WRI POLICY NOTE

WATER QUALITY: EUTROPHICATION AND HYPOXIA No. 3

WORLD RESOURCES INSTITUTE

Eutrophication: Policies, Actions, and Strategies to Address Nutrient Pollution

MINDY SELMAN AND SUZIE GREENHALGH

Key Messages

Nutrient overenrichment of freshwater and coastal ecosystems—or eutrophication—is a rapidly growing environmental crisis. Worldwide, the number of coastal areas impacted by eutrophication stands at over 500. In coastal areas, occurrences of dead zones, which are caused by eutrophic conditions, have increased from 10 documented cases in 1960 to 405 documented cases in 2008. In addition, many of the world's freshwater lakes, streams, and reservoirs suffer from eutrophication; in the United States, eutrophication is considered the primary cause of freshwater impairment.

In order to reverse eutrophication trends and mitigate nutrient losses to aquatic ecosystems, policymakers should:

1. *Implement research and monitoring programs* to characterize the effects of eutrophication, collect water quality data, and inform adaptive management strategies. Information is a key element in the development of robust strategies to reduce eutrophication.
2. *Raise awareness of eutrophication.* Eutrophication and its effects are not well understood by the public or policymakers. Public awareness campaigns, school environmental education programs, and targeted outreach and technical assistance are all important components of raising the profile of eutrophication within communities and building a foundation and support for effective actions to reduce nutrient losses and eutrophication.
3. *Implement regulations to mitigate nutrient losses*, such as standards, technology requirements, or pollution caps for various sectors.
4. *Create fiscal and economic incentives to encourage nutrient-reducing actions* using taxes and fees, subsidies, or environmental markets.
5. *Preserve and restore natural ecosystems* that capture and cycle nutrients.
6. *Establish strong, engaged, and coordinated institutions* to address eutrophication. Effective institutions to implement and enforce policies are important to the success of any eutrophication strategy, especially where multiple jurisdictions are involved.
7. *Capitalize on environmental synergies* when designing comprehensive policies to address eutrophication. Many policies and activities associated with reducing nutrient pollution have synergies with other environmental problems such as climate change, smog, and acid rain. Policies selected and implemented should seek to maximize environmental benefits.

Nutrient overenrichment—or eutrophication—of freshwater and marine ecosystems is growing rapidly as a result of human activities (MA 2005; Mee 2006; Diaz 2007). Some of the more obvious signs of eutrophication include excessive phytoplankton and macroalgae growth, harmful algal blooms, proliferation of gelatinous organisms, and in the worst cases, the formation of hypoxic or "dead" zones. Nutrients reach coastal systems through surface water, groundwater, and air. The complexity and pervasive nature of nutrient losses means that reduction strategies need to be comprehensive, addressing multiple sources and pathways (Table 1).

The drivers of eutrophication are diverse and include complex and interrelated socioeconomic factors that ultimately lead to increasing levels of nutrient pollution. The direct drivers of nutrient pollution include energy consumption and fertilizer use which result in increased nutrients lost to the environment, as well as land-use conversion which diminishes the capacity of ecosystems to capture and cycle nutrients before they reach aquatic ecosystems. Indirect drivers of nutrient pollution include demographic shifts, expansion of intensive agriculture, and economic growth (Howarth 2008; Selman and Greenhalgh 2009).

TABLE 1. Primary Sources and Pathways of Nutrients

	Pathways		
Sources	**Air**	**Surface Water**	**Ground-water**
Sewage treatment plants		✔	
Industry	✔	✔	
Septic systems		✔	✔
Urban stormwater runoff		✔	
Agricultural fertilizers	✔	✔	✔
Livestock operations	✔	✔	✔
Aquaculture		✔	
Fossil fuel combustion	✔		

Purpose and Methods

This policy note provides an overview of the range of actions, policies, and institutions around the globe that address nutrient pollution and eutrophication. It complements two previous notes in this series, *Eutrophication and Hypoxia in Coastal Areas: A Global Assessment of the State of Knowledge* (Selman et al. 2008), and *Eutrophication: Sources and Drivers of Nutrient Pollution* (Selman and Greenhalgh 2009).

The policies and actions described in this policy note are findings from a study (see acknowledgements) undertaken by WRI to identify the important components of national and local policies, actions, and strategies (hereafter "policies") to reduce eutrophication. The policies presented in this paper were compiled using a combination of literature searches and interviews with eutrophication experts. This policy note does not attempt to develop an exhaustive list of all the policies that can be employed to address eutrophication, nor does it attempt to assess the effectiveness of these policies. Rather, it seeks to highlight approaches that are being used in various regions to address eutrophication either directly or indirectly. The policies presented in this paper are primarily drawn from regions that have already developed or are in the process of developing strategies to address eutrophication, including the Chesapeake Bay and the Mississippi-Atchafalaya Basin in the United States, the Baltic and Black seas in Europe, the Pearl River Delta in China, and the Seto Inland Sea in Japan.

Addressing Eutrophication

Given the diversity of pathways, sources, and drivers of nutrient pollution, policies to address eutrophication cannot be limited to traditional command-and-control approaches such as regulatory standards, nor can they be focused exclusively on a single sector such as municipal wastewater. Policymakers should look more broadly at agricultural, energy, land use, and public health policies and design these policies to mitigate nutrient pollution.

Types of policies to consider in a comprehensive nutrient reduction framework include (a) research, monitoring, and evaluation; (b) education and outreach; (c) regulatory approaches; (d) fiscal and economic incentives; (e) ecosystem preservation and restoration; (f) institutions and capacity building; and (g) synergies with other environmental goals.

These policies are described below, together with examples of how they have been implemented in specific regions to reduce nutrient pollution.

Research, Monitoring, and Evaluation

Research, monitoring, and evaluation activities are essential for characterizing the nature of the eutrophication problem, providing information and support tools to inform policies, and establishing effective measures for managing and reducing nutrient losses.

Relevant data and information to collect or derive include:

- Time series monitoring data to evaluate long-term trends and provide a better understanding of the drivers, sources, and impacts of eutrophication;
- Monitoring data to calibrate watershed models that assess nutrient fate and transport within watersheds, inform management scenarios, provide watershed analysis, and evaluate progress toward environmental goals;
- Nutrient source information such as location of sources, land use information, animal numbers, and population information;
- Watershed boundaries, location of waterways, and groundwater flows; and
- Nutrient budgets—watershed analyses that identify the amount and sources of nutrients entering waterways—to identify the appropriate actions to reduce nutrient losses. Nutrient budgets form the basis of nutrient reduction strategies and identify those actions needed to meet reduction targets for agricultural, urban, and point sources.

While research, monitoring, and evaluation efforts are critical, the quest for "perfect knowledge" has often delayed the development and implementation of strategies to mitigate eutrophication. For instance, research conducted over 20 years has found that nitrogen runoff from the Mississippi-Atchafalaya

River Basin is the primary cause of the Gulf of Mexico hypoxic zone, with agriculture being the primary source of nitrogen. Despite overwhelming scientific evidence, however, the Hypoxia Task Force—a body of experts and officials convened to address the issue of hypoxia in the Gulf of Mexico—continued to call for lengthy scientific reviews. Many criticized this as a tactic that allowed states to postpone implementing meaningful policies and actions to reduce nutrient pollution (Boesch 2007).

Because science may never be perfect and watershed conditions are likely to vary over time, policymakers should adopt an adaptive management approach when designing actions and policies for addressing eutrophication. Adaptive management recognizes that long-term management decisions based on conceptual modeling or limited knowledge may not be effective or practical because of the high levels of scientific uncertainty about natural systems (McQuatters-Gallop and Mee 2007). It creates flexible and pragmatic approaches that allow for the revision of management policies and goals as new information and data are received. The Black Sea Commission and its partner organizations, for example, use an adaptive management framework to inform management strategies and operational targets for eutrophication in the Black Sea. Ongoing monitoring and periodic watershed analyses are used to update these goals and management strategies.

In addition to the need for adequate data about eutrophication and its effects, it is important to support research and development of technologies, processes, and practices for mitigating and controlling nutrient losses. In the United States, for example, researchers have developed algal turf scrubbers to reduce nutrients in the water. The system diverts water from a river or reservoir to a pond where large quantities of algae are allowed to grow. The algae utilize nitrogen and phosphorus, reducing nutrient levels in the water. The algae can then be harvested and used for cattle feed or biofuel production. Demonstration projects using this technology are in place in Florida and California (Algal Turf Scrubber 2009).

Table 2 outlines important research, monitoring and evaluation activities, where they have been implemented, and conditions that impact their effectiveness.

Education and Outreach

Education and outreach include shaping values through environmental education in schools, building knowledge and skills through outreach to communities and industry, and raising public awareness and support for political action through targeted communication campaigns.

Environmental Education

Environmental education helps shape values and raise environmental awareness from an early age. It focuses on teaching the inherent value of the environment; the interconnectedness of environment, economy, culture, and health; and how human actions affect the environment. Environmental education may be the most important avenue for addressing the indirect drivers of eutrophication. It informs people about how the choices they make ultimately impact the environment and can lead to changes in individual behaviors and lifestyles that reduce nutrient pollution.

While some countries incorporate environmental education into primary and secondary school curricula, many do not. For instance, environmental education is lacking in many former Communist countries in the Black Sea region; as a result, social attitudes reflect the low value placed on the environment (McQuatters-Gallop and Mee 2007). Despite efforts by nongovernmental organizations (NGOs) in countries such as Romania, Russia, Bulgaria, Turkey, Georgia, and Ukraine, environmental education is still not widely incorporated in school curriculums.

In contrast, environmental education is an important component of efforts to restore the Chesapeake Bay in the United States. As part of the *Chesapeake 2000* agreement, states within the Chesapeake Bay drainage area agreed to incorporate Chesapeake Bay issues into school curriculums. For example, *Chesapeake 2000* stipulates that every student residing in the Chesapeake Bay region should have a "meaningful Chesapeake Bay and/or stream experience" before graduation from high school (Chesapeake Bay Program 2001).

Public Awareness

Raising awareness can change public perceptions of eutrophication, alter individual behavior, and pressure governments to take steps to mitigate eutrophication (Environment Australia 1999). The first step in raising awareness is to pose the question: "Why does it matter to me?" Relevant and reliable data and research are needed to underpin and create compelling messages. While messages should be based on sound science, they should be expressed in terms and concepts that are easily understood by the public.

In the Chesapeake Bay, for instance, public awareness efforts include iconic images of crabs and slogans such as "Save the Bay" and "Treasure the Chesapeake." Other efforts in the Chesapeake Bay include marking storm drains that carry runoff into the Chesapeake Bay or its tributaries (in an effort to

TABLE 2. Examples of Eutrophication Research, Monitoring, and Evaluation Activities

Activity	Example	Key Conditions Impacting Effectiveness
Monitoring	Organizations such as the Chesapeake Bay Program (Chesapeake Bay, U.S.), LUMCON (Gulf of Mexico, U.S.), and Environment Wiakato (Lake Taupo, NZ) coordinate ongoing water quality monitoring efforts for their respective jurisdictions. The Black Sea Global Ocean Observing System (GOOS), currently under development, will provide a data portal to improve public access to high-quality information and time series data.	• Sufficient funding for routine monitoring • Sufficient expertise to undertake monitoring, evaluate the data, and modify management practices or policies (where necessary) • Effective means of collecting, coordinating, and disseminating monitoring data in a way that is useful to researchers and policymakers
Assessment of water bodies (based on monitoring data)	The Clean Water Act in the United States requires biannual assessment of water bodies to determine if they are impaired for their designated use (e.g., fishing, swimming, drinking) and, if so, identify the sources of impairment. The OSPAR Commission (North-East Atlantic, Europe) adopted the Common Procedure for Identification of the Eutrophication Status of the OSPAR Maritime Area. The procedure is used by all signatory countries to assess their national waters and identify areas that are eutrophic or at risk of eutrophication.	• Sufficient monitoring data to make informed assessments • Sufficient funding and expertise • Institutions and expertise to undertake these assessments • Expertise to evaluate the data and establish processes to adapt management practices or policies if necessary
Watershed modeling	The Chesapeake Bay Watershed Model in the United States is used to estimate nutrient and sediment delivery to the Chesapeake Bay and run predictive scenarios of nutrient loads based on watershed management strategies.	• Sufficient funding and expertise to develop, calibrate, and run a model • Availability of monitoring data to set model parameters and calibrate models
Evaluation and management frameworks	The United Kingdom is piloting Eutrophication Control Action Plans (ECAPs) as a broad framework for addressing eutrophication. The framework calls for (a) identifying the problem; (b) assessing nutrient sources; (c) assessing management options; (d) determining best approaches; and (e) implementing agreed-upon actions.	• Existence of an organization with the expertise to undertake research and develop tools • Sufficient resources (technological, financial) to develop tools and frameworks
Nutrient reduction research and development	Several efforts are under way to develop crops with increased nutrient efficiencies that will reduce fertilizer needs.	• Sufficient funding • Adequate means to distribute findings and bring technologies to market

Sources: Black Sea Global Ocean Observing System 2009; Chesapeake Bay Program 2009a; Defra 2007; OSPAR Commission 2009.

prevent dumping); marking watershed boundaries with road signs; offering license plates with a Chesapeake Bay theme; implementing subway advertising campaigns and educational displays; and garnering newspaper and television media coverage of the issue.

Outreach and Technical Assistance

Outreach activities and technical assistance are important for building the knowledge and skills required for individuals and industries to begin addressing nutrient pollution. For example, outreach to the agricultural community can educate farmers on nutrient-related pollution issues and farm-level management practices that mitigate nutrient losses. In the United States, the U.S. Department of Agriculture provides support to educate farmers on conservation practices and provides technical assistance to farmers implementing nutrient-reducing management practices, such as appropriate manure handling and fertilizer application rates. As with most policies, the success of outreach and technical assistance will vary depending on the effectiveness of the outreach strategy, suitability of the technology or practice being promoted to meet community needs, ease of adoption, and willingness to change on the part of the targeted community.

Table 3 provides an overview of different types of education and outreach actions, along with some examples and conditions that will impact their effectiveness.

Regulatory Approaches

Regulatory approaches, also referred to as “command-and-control” approaches, represent one of the most straightforward approaches to controlling pollution, including nutrients.

Environmental regulations can take two general forms: standards and emissions/effluent caps or limits. While standards

TABLE 3. Examples of Education and Outreach Actions to Address Eutrophication

Policy / Strategy	Example	Key Conditions Impacting Effectiveness
Environmental education programs in schools	The Baltic Sea Project includes an association of over 200 schools that have pledged to combine environmental education focused on the Baltic Sea with intercultural learning. The project seeks to raise student awareness of environmental problems in the Baltic region and to help them develop a sense of responsibility for the environment. Schools from Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, and Sweden take part in the project.	• Funding to develop programs • Literacy of proposed audience • Capacity of educators to develop curriculum and teach the subject matter • Ability to integrate environmental education concepts across various subject matters as well as across grade levels
Public awareness campaigns	Japan carried out various public awareness campaigns to emphasize the importance of water quality. For example, September 10 of each year was named Sewage Day and October 1 was named the Promotion Day for Combined Household Wastewater Treatment Facilities.	• Existence of an organization to undertake campaign • Understanding of the messages and media that will be most effective at reaching the target audience • Funding to undertake campaigns
Public access to environmental information	The Chesapeake Bay Program has created a data clearinghouse that allows decisionmakers, scientists, and the public to access data on the state of the Bay's environmental conditions.	• Availability of credible and reliable information • Presence of an organization/body to undertake public environmental education • Factors that may limit access to information such as access to the Internet • Existence of legislation/policies that bestow rights on citizens to access information on the environment
Technical assistance/targeted outreach and education	The GEF-sponsored Agricultural Pollution Control Project in Romania led to the development of a "Code of Good Agricultural Practices." The code provided explicit linkages between the EU Nitrates Directive and best management practices on the farm. The document was disseminated to agricultural extension agents in Romania and used an easy-to-follow format that allowed for easy application of these practices at the farm level. Japan's "Upgrading Promotion Project" under the New Generation Sewage Support System is being implemented to promote improved sewage technologies and increased efficiency in operations.	• Farming community buy-in • Expertise of potential technical assistance providers • Knowledge and understanding of the sources—e.g., agriculture, municipal wastewater—that contribute to nutrient pollution • Knowledge or existence of practices/technologies to mitigate nutrient losses from the source • Capacity/willingness of sources to adopt nutrient-reduction practices/technology • Adequate funding/capacity for outreach activities or technical assistance

Sources: Baltic Sea Project 2004, Chesapeake Bay Program 2009b, GEF and World Bank 2006, Japan Ministry of the Environment 2003

specify certain technologies, practices, or processes that must be implemented, regulatory caps set a level of acceptable pollution but do not dictate how this level is to be achieved. The two regulatory approaches are described in more detail below.

Standards

Standards prescribe particular technologies, practices, or processes that are meant to achieve a specific outcome. Standards might also impose limits on pollution or activities in order to protect the environment. Examples of regulatory standards are listed below (adapted from Sands 2003):

- *Environmental quality standards* restrict pollution or activities in order to protect the resource or the environment. For example, harvest limits on oysters in the Chesapeake Bay are being used to lessen pressures on the oyster population in the Bay. Oysters provide a valuable ecosystem service by consuming algae and other waterborne nutrients.
- *Product/manufacturing standards* establish levels of pollutants that cannot be exceeded in the manufacture of a product or emissions from a product. Product standards might also specify the properties or specifications for product design. For example, U.S. law includes NOx

TABLE 4. Examples of Regulatory Standards for Control of Nutrient Pollution

Policy / Strategy	Example	Key Conditions Impacting Effectiveness
Environmental quality standards	The European Union (EU) Nitrate Directive requires that areas designated as Sensitive Farming Areas (SFAs) must not have manure application rates that exceed 170 kg/ha/yr. To meet this regulation, each country can design an action program that contains measures relating to 1) periods when application of animal manure and fertilizers is prohibited, 2) capacity of and facilities for the storage of animal manure, and 3) limits to the amounts of animal manure and fertilizers applied to land.	• Ability to assess appropriate actions needed to protect the environment • Capacity to monitor and enforce compliance • Willingness of policymakers to regulate activities/impose standards
Product/ manufacturing standards	Several countries and U.S. states have implemented legislation to ban or reduce phosphates in dish and laundry detergents. U.S. appliance standards require manufacturers to produce appliances that meet minimum federal energy efficiency standards.	• Information on environmental impact of current and alternative product formulation or manufacturing process • Availability/cost-effectiveness of alternate formulations/processes • Willingness of policymakers to implement and fund enforcement of product/manufacturing standards • Capacity (in terms of funding and knowledge) of industry to implement product/manufacturing standards
Process/design standards	California's (U.S.) Energy Efficiency Standards for Residential and Nonresidential Buildings were first established in 1978 in response to a legislated mandate to reduce California's energy consumption. The standards were most recently updated in 2008 to incorporate recent innovations in technologies and methods.	• Information on environmental impact of current and alternative process/design standards • Availability/cost-effectiveness of required process/design standards • Willingness of policymakers to implement and fund enforcement of process/design standards • Capacity (in terms of funding and knowledge) of industry to adopt/implement process/design standards
Technology standards	Denmark requires biological nitrogen removal treatment for all wastewater treatment plants servicing more than 5,000 people. Stormwater permits in the United States require municipalities to manage urban stormwater runoff. The permits require municipalities to implement a suite of best management practices that reduce stormwater runoff volume and remove some pollutants.	• Information on environmental impacts of current and proposed technology standards • Availability/cost-effectiveness of required technology • Willingness of policymakers to implement and fund enforcement of technology standards • Capacity (in terms of funding and knowledge) of industry to adopt/maintain/operate new technology

Sources: California Energy Commission 2009; Defra 2009; Denmark Environmental Protection Agency and National Environmental Research Institute 2009; EPA 2009d.

emission standards for vehicles sold in the United States. Vehicles must be designed in such a way as to not exceed maximum NOx emission thresholds.

- *Process/design standards* include installation and design standards as well as operating standards. Installation and design standards set requirements that must be met in the design and construction of various installations. Operating standards determine requirements that must be met during the operation of an installation. In Maryland, the Stormwater Management Act of 2007 provides design standards for developers that require new developments to manage stormwater runoff and use design practices with low environmental impact. Mitigating stormwater runoff helps prevent nutrient losses through runoff.
- *Technology/practice standards* include prescriptions for the type of technology that must be used or the practices that must be implemented to achieve the desired environmental outcome. For example, in Maryland, all major treatment plants are required to upgrade to enhanced nitrogen removal treatment technologies. Enhanced nutrient removal is the current state-of-the-art technology for nutrient removal in wastewater treatment plants. It is capable of reducing nitrogen concentrations in wastewa-

TABLE 5. Examples of Regulatory Limits and Caps to Reduce Nutrient Pollution

Policy / Strategy	Example	Key Conditions Impacting Effectiveness
Effluent discharge limits (for wastewater and industrial facilities)	National Pollution Discharge Elimination System (NPDES) permits in the United States are increasingly written to include nitrogen and phosphorus effluent limits. Maryland, Virginia, and Pennsylvania (U.S.) are including annual nitrogen and phosphorus effluent limits in wastewater treatment plant permits.	• Information to set discharge limits • Availability of equipment/technology/expertise to monitor discharge • Willingness of policymakers/environmental agencies to set and enforce limits
Effluent limits (for agriculture and aquaculture operations)	Denmark has implemented effluent limits for nitrogen and phosphorus discharges from marine aquaculture operations. New Zealand's Lake Taupo watershed created nitrogen discharge allowances for agricultural land within the watershed.	• Availability of necessary information to set limits • Availability of equipment/technology/expertise to control discharge • Existence of organization/body to set and enforce limits • Willingness to regulate agricultural community
Emission caps (for industry)	The U.S. Clean Air Interstate Rule (CAIR) was designed to set a cap for NOx emissions with the goal of reducing emissions by 70 percent.*	• Availability of information to set discharge limits • Availability of equipment/technology/ expertise to monitor discharge • Willingness of policymakers/environmental agencies to set and enforce caps
Watershed-based caps	In Japan, waters that do not meet environmental quality standards are subject to area-wide total pollutant load control reduction targets.	• Availability of information to set watershed cap and appropriately allocate loads across sectors • Existence of organization/body to set cap and administer program to reach cap • Enforcement of the cap/accountability of various sources to meet their load allocation

Sources: Danish Ministry of the Environment 2004; EPA 2009f; National Institute of Water and Atmospheric Research, New Zealand 2008.
Note: *The Clean Air Interstate Rule was vacated in 2008. However, an appeals court later ruled that the rule would remain in place until the U.S. Environmental Protection Agency develops a new clean air program for power plants.

ter discharge to 3 mg/l and phosphorus concentrations to 0.3 mg/l. In contrast, biological nutrient removal technology can only reduce nitrogen concentrations to 8 mg/l and phosphorus concentrations to 3 mg/l (Saffouri 2005).

Table 4 outlines examples of environmental quality, product, process, and technology standards that have been employed to directly or indirectly reduce nutrients.

Effluent/Emissions Limits and Caps

Effluent/emissions limits and caps include limits on the amount of allowable pollution discharge that can be emitted to the air or water. Unlike standards, regulatory caps do not prescribe the implementation of specific technologies or practices; rather, they place limits on the amount of pollution (e.g., nutrients) that can be released into the environment. The regulated source is generally given flexibility on how this cap is met.

In some cases, regulatory caps are placed at the watershed level, or at some other aggregate level. In the case of watershed caps, the amount of nitrogen or phosphorus leaving a watershed is capped and individual sources of nutrient pollution within the watershed must ensure that this cap is met. For example, under the U.S. Clean Water Act, states must develop and implement a total maximum daily load (TMDL) for water bodies that are impaired by excess nutrients. The TMDL sets a watershed cap and identifies the nutrient sources and reductions required from each source to comply with the TMDL. For instance, in the Long Island Sound (Connecticut and New York, U.S.) a TMDL was developed for nitrogen that calls for the removal of 24,000 tons of nitrogen by 2014. The TMDL identified that 80 percent of the nitrogen load was from wastewater treatment plants, with the remainder of the load coming from urban stormwater runoff and atmospheric sources originating outside of the watershed. The implementation of the TMDL resulted in effluent nitrogen limits for all wastewater treatment plants in the basin, effectively requiring a 64 percent reduction in nitrogen discharges from regulated facilities (Connecticut Department of Environmental Protection 2001).

Table 5 outlines examples of effluent and emissions limits and watershed caps.

Economic and Fiscal Incentives

Economic and fiscal incentives for reducing eutrophication include ecotaxes, incentive payments/subsidies, ecolabeling, and environmental markets (adapted from Sands 2003). These mechanisms are meant to complement or avoid regulatory approaches. These policies are described in more detail below.

Ecotaxes

Ecotaxes, also known as green fees and taxes, are meant to create "full cost accounting" of economic activities by using fiscal policies to internalize negative externalities. Some examples of green fees and taxes that can be used in the context of mitigating eutrophication include:

- *Polluter-pays tax*. A polluter-pays tax provides economic incentives for ecologically sustainable activities—or, conversely, disincentives for activities that are not ecologically sustainable. For example, Denmark's wastewater tax, imposed on point sources (industry and wastewater treatment plants), levies a tax on every unit of nitrogen, phosphorus, and biological oxygen demand (BOD) discharged in wastewater (EcoTech 2001). Similarly, the Netherlands employs a fee system for agriculture that levies fines on farms with nitrogen and phosphorus in excess of their approved nutrient budget (Hoffmann and Boyd 2006).
- *Dedicated environmental tax*. Governments can impose taxes and fees directly on a sector or population, and then use the revenue to fund nutrient reducing activities or technologies. For example, in Maryland (U.S.) an annual fee commonly called the "flush tax" is levied on every household and business in the state via their water and sewer bill. The revenues from this tax are used to upgrade wastewater treatment plants with nutrient removal technologies and add nitrogen-removing capability to septic systems.
- *Taxes on technologies/products/inputs with negative environmental impacts.* Placing a tax on technologies, products or inputs that are associated with negative externalities creates a price signal aimed to reduce demand for the taxed good. The effectiveness of this kind of tax is dependent on the elasticity of demand and availability of substitutes.

Incentives and Subsidies

Incentive payments, subsidies, tax credits, and low-interest loan programs are economic instruments used to encourage adoption of desirable practices. Agricultural conservation subsidies in the United States are used to encourage farmers to implement best management practices that will reduce nutrient and soil loss on farms. In Pennsylvania, the Resource Enhancement and Protection Program provides a tax credit for farmers who implement best management practices that improve water quality. Pennsylvania estimated that over a two-year period (2007-2008) the program reduced nitrogen pollution by 162,176 pounds and phosphorus runoff by 14,939 pounds (Pennsylvania Department of Agriculture 2009). The U.S. Clean Water State Revolving Fund (CWSRF) loan program currently offers $5 billion annually in low-interest loans to municipalities and wastewater treatment plants to help fund water quality protection projects for wastewater treatment and watershed management (EPA 2009a). Since inception, the CWSRF program has spent more than $2.9 billion to control pollution from nonpoint sources and for estuary protection (EPA 2009a).

The effectiveness of incentive payments improves when performance-based approaches are used (Greenhalgh et al. 2006). Performance-based approaches use incentive payments based on actual environmental outcomes rather than paying for actions and implementation of practices. Performance-based approaches can include incentive payments based on quantitative estimates of environmental benefits as well as mechanisms such as reverse auctions. Reverse auctions have been used in the United States and Australia to cost effectively allocate money to landowners who reduce nutrient losses (Eigenraam 2005; Greenhalgh et al. 2007; Selman et al. 2008). In reverse auctions, multiple sellers (e.g., landowners) compete to supply a single buyer (e.g., the government) with a specified good or service, enabling the buyer to locate the most competitive sellers. In an environmental context, reverse auctions can be used to maximize environmental benefits given a limited funding budget.

Ecolabeling

Ecolabeling is a voluntary method of certifying products that are produced in a way that is environmentally preferable to other products in the same product/service category based on life cycle considerations. Ecolabeling is meant to create consumer preference for "green" products and thus generate a financial return to the supplier of the certified product in the form of increased revenues. Ecolabeling of agricultural products can provide incentives for farmers who wish to certify their products and adopt sustainable agricultural practices.

Environmental Markets

Environmental markets, including regulatory and voluntary markets, use a market to provide price signals for environmental goods and are meant to align behavior with environmental goals.

TABLE 6. Examples of Economic and Fiscal Incentives to Reduce Nutrient Pollution

Policy / Strategy	Example	Key Conditions Impacting Effectiveness
Polluter-pays tax	Florida (U.S.) has imposed an Everglades Agricultural Privilege Tax for every acre of productive land in the Everglades Agricultural Area. Landowners who maintain a minimum phosphorus concentration (50ppb) in water discharged from their land have a lower tax rate.	• Willingness of policymakers to levy taxes/impose fees • Organization/agency to levy tax and collect revenue • Ability to identify and measure the inputs that could be taxed • Ability to monitor and assess effluent
Dedicated environmental fee/ tax	In Croatia, there are various water-related fees including water use fees, water protection fees, sand and gravel extraction fees, and basin water management charges. A public utility, Croatian Waters, is responsible for collecting the fees. All revenues from collected fees go towards financing sewage and water treatment projects.	• Willingness of policymakers to levy taxes/impose fees • Existence of an organization/agency to levy tax and collect revenue • Fiscal discipline to reserve tax revenues for their intended use
Technology/ product/input taxes	Sweden imposes a nitrogen fertilizer tax. Tax revenues are used to fund other measures to control nitrogen losses from farms.	• Willingness of policymakers to levy taxes/impose fees • Existence of an organization/agency to levy tax and collect revenue • Ability to identify what inputs or outputs could be taxed to mitigate the problem
Subsidies and low-interest loans (for wastewater facilities)	The World Bank is providing loans to China to finance the Guangdong province Pearl River Delta Clean-up Campaign. The money will be used primarily to finance wastewater treatment plant upgrades.	• Capacity of wastewater facilities to undertake necessary upgrades • Availability of funding from lending/grants institution • Capacity of wastewater facilities to repay loans
Subsidies (for households)	In Japan, some municipalities subsidize individuals for installing household wastewater treatment facilities.	• Willingness of individuals to take voluntary action • Awareness of how individuals can reduce their own nutrient pollution • Availability of funding

Regulatory markets are meant to provide flexibility to regulated sources, thereby reducing the financial burden of regulatory compliance with limits or caps on nutrient emissions. For example, regulatory water quality trading markets for nutrients exist in the United States, Canada, and New Zealand (Selman et al. 2009) and are designed both to minimize the costs of complying with effluent nutrient caps and to offset new nutrient discharges from new and expanding sources. One example of an active water quality trading program is the Long Island Sound Nitrogen Credit Exchange in Connecticut. Connecticut allows wastewater treatment plants capped under the Long Island Sound TMDL to meet their nitrogen discharge limits by upgrading their facility or by purchasing nitrogen offsets from another facility that is operating below its discharge limit. Another example is in New Zealand. Farmers in Lake Taupo are able to purchase additional nitrogen discharge allowances from other farms or implement management practices to meet their regulatory obligations or expand their production.

Conversely, voluntary markets are not driven by regulation, but by the value placed on the environmental good or service by the buyer. Voluntary markets generally follow the "payment for ecosystem services" model, where buyers (motivated by altruism or self-interest) are willing to pay landowners to maintain or enhance ecosystem services (e.g., water purification, flood control, carbon sequestration). For example, in the Chesapeake Bay, a consortium of NGOs has established a voluntary nutrient market called the Chesapeake Fund. Individuals and companies that wish to offset their "nutrient footprint" can purchase nutrient offsets from the Fund. In turn, the Chesapeake Fund uses these revenues to pay farmers in the watershed to implement nutrient-reducing best management practices.

Table 6 outlines some economic and fiscal incentives used to reduce nutrient pollution.

TABLE 6. *continued*

Policy / Strategy	Example	Key Conditions Impacting Effectiveness
Subsidies (for agriculture)	The EU's Common Agricultural Policy (CAP) provides green payments to farmers who reduce fertilizer use, introduce organic farming measures, promote biodiversity, or reduce grazing density.	• Institutional capacity to administer programs • Knowledge of appropriate nutrient-reducing management practices and their effectiveness • Existence of policies that may reduce program effectiveness or participation (e.g., commodity title of U.S. farm bill) • Availability of funding
Ecolabeling	Water Stewardship, Inc. is working with agricultural producers in the Chesapeake Bay and other areas of the country to develop and implement Continuous Improvement Programs (CIPs) to reduce nutrient-related impacts on water. Producers that implement these plans will be able to market their products to beverage manufacturers, processors, and distributors as sustainably produced.	• Customer demand for products with ecolabels • Agreed-upon sustainability criteria • Adequate certification measures in place to ensure that producers are following sustainability criteria
Regulatory environmental markets	Pennsylvania's water quality trading program (U.S.) caps existing wastewater treatment plants at 6 mg/l nitrogen and 0.8 mg/l phosphorus (at design flow) and stipulates that there will be no waste load allocation for new or expanding facilities. Treatment plants are allowed to trade (or purchase offsets) with other treatment plants or with nonregulated nutrient sources to meet their waste load allocations. Facilities with no allocation must obtain offsets for 100 percent of their load.	• Expertise to establish environmental market • Information and willingness/ability to set regulated caps • Existence of an organization/body to administer the market • Availability of necessary infrastructure to administer the market • Sufficient nutrient mitigation options to generate offsets
Voluntary environmental markets/payments for ecosystem services	The New York City (U.S.) water utility pays farmers in the Catskill basin to implement agricultural best management practices that reduce nutrient losses. Similar payment schemes exist in France, where Nestlé-Vittel and Danone-Evian pay farmers near their water bottling operations to implement measures that protect water quality.	• Willingness of institution/organization to purchase nutrient reductions or implement a program • Ability to measure and monitor the ecosystem service provided • Ability to identify providers of the ecosystem service

Sources: Campbell et al. 2004; European Commission 2009; Morris and Kis 2004; Pennsylvania Department of Environmental Protection 2009; Perrot-Maitre 2006; South Florida Water Management District, Office of the Inspector General 1998; United States Department of Commerce, Commercial Service 2008; Water Stewardship, Inc. 2009; World Bank 2009.

Ecosystem Preservation and Restoration

Preserving and restoring riparian forests, wetlands, mangroves, and open areas can mitigate nutrient pollution by creating and maintaining natural nutrient sinks. These policies can take many forms, including:

- *Protected areas*. Establishing protected areas through legal measures can serve to protect and preserve critical ecosystems. In 1998, 6,264 km^2 of the Danube Delta (Romania and Ukraine) were protected as part of the UNESCO Man and Biosphere program. The Danube Delta lies on the coast of the Black Sea and is Europe's largest wetland and reed bed. It is a critical ecosystem for capturing and cycling nutrients (UNESCO 2007).
- *Land purchases and establishment of conservation easements*. Public and private purchases of ecologically valuable land as well as establishment of conservation easements (i.e., the purchase of development rights) can help reduce nutrient pollution by protecting ecosystems that capture and cycle nutrients. For example, the Worcester Land Protection Partnership is a partnership between the city of Worcester (Massachusetts, U.S.) and the Trust for Public Land, a nonprofit land conservation organization, aimed at identifying and acquiring priority watershed land for the purpose of improving and maintaining water quality within the rivers and reservoirs (Trust for Public Land 2008).

TABLE 7. Examples of Ecosystem Protection and Restoration Policies to Mitigate Eutrophication

Policy / Strategy	Example	Key Conditions Impacting Effectiveness
Protected areas	The Wadden Sea—a highly eutrophic sea bordered by the Netherlands, Denmark, and Germany—contains several designated protected areas. Under the EU's Birds and Habitats directives, which provide a legal framework for protecting critical species and habitats, several areas of the Wadden Sea have been designated as Special Protection Areas (SPAs). Within SPAs, measures must be taken to ensure sustainable use of resources and protection of critical plants and animals. In addition, the Ramsar Convention on Wetlands (an international framework for protecting wetlands) has designated several wetlands and marsh areas along the coast of the Wadden Sea as Ramsar sites. Finally, the individual countries bordering the Wadden Sea have taken independent steps to create state nature preserves and national parks.	• Availability of land to protect • Ability to identify/target most appropriate areas to protect • Ability to enforce land protection • Adequate funding to purchase/maintain protected areas
Land purchases/ conservation easements	Established in 1969, Maryland's "Program Open Space" (U.S.) provides funds for the state to purchase land that will be maintained as open space. These parcels may become parks or maintained as natural areas. In part, the open space policy is aimed at creating and maintaining "green infrastructure" in urban settings, which reduces nutrient runoff.	• Ability/willingness of individuals/NGOs/ governments to purchase land • Willingness of landowners to sell land/development rights • Adequate funding to purchase/maintain land
Ecosystem restoration	Denmark launched a wetland restoration strategy in 1998 to restore 3,000 hectares of former wetlands every year for 20 years (equal to 2 percent of the present farmland area). These areas will be restored as lakes, bogs, meadows, marshes, and swamp forests.	• Existence of an institution/agency to undertake restoration efforts • Funding to restore habitat • Scientific and technical knowledge of appropriate restoration efforts

Sources: Common Wadden Sea Secretariat 2009; Maryland's Program Open Space 2009; Ramsar 2001.

- *Habitat restoration*. Often the aquatic ecosystems most severely impacted by eutrophication are those that are already degraded due to other causes (Mee 2006). Shoreline erosion, loss of submerged aquatic vegetation, and human pressures on fish stocks make ecosystems more vulnerable to the impacts of eutrophication. In the United States, Maryland and Virginia have both funded restoration efforts aimed at restoring submerged aquatic vegetation and replenishing oyster beds in the Chesapeake Bay.

Table 7 lists examples of policies to protect or restore ecosystems.

Institutions and Capacity

Without strong institutional authority, adequate funding, and properly trained personnel, the effectiveness of regulations, policies and actions to reduce eutrophication is limited. China, for example, has several aggressive policies addressing water quality, but the implementation and enforcement of these measures at the local level has been inadequate. Until recently, China's State Environmental Protection Agency (SEPA) had only about 300 staff and no independent fiscal resources (McGray 2007). In 2008, SEPA was upgraded to ministerial level and became the Ministry of Environmental Protection (MEP) with independent fiscal resources and greater staff, signaling the government's intention to strengthen the authority of the environmental protection office. The elevation of the former SEPA to ministerial level has allowed the local Environmental Protection Bureaus (EPBs) to exert greater influence over certain projects within their regions. However, while reorganization of the MEP has been an important step in strengthening environmental oversight in China, there are still only 2,600 MEP staff—a number far below countries with "strong" environmental protection institutions. The United States Environmental Protection Agency (EPA), for example, has 17,000 employees across the country (EPA 2009b), and this figure does not include staff in state environmental offices who are responsible for implementing and enforcing many of the national environmental regulations.

In addition to transparency, accountability, and capacity of existing institutions that are tasked with carrying out policies for reducing nutrient pollution, a comprehensive framework for addressing eutrophication will also likely require significant cooperation among the various government agencies, jurisdictions, and stakeholders. Because the sources and causes of eutrophication are varied, it is unlikely that any single agency will have the mandate to fully implement a comprehensive strategy for mitigating eutrophication, making it necessary to forge partnerships with key institutions and in some cases create bridging institutions to coordinate information and activities among the various agencies, stakeholders, and national authorities.

A number of actions can help strengthen institutions, address institutional and capacity shortfalls, and create the kind of institutional cooperation that is needed to address eutrophication. Some actions include:

- *Creating transparency and accountability in institutions and government.* Communities with access to information can participate in the decision-making process, and those with access to justice are more assured that policy decisions will consider sustainable development and the interests of the poor. An informed and empowered public monitors government and corporate performance, is alert to problems, challenges the conventional wisdom of government or corporate decisionmakers, discusses the issues, organizes social and political change, and demands improvements (WRI 2009).
- *Building capacity in existing institutions.* Often institutions lack the funding, staff and/or technical expertise to enforce environmental regulations or otherwise carry out their mandate. Civil society organizations and/or the general public can exert pressure to obtain sufficient funding, increase staffing, implement training programs, and improve management of important institutions.
- *Creating new institutions.* Creating new institutions or changing the mandate of existing institutions may be necessary to effectively address eutrophication. For instance, since 1990 stormwater control regulations in the United States have required municipalities to obtain permits for stormwater discharge, but often the municipal regulatory institutions were not well-equipped to manage and assess compliance with these permits. As a result, community-based stormwater utilities have been formed with the authority to charge fees, dedicate revenue to compliance measures, and coordinate community activities.
- *Creating key partnerships and/or bridging institutions.* The multisectoral and transboundary nature of many eutrophication issues requires coordination among agencies and jurisdictions to effectively reduce nutrient pollution. Water quality monitoring and information management are two important areas for cooperation among agencies, jurisdictions, and countries. In some instances, cooperation might entail closer agency or jurisdictional cooperation and partnerships that include a commitment to share information and coordinate actions. For large regional issues, however, a coordinating agency or bridging institution may create a better platform for coordination among the various stakeholders. The Chesapeake Bay Program in the United States, for instance, is a bridging institution that was created to bring together members of various federal, state, local, academic, and nongovernmental organizations to build and adopt policies that support the Bay's restoration. The Chesapeake Bay Program directs and conducts the restoration of the Chesapeake Bay, coordinates policy responses, conducts research and monitoring, and compiles and distributes data. Similarly, the DABLAS Task Force in the Black Sea provides a platform for cooperation for the protection of water and water-related ecosystems of the wider Black Sea region. Its mandate is to develop conservation activities, identify funding sources for priority projects, and develop regional eutrophication strategies with the International Commission for Protection of the Danube River (ICPDR) and Black Sea Commission to address eutrophication issues.

Table 8 outlines actions related to institutions and capacity that are aimed at facilitating implementation of policies to reduce nutrient pollution.

Exploiting Synergies with Other Policy Goals

Because there are strong linkages between the sources and drivers of eutrophication, climate change, and other important environmental issues such as air pollution and acid rain, policymakers should exploit the linkages between eutrophication and other local, regional, and global environmental issues and identify those policies that minimize tradeoffs and maximize environmental benefits. Combustion of fossil fuels, for example, emits NOx, which can be a significant source of nutrient pollution to aquatic ecosystems through the process of atmospheric deposition (Spokes and Jickells 2006). NOx also contributes to other environmental problems such as acid rain and smog. In addition to NOx, combustion of fossil fuels also releases significant amounts of carbon dioxide—the gas that is primarily responsible for climate change—into the atmosphere. Policies aimed at reducing combustion of fossil fuels through energy conservation, energy efficiency, and promotion of alternative energy thus have multiple environmental and public health benefits (Moomaw 2002).

TABLE 8. Examples of Actions to Strengthen Institutions and Capacity to Reduce Nutrient Pollution

Policy / Strategy	Example	Conditions Impacting Effectiveness
Institutional transparency and accountability	The newly created Institute of Public and Environmental Affairs (IPEA), based in Beijing, recently launched a groundbreaking website that displays data on water quality in China and highlights the emissions of high- and low-performing industries. IPEA aims to hold industry and government accountable to water quality goals by supporting community-based water quality monitoring.	• Access to information • Access to justice • Access to public participation • Existence of watchdog groups/concerned citizenry
Institutional capacity	UNESCO-IHE Institute for Water Education has several projects to strengthen institutional capacity. In one project, UNESCO-IHE is providing skills and training to university staff in China and India. The project promotes dissemination of principles about green design and pollution prevention among Chinese and Indian academics, engineers, and government agency staff. The goal is to enable China and India to improve their own expertise in pollution prevention, green engineering, and environmentally benign products to promote sustainable development. It also promotes communication and information exchange on environmental topics among European and Asian partners and creates a basis for further cooperation.	• Adequate funding • Adequate educational resources
Innovative institutions	To address stormwater issues and comply with permits, several cities in the U.S. have created stormwater utilities that are given fiscal resources and authority to coordinate compliance activities.	• Political will to create such institutions • Sufficient institutional mandate and authority • Adequate funding and personnel
Partnerships between key agencies	A partnership agreement signed between the U.S. Department of Agriculture and the U.S. Environmental Protection Agency in 2006 agreed to coordinate efforts related to water quality trading markets.	• Existence of appropriate agencies to form such partnerships • Willingness of agencies to partner
Bridging institutions	Helsinki Commission: Baltic Marine Environment Protection Commission (HELCOM) is composed of members from nine countries that border the Baltic Sea. It develops policy, provides data, and coordinates multilateral environmental actions. Specifically, HELCOM is in charge of monitoring and implementing the 50 percent nutrient reduction targets for the Baltic Sea.	• Relationship between authorities in different jurisdictions • Ability to enforce multijurisdictional actions • Shared level of knowledge and expertise across jurisdictions

Sources: HELCOM 2009; Institute of Public and Environmental Affairs 2009; UNESCO-IHE Institute for Water Education 2009; USDA NRCS and EPA OW 2006.

Another area with considerable environmental synergies is agricultural policy (Greenhalgh and Sauer 2003). Agricultural policies aimed at providing incentives to farmers to install and implement improved nutrient management on their farms often have several environmental benefits beyond improved water quality. Best management practices that reduce nutrient runoff can also improve wildlife habitat, reduce soil erosion, sequester carbon dioxide, and reduce emissions of nitrous oxide, a greenhouse gas with a warming potential 281 times greater than carbon dioxide (EPA 2009c).

In contrast, policies aimed at mitigating eutrophication that are narrowly focused on regulating wastewater treatment plants have very few environmental co-benefits. In fact, many of the nutrient removal technologies that would be installed by wastewater treatment plants use significantly more energy—which, depending on the method of energy generation, may lead to greater emissions of NOx and carbon dioxide—and possibly emit a significant portion of the captured nitrogen into the atmosphere through volatilization (Foley 2007). While controlling nutrient discharges from wastewater treatment plants can be important for addressing eutrophication, it is necessary for policymakers to weigh tradeoffs and ensure that the selected policies adequately consider the various sectors, sources of nutrient pollution, and other environmental issues.

Conclusions and Key Findings

Without decisive action by policymakers, the number of water bodies affected by eutrophication will continue to increase, given that the drivers of eutrophication—population growth, agricultural intensification, and changing consumption patterns—are expected to result in even greater nutrient losses to the environment (MA 2005; Howarth 2008; Selman 2009). The actions needed to mitigate nutrient losses—and therefore reduce eutrophication—are far-reaching and diverse. Key areas for policymakers to focus are:

1. *Implementing research and monitoring programs* to characterize the effects of eutrophication, collect water quality data, and enable the use of adaptive management strategies. Information is a key element in the development of robust strategies to reduce eutrophication. While good information is important for the development of robust strategies, it is important to recognize that the science may not be perfect, and watershed conditions may continue to change. Adaptive management approaches allow for immediate action while permitting the adjustment of targets, actions, and policies as new science becomes available.
2. *Raising awareness of eutrophication*. Eutrophication and its effects are not well understood by the public or policymakers. Public awareness campaigns, school environmental education programs, and targeted outreach and technical assistance are all important components of raising the profile of eutrophication within communities and building the foundation for effective actions to reduce nutrient losses and eutrophication.
3. *Implementing regulations to mitigate nutrient losses*. These regulations may include standards, technology requirements, or pollution caps.
4. *Creating fiscal and economic incentives to encourage nutrient-reducing actions*. These types of economic and fiscal incentives include ecotaxes and fees, subsidies, and environmental markets.
5. *Preserving and restoring natural ecosystems.* Preserving and restoring natural ecosystems such as wetlands and forests can help increase or preserve the natural ecosystem functions that capture and cycle nutrients.
6. *Establishing strong, engaged, coordinated, and active institutions.* Effective institutions to implement and enforce policies are important to the success of any eutrophication strategy, especially where multiple jurisdictions are involved. In some instances, effective policy implementation may involve creating new institutions or changing the mandate of existing ones.
7. *Capitalizing on environmental synergies when designing eutrophication policies*. Awareness and consideration of environmental synergies when designing eutrophication policies will help reduce negative environmental tradeoffs associated with certain policies, capitalize on policies that generate multiple environmental benefits, and potentially create broader public interest, awareness, and additional funding opportunities.

Given that nutrient pollution is expected to increase in the next 50 years, leading to increased eutrophication and more severe impacts on aquatic ecosystems, it is imperative that policymakers begin taking decisive actions now. While developing strategies and policies for addressing eutrophication, it is important to consider not only the multiple sources of nutrient pollution and the multiple nutrient pathways (groundwater, surface water, and air), but also the other environmental issues that have close synergies with water quality. Policymakers should carefully consider policies that maximize environmental returns. Energy and agricultural policy represent areas where significant opportunities exist to achieve multiple environmental benefits in the pursuit of reducing the impacts of eutrophication.

About the Authors

Mindy Selman is a senior associate in the People & Ecosystems Program of the World Resources Institute.

Suzie Greenhalgh is the research leader for Sustainable Ecosystems and a senior economist at Landcare Research New Zealand Ltd.

Acknowledgments

The authors are grateful to Donald Anderson (Woods Hole Oceanographic Institution), Robert Diaz (Virginia Institute of Marine Science), James Galloway (University of Virginia), Paul Harrison (Hong Kong University), Laurence Mee (Plymouth University, UK), Nancy Rabalais (Louisiana University Marine Consortium), and Qian Yi (Tsinghua University, China), who served on a WRI eutrophication advisory panel and provided input to the original unpublished study: *Eutrophication: an Overview of Status, Trends, Policies and Strategies.* The authors would like to thank Sara Walker for her research assistance and Craig Hanson, Janet Ranganathan, and Cy Jones for reviewing earlier drafts of this paper. Finally, we extend our thanks to the David & Lucile Packard Foundation and the Linden Trust for Conservation for their support.

References

Algal Turf Scrubber. 2009. "Ecological Systems Technology." Available at: http://www.algalturfscrubber.com/about.htm.

Black Sea Global Ocean Observing System. 2009. "Major aims and objectives." Available at: http://www.ims.metu.edu.tr/black_sea_goos/index.htm.

Baltic Sea Project. 2004. "About BSP." Accessed at: http://www.bspinfo.lt/.

Boesch, D. 2007. Comments to the Mississippi River Basin and Gulf of Mexico Hypoxia Task Force, Thirteenth Meeting. Available at: http://www.umces.edu/President/TaskForceComments.pdf.

California Energy Commission. 2009. "Title 24: California's Energy Efficiency Standards for Residential and Nonresidential Buildings." Available at: http://www.energy.ca.gov/title24/.

Campbell N., V. Novotny, A. Frost, B. D'Arcy, and A. Sansom. 2004. *Diffuse pollution: an introduction to the problems and solutions.* Cornwall, UK: IWA Publishing.

Chesapeake Bay Program. 2001. *Stewardship and Meaningful Watershed Education Experiences.* Available at: http://chesapeakebay.net/pubs/subcommittee/cesc/c2k.pdf.

Chesapeake Bay Program. 2009a. "Modeling." Available at: http://www.chesapeakebay.net/modeling.aspx?menuitem=19303.

Chesapeake Bay Program. 2009b. "Bay Resources Library." Available at: http://www.chesapeakebay.net/bayresourcelibrary.aspx?menuitem=13998.

Common Wadden Sea Secretariat. 2009. "About the Trilateral Wadden Sea Cooperation: Protection of the Wadden Sea." Available at: http://www.waddensea-secretariat.org/trilat/brochure/3protection.html.

Connecticut Department of Environmental Protection. 2001. "The Long Island Sound TMDL: Frequently Asked Questions." Hartford, CT: CDEP. Available at: http://www.ct.gov/dep/lib/dep/water/lis_water_quality/nitrogen_control_program/tmdlfaq.pdf.

Danish Ministry of the Environment. 2004. *Nature & Environment 2003: Water in Denmark*. Available at: http://www2.mst.dk/common/Udgivramme/Frame.asp?pg=http://www2.mst.dk/udgiv/Publications/2004/87-7614-380-5/html/kap03_eng.htm.

Defra. 2007. "Science and Research Projects: Development of a risk assessment and decision-making tool to control diffuse loads of P and particulates from agricultural land." Available at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=1&ProjectID=9692.

Defra. 2009. "Implementing the Nitrates Directive in England." Accessed at: http://www.defra.gov.uk/ENVIRONMENT/water/quality/nitrate/directive.htm.

Denmark Environmental Protection Agency and National Environmental Research Institute. 2009. "Nutrients and Eutrophication in Danish Marine Waters: Nutrient reduction strategies in Denmark." Available at: http://www2.dmu.dk/1_viden/2_miljoe-tilstand/3_vand/4_eutrophication/Nutrient_reduction.asp.

Diaz, R. and R. Rosenberg. 2008. "Spreading Dead Zones and Consequences for Marine Ecosystems." *Science* 321(5891): 926–929.

EcoTech. 2001. "Study on Economic and Environmental Implications of the use of Environmental Taxes and Charges in the European Union and Member States." Available at: http://ec.europa.eu/environment/enveco/taxation/pdf/xsum_table_of_content.pdf.

Eigenraam, M., C. Beverly, G. Stoneham, and J. Todd. 2005. "Auctions for multiple environmental outcomes, from desk to field in Victoria, Australia." Paper presented at the 80th Annual Western Economic Association International Conference, July 4-8, San Francisco, CA.

Environment Australia. 1999. *Today Shapes Tomorrow: Environmental Education for a Sustainable Future.* Available at: http://www.environment.gov.au/education/publications/discpaper/index.html#toc.

European Commission. 2009. "Agriculture and Rural Development: Agriculture and the environment." Available at: http://ec.europa.eu/agriculture/envir/index_en.htm.

Foley, J., D. Haas, K. Hartley, and P. Lant. 2007. "Life Cycle Assessment of Biological Nutrient Removal Wastewater Treatment Plants." Paper presented at the 3rd International Conference on Life Cycle Assessment, August 27-29, Zurich, Switzerland. Available at: http://www.lcm2007.org/paper/180.pdf.

Global Environmental Facility (GEF) and the World Bank. 2006. "How Codes of Good Agricultural Practices Contribute to Nutrient Reduction." *International Waters Experience Notes* 2006-010.

Greenhalgh, S. and A. Sauer. 2003 *Awakening the Dead Zone: An Investment for Agriculture, Water Quality, and Climate Change*. Washington, DC: World Resources Institute.

Greenhalgh, S., M. Selman, J. St. John, and J. Guiling. 2007. *Paying for Environmental Performance: Using reverse auctions to allocate money for conservation*. Washington, DC: World Resources Institute. Available at: http://pdf.wri.org/pep_reverseauction.pdf.

Helsinki Commission: Baltic Marine Environment Protection Commission (HELCOM). 2009. "About HELCOM." Available at: http://www.helcom.fi/helcom/en_GB/aboutus/.

Hoffmann, S. and J. Boyd. 2006. *Environmental Fees: can incentives help solve the Chesapeake's nutrient pollution problems*. Washington, DC: Resources for the Future.

Howarth, R. 2008. "Coastal nitrogen pollution: A review of sources and trends globally and regionally." *Harmful Algae* 8(1): 14–20.

Institute of Public and Environmental Affairs. 2009. "China Water Pollution Map." Available at: http://en.ipe.org.cn/.

Japan Ministry of the Environment. 2003. *Quality of the Environment in Japan 2003.* Tokyo: Japan Ministry of the Environment. Available at: http://www.env.go.jp/policy/hakusyo_e/honbun.php3?kid=221&bflg=1&serial=2.

Japanese Ministry of the Environment. 2003. *Quality of the Environment in Japan 2003*. Available at: http://www.env.go.jp/policy/hakusyo_e/honbun.php3?kid=221&bflg=1&serial=2.

Maryland's Program Open Space. 2009. "Program Open Space Grants: an overview." Available at: http://www.dnr.state.md.us/land/pos/pos_101.asp.

McGray, H. and K. McDonald. 2007. *China's Yunnan Province: Challenges and Opportunities in Environmental Governance*. Unpublished.

McQuatters-Gallop, A. and L. Mee. 2007. *Eutrophication in the Black Sea: A Case Study.* Unpublished.

Mee, Laurence. 2006. "Reviving Dead Zones." *Scientific American* 295 (5): 79–85.

Millennium Ecosystem Assessment (MA). 2005. *Ecosystems and Human Well-Being: Current State and Trends.* Washington, DC: Island Press. Available at: www.millenniumassessment.org/en/products.global.overview.aspx.

Moomaw, W. 2002. "Energy, Industry and Nitrogen: Strategies for Decreasing Reactive Nitrogen Emissions." *Ambio* 31(2): 184–189.

Morris, G. E. and A. Kis. 2004. *Assessment and Development of Municipal Water and Wastewater Tariffs and Effluent Charges in the Danube River Basin.* New York, NY: United Nations Environment Program Global Environment Facility. Available at: http://www.undp-drp.org/pdf/1.6-1.7_Tariffs%20and%20Charges%20-%20phase%201/1.6-7_Tariffs-Charges_Vol1-Aug04.pdf.

National Institute of Water and Atmospheric Research, New Zealand (NIWA). 2008. "Nutrient trading to improve and preserve water quality." Available at: http://www.niwa.co.nz/news-and-publications/publications/all/wa/17-1/trading.

OSPAR Commission. 2009. "Eutrophication." Available at: http://www.ospar.org/content/content.asp?menu=00190303000000_000000_000000.

Pennsylvania Department of Agriculture. 2009. *Resource Enhancement and Protection Program: 2007–2008 Report*. Harrisburg, PA: Pennsylvania Department of Agriculture, State Conservation Commission. Available at: http://www.agriculture.state.pa.us/agriculture/lib/agriculture/pasccfiles/documents/2007_-2008_REAP_Rpt.pdf.

Pennsylvania Department of Environmental Protection (PADEP). 2009. "PA Nutrient Trading." Available at: http://www.dep.state.pa.us/river/Nutrient%20trading.htm.

Perrot-Maitre, D. 2006. *The Vittel payments for ecosystem services, a perfect PES case?* London, UK: International Institute for Environment and Development.

Ramsar Convention on Wetlands. 2001. "A preliminary overview of national wetland policies in Europe." Available at: http://www.ramsar.org/mtg/mtg_reg_europe2001_nwps2.htm.

Saffouri, W. 2005. *Maryland goes beyond other states in enhanced nutrient removal (ENR)*. Baltimore, MD: Maryland Department of the Environment. Available at: http://www.mde.state.md.us/ResearchCenter/Publications/General/eMDE/vol1no7/enr.asp.

Sands, Philippe. 2003. Principles of International Environmental Law (Second Edition). Cambridge: Cambridge University Press.

Selman, M., S. Greenhalgh, E. Branosky, C. Jones, and J. Guiling. 2009. *Water Quality Trading: An International Overview*. Washington, DC: World Resources Institute.

Selman, M. and S. Greenhalgh. 2009. *Eutrophication: Sources and Drivers of Nutrient Pollution*. Washington, DC: World Resources Institute.

Selman, M. S. Greenhalgh, R. Diaz, and Z. Sugg. 2008. *Eutrophication and Hypoxia in Coastal Areas: A global assessment of the state of knowledge*. Washington, DC: World Resources Institute.

Selman, M. S. Greenhalgh, M. Taylor, and J. Guiling. 2008. *Paying for Environmental Performance: Potential Cost Savings Using a Reverse Auction in Program Sign-up.* Washington, DC: World Resources Institute.

South Florida Water Management District, Office of the Inspector General. 1998. *Audit of the Everglades Agricultural Privilege Tax*. Available at: http://www.sfwmd.gov/pls/portal/docs/PAGE/PG_GRP_SFWMD_INSPECTORGENERAL/PG_SFWMD_INSPGEN_REPORTS/PORTLET_REPORTS/TAB372033/AGTAX.PDF.

Spokes, L.J., and T.D. Jickells. 2005. "Is the atmosphere really an important source of reactive nitrogen to coastal waters?" *Continental Shelf Research* 25: 2022-2035.

Trust for Public Land. 2008. "Worcester Watershed Land Partnership." Available at: http://www.tpl.org/tier3_cd.cfm?content_item_id=14796&folder_id=260.

UNESCO-IHE Institute for Water Education. 2009. "Project Activities: Human Resources Development for the improvement and protection of environment in Asia." Available at: http://www.unesco-ihe.org/Project-activities/Project-database/Human-Resources-Development-for-the-improvement-and-protection-of-environment-in-Asia.

UNESCO-MAB. 2007. "Biosphere Reserve Information: Danube Delta." Available at: http://www.unesco.org/mabdb/br/brdir/directory/biores.asp?mode=all&code=ROM-UKR+01.

United States Department of Agriculture, Natural Resources Conservation Service (USDA NRCS) and United States Environmental Protection Agency, Office of Water (EPA OW). 2006. "Partnership Agreement Between the United States Department Of Agriculture Natural Resources Conservation Service and the United States Environmental Protection Agency Office of Water." Available at: http://www.nrcs.usda.gov/NEWS/pdf/wqtpartnershipagreement.pdf.

United States Department of Commerce, Commercial Service. 2008. *Croatia Wastewater and Sewage Market Report 2008*. Washington, DC: U.S. Department of Commerce. Available at: *www.buyusa.gov/environmental/92.doc*

United States Environmental Protection Agency (EPA). 2009a. "Clean Water State Revolving Funds." Available at: http://www.epa.gov/owm/cwfinance/cwsrf/.

United States Environmental Protection Agency (EPA). 2009b. "About EPA." Available at: http://www.epa.gov/epahome/aboutepa.htm.

United States Environmental Protection Agency (EPA). 2009c. "Clean Energy: Greenhouse Gas Equivalencies Calculator." Available at: http://www.epa.gov/cleanrgy/energy-resources/calculator.html.

United States Environmental Protection Agency (EPA). 2009d. "National Pollution Discharge Elimination System: Stormwater Program." Available at: http://cfpub.epa.gov/npdes/home.cfm?program_id=6.

United States Environmental Protection Agency (EPA). 2009f. "Clean Air Interstate Rule." Available at: http://www.epa.gov/interstateairquality/.

Water Stewardship Inc. 2009. "About Water Stewardship, Inc." Available at: http://www.corporatewaterstewardship.org/about.php.

World Bank. 2009. "Projects and Operations: CN-Second Guangdong Pearl River Delta Urban Environment Project." Available at: http://web.worldbank.org/external/projects/main?Projectid=P081776&theSitePK=40941&pagePK=64283627&menuPK=228424&piPK=73230

World Resources Institute. 2009. "The Access Initiative." Available at: http://www.wri.org/project/access-initiative.

About WRI

The World Resources Institute is an environmental think tank that goes beyond research to find practical ways to protect the Earth and improve people's lives. Our mission is to move human society to live in ways that protect the Earth's environment and its capacity to provide for the needs and aspirations of current and future generations.

Other publications in this series include:

- Eutrophication and Hypoxia in Coastal Areas: A Global Assessment of the State of Knowledge (March 2008)
- Eutrophication: Sources and Drivers of Nutrient Pollution (June 2009)

Please visit www.wri.org/publications for links to available publications.

ISBN: 978-1-56973-732-3