Hey et al. 2005).

Less is known about the costs of other types of nutrient removal investments. One firm promoting algal turf scrubbers places the cost of nitrogen removal in one case study area to be $40/lb (Zivojnovich 2007), while other studies estimate the costs could be as low as $7/lb/yr (Jones et al 2009). Nitrogen removal via oyster aquaculture can range from $0 to $75/lb/yr (Stephenson et al. 2010. Cost estimates vary depending on assumptions about oyster prices, input costs, growth and nitrogen removal efficiencies.

While drawing conclusions from cost studies is difficult given the uncertainties, tentative evidence suggests that nutrient assimilation could be, depending on circumstances and technologies, cost competitive with nonpoint source reductions. A well-designed performance-based incentive program would reveal better information on the relative cost of the different methods of improving water quality.

Conclusions

When considering a number of water quality and economic evaluative criteria, nutrient assimilation credits may provide stronger buyer assurance that expected water quality outcomes are in fact being realized compared nonpoint source credits. Many types of nutrient assimilation projects offer more certainty in quantifying changes in nutrient loads compared to nonpoint reduction projects. Some types of nutrient assimilation credit-generating activities will require efforts to verify nutrient load reductions, ensure achievement of additional reductions, and prevent leakage, but these issues are not unique to nutrient assimilation credits. As the discussion above illustrates, similar issues confront the definition of nonpoint source credits. Credit definition protocols can be devised to address verification, additionality, and leakage issues for both nutrient assimilation credits and nonpoint source credits.

Achieving these coastal water quality goals will be challenging, but achieving and maintaining those goals in the face of population and economic growth will require a level of innovation and commitment far greater than what has so far been achieved. As additional nutrient sources are reduced, the cost of achieving incremental improvements will also be increasing. Recognition and incentivizing investment in nutrient assimilation services may offer water quality managers and regulated parties new ways to control costs and achieve additional water quality improvements. This discussion points out that nutrient assimilation credits can be used in similar ways as source reductions in incentive-based programs. Taken as a whole, nutrient assimilation credits may provide buyers and the public equal or additional certainty in achieving desired water quality outcomes than conventional nonpoint source reductions.

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