WRI ISSUE BRIEF

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AWAKENING THE DEAD ZONE:
An Investment for Agriculture, Water Quality, and Climate Change

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EXECUTIVE SUMMARY

The Dead Zone in the Gulf of Mexico is a seasonal phenomenon in which depletion of oxygen in the water column kills bottom-dwelling organisms and drives mobile marine life from the area. In the summer of 2002, the affected area was the size of Massachusetts. This hypoxia, or seasonal reduction of oxygen in the waters of the Gulf, is caused by nutrient pollution, primarily nitrogen, which is believed to come mostly from agricultural sources.

Decreasing the size of the Dead Zone and its negative effects on marine organisms will require reducing the amount of nitrogen reaching the Gulf by 20 percent to 30 percent. Though seemingly unrelated, achieving reductions in agricultural nutrients in waterways emptying into the Gulf of Mexico is related to the global problem of climate change. Despite the refusal of the United States to ratify the Kyoto Protocol, an international treaty aimed at reducing the greenhouse gas (GHG) emissions that cause global warming, climate change remains a serious environmental problem and an important national issue. These two problems are linked because policies to reduce agricultural water pollution contributing to the formation of the Dead Zone may also help mitigate climate change.

In an attempt to identify a cost-effective strategy to alleviate the problem of hypoxia in the Gulf of Mexico, the World Resources Institute undertook an analysis of possible policy approaches. This analysis specifically included other associated environmental benefits, such as climate change mitigation and improved local water quality, resulting from different policy approaches.

Although very different environmental issues, climate change mitigation and water quality improvements are interrelated, since any decreases in nitrogen reaching waterways from agricultural land have implications for nitrous oxide emissions, a potent GHG. For instance, lower nitrogen fertilizer use reduces both the nitrogen that is leached into waterways and the amount that is volatilized as GHGs. Moreover, agricultural practices and management decisions that slow the rate of nutrient losses to waterways frequently improve carbon sequestration and storage in the soil. Agriculture has an important role to play in climate change mitigation because the sector is a large emitter of nitrous oxide in the United States and also captures and stores carbon from the atmosphere. Thus, a single environmental strategy has the potential to address multiple problems simultaneously.

Our analysis shows that the use of market mechanisms like nutrient trading provides not only the greatest overall environmental benefits but also is the most cost-effective strategy. Nutrient trading allows sources with high mitigation costs to obtain credits from sources that can reduce their contribution of pollutants to waterways at a lower cost. Trading focuses on reducing the cause of the environmental concern at hand rather than promoting a specific practice or set of practices. For instance, under a nutrient trading program, farmers would be paid according to the size

CONTENTS

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of the reductions they achieve in nitrogen or phosphorus loss, not on the number of acres placed in conservation tillage or the buffer strips they plant. This approach provides greater flexibility for local policymakers and farmers to identify and implement the most appropriate solutions in their region.

Other potential policies examined in this study did not perform as well as nutrient trading in reducing the amount of nitrogen delivered to the Gulf or in providing other associated environmental benefits. GHG trading at $14 per metric ton of carbon provided reductions in GHG emissions and nitrogen delivered to the Gulf as well as improvements to local water quality and farm income. However, at the current world price of around $5 per ton of carbon, incentives are insufficient to attract widespread participation by farmers in trading. Consequently, this policy option produces fewer GHG reductions, significantly lower water quality improvements, and smaller increases in farm income. Combining nitrogen trading with payments for reducing GHG emissions provides similar benefits to the Gulf and local water quality as nitrogen trading alone, but offers slighter greater climate benefits.

Other policy options examined, such as a tax on nitrogen fertilizer or a subsidy to farmers converting from conventional tillage practices to conservation tillage, provided some water quality and climate change benefits, but also led to declines in farm income. The latter effect makes taxes on nitrogen fertilizer or subsidies for conservation tillage less appealing options.

The final policy tested, an expansion of the Conservation Reserve Program to 40 million acres, produces all around positive benefits, but the magnitude is typically lower than those achieved under nutrient trading and thus does not provide an adequate solution to the problem.

To more effectively address the problem, the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (the federal, state, and tribal taskforce dealing with hypoxia in the Gulf) or its constituent agencies can set a target and provide a mechanism to reduce the size of the Dead Zone. This can be achieved by formally introducing a reduction goal to support the Task Force's Action Plan and endorsing programs that embrace performance-based nutrient reduction opportunities, such as nutrient trading. Federal and state agricultural policy can also provide further motivation for farmers to reduce their nutrient losses by focusing incentive mechanisms, like nutrient trading, in those areas that contribute the greatest amount of nutrients to waterways and the Dead Zone.

INTRODUCTION

The Dead Zone in the Gulf of Mexico is a phenomenon caused by nutrient pollution, particularly from nitrogen, where dissolved oxygen levels drop below that necessary to sustain most marine life. Also attributed to human activities, climate change is a global trend that is contributing to sea level rise, warming temperatures, uncertain impacts on forest and agricultural systems, and increased variability and volatility in our weather patterns. Little national progress has been made in reducing nutrient runoff or GHG emissions—the root causes of these problems.

To tackle the pervasive problem of the Dead Zone and take advantage of the linkages with climate change, the World Resources Institute (WRI) undertook a study assessing the cost-effectiveness of policy options to alleviate hypoxia in the Gulf of Mexico and reduce the impact of U.S. agriculture on climate change. Studies commissioned by the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force indicate that a 20 percent to 30 percent reduction in the amount of nitrogen reaching the Gulf should be sufficient to reduce the size of the hypoxic zone. How this reduction will be achieved is still unclear. The challenge provides an opportunity for policymakers to develop an environmental strategy that will create multiple benefits for environmental quality and the agricultural community.

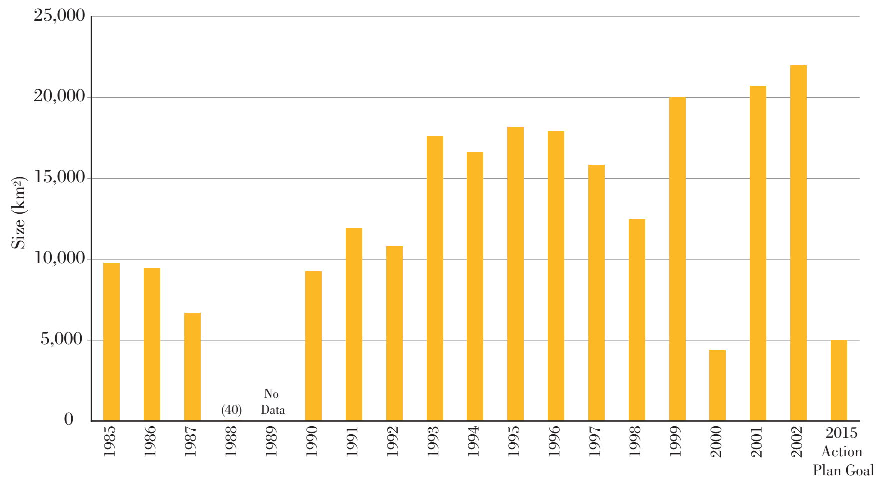
THE DEAD ZONE IN THE GULF OF MEXICO

The Dead Zone is a large hypoxic area that forms every summer off the shores of Louisiana and Texas in the northern Gulf of Mexico, in some of the most important and profitable fishing waters in the United States. This Dead Zone is one of the largest anthropogenic (i.e., caused by human activities) hypoxic areas in the world (CAST, 1999).

The Size

The size and extent of the Dead Zone in the Gulf of Mexico varies both seasonally and annually. Hypoxic waters can stretch from the mouth of the Mississippi River to beyond the Texas border, and as far as 130 kilometers (km) offshore (CAST, 1999). Consistent monitoring of hypoxia began in 1985, and since that time the Dead Zone has doubled in size, reaching 22,000 square kilometers (km^2), or 8,500 square miles, in 2002 (Rabalais et al., 1999; Dunne, 2002; LUMCON, 2002). (*See Figure 1.*)

FIGURE 1 Size of the Hypoxic Zone in the Gulf of Mexico: 1985–2002



Source: Rabalais, Nancy N., Turner, R.E., and Wiseman, W.J. Jr., 2002, LUMCON (unpublished data).

The Formation

The principal factors leading to the development of hypoxic zones are (1) the stratification of the saltwater/freshwater column and (2) the decomposition of organic matter from nutrient over-enrichment (CAST, 1999; Rabalais and Turner, 2001). During the summer months, warmer weather and calmer seas cause stratification, in which warmer freshwater floats above the colder, denser seawater. Stratification limits the mixing of the two layers, cutting off the flow of oxygen from the surface layer to the deeper saltwater layer. The surface layer contains freshwater from the Mississippi River, which is rich in nutrients that promote algal growth.

The principal nutrients responsible for eutrophication (i.e., over-enrichment) and subsequent hypoxia in coastal zones around the world are nitrogen, phosphorus, silica, or some combination of the three. As large numbers of algae die or are consumed by other aquatic species, organic matter collects on the sea floor. Decomposition of the organic matter consumes oxygen in the saltwater layer, causing hypoxic conditions. This condition is alleviated in the autumn, when stormier weather conditions and/or cooler surface temperatures cause increased mixing of the layers, allowing oxygen to move through the water column again.

The Impact

In the northern Gulf of Mexico, hypoxia occurs when oxygen levels fall below 2 parts per million dissolved oxygen.[1] At this point, bottom-dwelling fish or shrimp disappear from trawlers' nets (Rabalais and Turner, 2001). Hypoxic areas are commonly called "dead zones" because of the resulting widespread loss of marine life. Mobile organisms flee hypoxic waters, while less mobile organisms suffocate as oxygen levels become insufficient to sustain their metabolic processes. Evidence of the impacts on Gulf of Mexico fisheries include declines in food sources for fish and shrimp in hypoxic areas, as well as reduced abundance of fish and shrimp as the size of the hypoxic zone has increased (CAST, 1999).

The northern Gulf of Mexico is one of the most important fishery resources in the United States, generating $2.8 billion annually and providing 200,000 jobs (Earles, 2000). Louisiana shrimp fisheries alone make up 33 percent of the nation's total fishery catch and 40 percent of the catch in the Gulf of Mexico (CAST, 1999). Despite the presence of hypoxia, fisheries have been able to maintain "normal" catches thus far. However, the current lack of direct evidence of economic impacts in the Gulf of Mexico (Diaz and Solow, 1999) does not preclude increasingly serious future impacts on fisheries and the environment as hypoxic zones continue to grow (Baden et al., 1990; Caddy, 1993; Diaz and Rosenberg, 1995), possibly causing significant economic impacts.

The Suspected Causes

The underlying cause of hypoxia is widely believed to be nutrient runoff, particularly nitrogen from inorganic fertilizers applied to agricultural lands in the Mississippi River Basin. Though important for algal growth, phosphorus and silica are not thought to play the principal role in hypoxia in the Gulf of Mexico (Goolsby et al., 1999). Nitrogen is commonly a key causal factor for hypoxia in salt water, while phosphorus tends to be a limiting nutrient in freshwater systems.

The total annual nitrogen load from the Mississippi River to the Gulf of Mexico has increased over the last 30 years. In particular, the nitrate load is three times greater than 30 years ago. Nitrogen comes from both point sources (such as industrial facilities and municipal water treatment plants) and non-point sources (such as runoff from agricultural land and urban areas). Non-point sources are thought to contribute as much as 90 percent of the nitrogen flowing into the Gulf of Mexico annually, with 56 percent entering the Mississippi River above the Ohio River. Commercial fertilizer and mineralized soil nitrogen make up about 50 percent of the total load, while atmospheric deposition, soil erosion, and groundwater discharge contribute 24 percent, animal manure 15 percent, and point sources 11 percent.[2] Of these sources, only commercial fertilizer has increased significantly since the 1950s (Smith et al., 1997; Goolsby et al., 1999).

In contrast, the annual phosphorus load reaching the Gulf of Mexico has not increased significantly over the years, though there is large annual variation (Turner and Rabalais, 1991). Approximately 31 percent of the total annual phosphorous load comes from commercial fertilizers, 18 percent from animal manure, and 10 percent from point sources. Another 41 percent originates from sources such as phosphorus attached to soil particles[3] (Goolsby et al., 1999). Silica is not thought to be a principal causal factor in hypoxia in the Gulf of Mexico. Since 1950, the mean annual concentration of silicates has declined and stabilized (Turner and Rabalais, 1991).

While nutrients from agricultural non-point sources play a primary role in the development of hypoxia in the Gulf of Mexico, industrial facilities and municipal wastewater treatment plants (WWTPs) are the primary regulated[4] sources of nutrients in the Mississippi River Basin. They discharge approximately 286,400 metric tons of nitrogen per year and around 59,000 metric tons of phosphorus per year[5] (Goolsby et al., 1999). There are large discrepancies in nitrogen discharge for the various WWTPs, ranging from 3 milligrams per liter per day (mg/l/day) to 86 mg/l/day, with an average of 17 mg/l/day. Phosphorus discharge ranges from 0.07 mg/l/day to 8.5 mg/l/day across the Basin (USEPA, 2000a). WWTPs account for approximately 70 percent of nitrogen and 51 percent of phosphorus point-source discharge in the Mississippi River Basin.

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force and Action Plan

The hypoxic zone in the Gulf of Mexico became a high-priority problem with the establishment of the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (Gulf Hypoxia Task Force) in 1997 by the U.S. Environmental Protection Agency (USEPA). The Task Force, through the Committee on Environment and Natural Resources (CENR), studied the causes and effects of excess nutrient runoff in the Mississippi River Basin and developed an Action Plan to coordinate and implement nutrient reduction activities to alleviate hypoxia in the Gulf of Mexico. This Action Plan was released in January 2001 (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2001). The plan outlines three long-term goals (*see Box 1*), one of which (the coastal goal) is to reduce the five-year running average of the areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 km^2 by 2015.

The CENR reports suggest that total reductions in nitrogen load of between 20 percent and 30 percent would be sufficient to increase dissolved oxygen concentrations in bottom water by 15 percent to 50 percent (Brezonik et al., 1999; CENR, 2000) and meet the Action Plan's coastal goal. Options for reducing nutrient runoff to surface waters include the following: improving the efficiency of farming practices, restoring wetlands, establishing riparian buffers, and instituting tighter controls on WWTPs and other point sources. Many of the mitigation options available to reach this targeted reduction in nutrient levels will also provide local water

BOX 1 Goals of the Gulf Hypoxia Task Force Action Plan

Coastal Goal: By the year 2015, subject to the availability of additional resources, reduce the five-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 km^2 through implementation of specific, practical, and cost-effective voluntary actions by all states, tribes, and all categories of sources and removals within the Mississippi/Atchafalaya River Basin to reduce the annual discharge of nitrogen into the Gulf.

Within Basin Goal: To restore and protect the waters of the 31 states and tribal lands within the Mississippi/Atchafalaya River Basin through implementation of nutrient and sediment reduction actions to protect public health and aquatic life as well as reduce negative impacts of water pollution on the Gulf of Mexico.

Quality of Life Goal: To improve the communities and economic conditions across the Mississippi/Atchafalaya River Basin, in particular the agriculture, fisheries, and recreation sectors, through improved public and private land management and a cooperative, incentive-based approach.

Source: Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (2001).

quality benefits by reducing phosphorus losses to local waterways and reducing agriculture-related impacts of climate change.

AGRICULTURE AND CLIMATE CHANGE

The efforts of the agricultural community to improve water quality are related to the broader issue of climate change, but policy making rarely acknowledges or tries to build on these linkages.

Climate change is a problem of both national and global interest. Increasing concentrations of GHGs in our atmosphere cause climate change, thereby impacting global climatic patterns. The creation of the Kyoto Protocol in 1997 was an international attempt to gain consensus on how to address this problem. The initial negotiations led to an agreement by the "Annex I" (primarily industrialized) nations to reduce their emissions of six GHGs: (1) carbon dioxide, (2) nitrous oxide, (3) methane, (4) hydrofluorocarbons, (5) perfluorocarbons, and (6) sulfur hexafluoride.

The United States was a key player in the Kyoto Protocol negotiations until it declined to ratify the treaty in 2001. Even though the U.S. was opposed to the mandatory reduction targets set by the Kyoto Protocol, reduction efforts have continued in the United States, focusing on voluntary initiatives (e.g., U.S. Department of Energy 1605(b) program), the development of state GHG registries (e.g., California Climate Action Registry), and privately funded initiatives, such as the Chicago Climate Exchange. Despite its withdrawal from the treaty, there is still significant momentum in the United States to address climate change from many stakeholder groups, including policymakers, federal agencies, and agricultural groups.

The Agricultural Sector's Contribution to Climate Change

One of the most vociferous debates surrounding climate change mitigation concerns the ability of agricultural and forestry lands and products to sequester carbon from the atmosphere. This essentially means that carbon dioxide is captured and then stored in the soil or

TABLE 1 Total U.S. and U.S. Agricultural Greenhouse Gas Emissions

	U.S. Total (MMTCE)	Agricultural Production Emissions (MMTCE)	Agricultural Production's Share of U.S. Total (percent)	Distribution of U.S. Agricultural Emissions[a] (percent)
Carbon Dioxide	1,593	19	1	14
Methane	168	46	28	34
Nitrous Oxide	116	86	74	64
HFCs, PFCs, and SF_6	33	~0	—	—
Land Use Change and Forest Sinks	(246)	(16)[b]	7	—
Total	1,663[c]	135[d]	8	—

Notes:
a. Based only on agricultural emissions; does not include carbon sequestration.
b. Includes agricultural soils (with CRP) only, and is net of emissions from organic soils (Eve et al., 2000).
c. Total includes carbon sequestered by land use change and forest sinks.
d. For comparison, the electricity generation sector emits 648 MMTCE, the transportation sector emits 512 MMTCE, and the industrial sector emits 359 MMTCE (USEPA, 2002).
MMTCE: million metric tons of carbon equivalents; HFC: hydrofluorocarbons; PFC: perfluorocarbons; and SF_6: sulfur hexafluoride.
Parenthesis indicate carbon sequestration or removal from the atmosphere.
Totals may not sum due to independent rounding.
Source: Eve et al., 2000, and USEPA, 2002a.

in plant products. However, there are significant and promising opportunities for reducing other GHGs that are frequently overlooked.

Agriculture is responsible for approximately 8 percent of the United States' total emissions of GHGs. (*See Table 1.*) Although carbon dioxide accounts for about 83 percent of U.S. GHG emissions, agriculture's share is less than 1 percent. A majority of carbon dioxide emissions from agriculture result directly from production practices involving energy use, while the rest are indirect emissions associated with the production of agricultural inputs, such as fertilizer (USEPA, 2002b). Agricultural soils also have the ability to sequester and store carbon dioxide from the atmosphere (Eve et al., 2000).

Nitrous oxide is a potent GHG. One ton of nitrous oxide emissions has the same warming impact (global warming potential, or GWP) as 310 tons of carbon dioxide.[6] Approximately 74 percent of all U.S. nitrous oxide emissions come from agriculture, primarily from agricultural soil management activities such as commercial fertilizer application and other cropping practices. Other sources of nitrous oxide include nitrogen fixation from crops, the application of sewage sludge and manure to croplands, and the cultivation of organic soils (USEPA, 2002b).

Agricultural soils have the potential to sequester and store carbon, thereby reducing agriculture's overall impact on climate change. For instance, tillage practices that cause little soil disturbance (such as no-till) result in greater carbon storage in soil than conventional tillage practices. Different crop rotations also affect the rate of soil carbon sequestration. Many practices that improve the ability of the soil or plants to sequester carbon also reduce the loss of nutrients from these lands. On the downside, the accumulated carbon may be released back to the atmosphere if these production changes or practices are interrupted or discontinued.

There are a number of opportunities, however, for the agricultural community to permanently lower GHG emissions. The reduction in nitrous oxide from fertilizer usage is one such example. If farmers reduce their use of nitrogen-based fertilizers, there will be fewer nitrous oxide emissions. This would also reduce carbon dioxide emissions associated with the production of fertilizers. Such reductions could ultimately help alleviate hypoxia in the Gulf of Mexico, whose formation is related to nitrogen losses from agricultural fertilizer applications. This benefit has been illustrated by Faeth and Greenhalgh (2000), where strategies to reduce GHG emissions also provided significant water quality cobenefits.

LINKING CLIMATE CHANGE TO WATER QUALITY FOR AGRICULTURE

As described previously, nutrients, particularly nitrogen, are believed to be the principal causal agents for hypoxia in the Gulf of Mexico. Commercial fertilizers are one of the larger sources of nitrogen in the Mississippi River Basin and typically are not fully utilized by the cropping systems to which they are applied. The unused nitrogen from fertilizer can be either retained in the soil or lost from the soil through (a) volatilization, (b) leaching into groundwater, or (c) surface runoff. Leached nitrogen and nitrogen lost through surface runoff moves into waterways, while a portion of the volatilized nitrogen (either as ammonia [NH_3] or nitrogen oxide [NO_x]) will convert to the GHG nitrous oxide through nitrification and denitrification processes. A portion of the leached nitrogen and nitrogen in surface runoff also converts to nitrous oxide emissions (Goolsby et al., 1999; USEPA, 1999). Mitigation options available to the agricultural community are to reduce fertilizer applications, change cropping rotations, or take land out of production. Lower fertilizer use will also reduce the energy used in fertilizer production, a highly energy-intensive process. Reduced nitrogen fertilizer use and reduced energy consumption both have positive implications for water quality and climate change.

Another mitigation option commonly used to reduce nutrient runoff is conservation tillage, which involves changing tillage practices to reduce soil disturbance. This has a number of effects. The first is to increase the amount of plant material left on and in the ground. This slows the rate of water movement across the soil surface, increasing percolation and reducing runoff. Conservation tillage also reduces the loss of phosphorus associated with sediment loss. However, in tile drainage[7] areas the increase in percolation could increase nitrogen loading as the nitrogen dissolved in water is transferred directly from the field to the waterway.

Enhancing the ability of the soil to sequester and store carbon through improved soil quality is another way to reduce the loss of nutrients. Further details on these sequestration and storage processes can be found in Lal et al.

(1998). Conservation tillage practices, which involve less frequent plowing, reduce net fuel consumption, thereby reducing carbon dioxide emissions. Taking land out of agricultural production produces similar benefits, but may also increase plant biomass and, consequently, increase the amount of carbon dioxide absorbed from the atmosphere. Riparian (i.e., adjacent to streams) buffer strips are another option for mitigating both nutrient runoff and GHG emissions. They slow the rate of surface flow and increase the absorption of nutrients, in addition to sequestering and storing carbon.

Livestock are potentially a source of methane and nitrous oxide as well as nutrient pollution. The largest emissions come from the practices used to store or dispose of animal wastes. Not all practices for storage and disposal necessarily provide both water quality and climate change benefits; additional research is needed to better understand any linkages that may exist.

DEVELOPING AN INTEGRATED ENVIRONMENTAL STRATEGY

Water quality is probably the environmental problem of greatest concern to the agricultural community. Issues related to water quality such as USEPA's Total Maximum Daily Load (TMDL) rule,[8] mitigation options for the hypoxic zones in the Gulf of Mexico and Chesapeake Bay, eutrophication of freshwater systems, and local efforts to improve drinking water quality are generally seen as more imperative for farmers to address than climate change. Taking advantage of substantial overlaps between the opportunities available to farmers for improving water quality and those for mitigating climate change is one way to move forward. The use of such co-benefits to address climate change is further explored as part of this analysis.

Methodology

The World Resources Institute used the U.S. Regional Agricultural Sector Model (USMP) to evaluate environmental strategies aimed at improving water quality for the Mississippi River Basin and the Gulf of Mexico while lessening the climate change impacts related to agricultural activities. Developed and maintained by the U.S. Department of Agriculture/Economic Research Service (USDA/ERS), USMP is the same model used to conduct the economic analysis commissioned by the Gulf Hypoxia Task Force.

Model

Designed for general-purpose economic, environmental, and policy analysis of the U.S. agricultural sector, USMP is a static model[9] that estimates how policy, demand, or technology changes will affect the following:

- regional supply of crops and livestock,
- commodity prices,
- use of production inputs,
- farm income, and
- environmental indicators such as nutrient and pesticide runoff, soil loss and GHG emissions, soil carbon fluxes, and energy use.

USMP is linked to a number of national databases: the regularly updated USDA production practices surveys, the USDA multi-year baseline, and geographic information systems databases such as the National Resources Inventory. Because of the grossness of the model, results are used to evaluate the relative effects of various policy options and not to predict absolute changes in production or environmental parameters.

Model Parameters

In the past, WRI has collaborated with USDA/ERS to improve the spatial delineation of USMP, increase the diversity of cropping rotations included in the model, and simulate the environmental impacts of various cropping production practices and the Conservation Reserve Program (CRP). The model includes 10 major crops (corn, sorghum, oats, barley, wheat, rice, cotton, soybeans, hay, and silage), a number of livestock enterprises (dairy, swine, poultry, and beef cattle), and a variety of different processed and retail products. There are 45 principal regions in the original model, derived from the intersection of the USDA farm production and land resource regions, and approximately 850 different cropping rotations based on the various crops and regions.

The environmental responses to policy changes are derived from a crop biophysical simulation model, Erosion/Productivity Impact Calculator (EPIC) (Williams et al., 1984; Sharpley and Williams, 1990). The dynamics of the nitrogen and carbon cycles are complex. The only sources of cropland nitrogen losses to water considered in this analysis are the losses associated with leaching, sediments, surface runoff, and subsurface flow. Sequestered soil carbon is determined from the total organic matter in soil and was calibrated to National Resource Inventory data (Eve et al., 2000). Nitrous oxide emissions from fertilizer use were derived using the same method as the USEPA Greenhouse Gas Inventory[10] (USEPA, 1999) and calibrating to their estimate. The phosphorus losses to water include those associated with sediment, leaching, and subsurface flow, while soil erosion encompasses wind, sheet, and rill erosion from cropland, as well as the erosion from CRP and pasture lands.

The nutrient and GHG emission reduction options available in our model include changing tillage practices, changing cropping rotations, changing nitrogen fertilizer management, and taking land out of production. Much of the land taken out of production is converted to CRP acreage, with the remainder moving into pasture. The environmental parameters are adjusted according to the change in land use. Reducing nitrogen fertilizer applications carries risk associated with decreased yields due to plant nitrogen deficiencies. Farmers make decisions by trading off the risk of decreased yield against the potential for increased farm income from both lower production costs and payments for achieving reductions in nutrient loss and/or GHG emissions. The model also accounts for the energy embodied in fuel use and fertilizer production.

Supplementary Water Quality Parameters

Building on the earlier Gulf Hypoxia Task Force economic analysis using USMP (Doering et al., 1999), we configured the model by watersheds. We added municipal WWTPs (point source) information as well as nitrogen transmission losses as water moves through the system from the Mississippi River Basin to the Gulf of Mexico. We used U.S. Geological Service (USGS) 8-, 4-, and 2-digit hydrological units to spatially delineate watersheds, which allows us to determine more explicitly the economic and environmental responses to policy changes both within and outside the basin.

To account for the loss of nitrogen as it moves through the basin, the attenuation coefficients derived using the SPARROW model (Alexander et al., 2000) were included in the model. These data, combined with the watershed delineation, provide more accurate information on the amount of nitrogen reaching the Gulf of Mexico from the Mississippi River sub-basins. The model is able to estimate the amount of nitrogen entering waterways (the total amount of nitrogen from agricultural cropping sources that finds its way into rivers and streams in the basin), as well as the amount of nitrogen finally delivered to the Gulf of Mexico (accounting for transmission losses along the way).

Point source discharges and their treatment levels were incorporated into the model using 1996 information collected for a USEPA-commissioned study (USEPA, 2000a). Additional point-source facilities were identified from the National Pollutant Discharge Elimination System (NPDES) database or directly from state databases.

Omitted Model Parameters

Not explicitly considered in this analysis were other elements influencing the delivery of nutrients to the Gulf of Mexico, including wetlands and buffer strips (grasslands or trees), tile drains, manure application, and river modification and channelization. Inclusion of additional mitigation options, such as wetlands or buffers, would have tended to decrease the cost of implementing the policies tested. However, the omission of tile drains may mean that more nitrogen is actually lost to waterways from certain areas of the United States than is accounted for in our analysis. The use of tile drains often allows nitrogen to bypass nutrient mitigation options, including wetlands or buffer strips. Mitigation options that reduce the amount of nitrogen use or improve tile drain design and drainage water management are effective solutions. Additional analyses that consider tile drains would add valuable information for identifying cost-effective options to improve ecosystems.

Manure applications are another source of pollution and have implications for both nutrient losses to waterways and GHG emissions. The inclusion of this source would have increased the number of mitigation options available and possibly the magnitude of point source discharges of nutrients in the nutrient trading options tested. In addition, afforestation, which could have implications for GHG sequestration results, is not included in this analysis.

Also omitted from this analysis are the transaction costs associated with implementing the policy options tested, as well as monitoring costs to evaluate the actual benefits accruing from these policies. These were omitted because the costs associated with these policy options can differ depending upon the design of the program, and much of this information is either unavailable or not documented. This is particularly relevant for the GHG and nutrient trading options. These costs could be used to further differentiate between policy options.

Policy Design

An enormous number of sources contribute to the hypoxic zone in the Gulf of Mexico, the majority of which are located at large geographic distances from the problem's manifestation. This makes it difficult to communicate to those far upstream in the Mississippi River Basin that reducing their nutrient losses will provide benefits to the Gulf of Mexico. Because people are typically more concerned with local environmental problems than those occurring far downstream, it is important to look for policies that have local as well as downstream environmental benefits.

Contributors to the hypoxia problem are diverse in nature, ranging from the municipal and industrial sectors to the agricultural community and urban dwellers. Currently, only point sources in the municipal and industrial sectors are subject to regulations requiring nutrient management; even then, the record on actual permitting of sources of nutrient discharge is spotty. As permits are renewed, additional nutrient discharge criteria are being added, but these criteria are not yet uniformly applied to all point sources. The other sources of nitrogen in the Mississippi River Basin, including agriculture and urban areas, are unregulated. The exception is concentrated animal feeding operations (CAFOs) which will now be required under a recent USEPA rule[11] to obtain permits regardless of whether they discharge only during large storms.

Many policy options aimed at addressing the hypoxic zone in the Gulf of Mexico also produce environmental co-benefits. Considering these co-benefits as part of the solution set provides a more comprehensive assessment of the overall improvement in environmental quality and helps to determine an appropriate policy to adopt.

The challenge is to devise a policy or series of policies to ensure that each source of nitrogen is part of the solution set for reducing the size of the Dead Zone, and that we are able to take advantage of environmental co-benefits. Any policy strategy should:

- reduce the size of the Dead Zone,
- maximize other environmental co-benefits, such as climate change mitigation and improved local water quality,
- be responsive to adverse impacts on farm income and the financial burden placed on point sources of nitrogen, and
- minimize any adverse regional impacts.

TESTING POSSIBLE POLICY OPTIONS

We tested several options aimed at improving water quality and/or reducing GHG emissions to determine their impact on a number of environmental and economic variables, such as the nutrient load at the mouth of the Mississippi River, GHG emissions, local water quality, and agricultural cash flows. The policy options tested were nutrient trading, GHG trading, conservation tillage subsidies, an extension of the Conservation Reserve Program, a tax on the use of nitrogen fertilizer, and a combined strategy of trading nitrogen while also paying farmers for their GHG reductions. With the exception of nutrient trading (which only operates in the Mississippi River Basin), all policy options are implemented nationally.

Nutrient Trading: Several state and federal agencies are exploring this market-based approach to reduce the cost of improving water quality in such areas as Michigan and the Chesapeake Bay. In addition, USEPA released its Water Quality Trading Policy in January 2003 (USEPA, 2003). Nutrient trading allows sources with high mitigation costs to obtain pollution reduction credits from sources that can reduce their nutrient contribution to waterways at a lower cost. Further details on nutrient trading are outlined in Box 2.

In the nutrient trading options tested here, municipal WWTPs (a point source of nutrient discharges) are the only potential buyers of nutrient reduction credits. The sellers of these credits are agricultural cropping enterprises that can reduce their nutrient losses by changing cropping rotations (including CRP acreage), tillage practices, or fertilizer use.

The analysis considers the trading of both nitrogen (N) and phosphorus (P). For each nutrient, we tested two scenarios with different WWTP discharge limits. These limits act as the "cap" for the system, as WWTPs are not able to discharge more than the new permitted limits. Consequently, WWTPs will need to purchase a limited number of credits, thereby constraining the number of credits that farmers can sell. As agricultural non-point sources do not operate under a cap, farmers receive payments for nutrient reductions but are not penalized for any increase in nutrient runoff.

For nitrogen, discharge limits of 8 mgl/day and 3 mg/l/day[12] were imposed on WWTPs. We tested the viability of nutrient trading with these nitrogen discharge limits using cost curves derived by USEPA (Wiedeman and Zhou, 2001). The WWTP cost curves for nitrogen were based on only biological methods of nitrogen removal. They did not include other nitrogen removal methods,

BOX 2

Nutrient Trading

The concept of trading is based on the difference in compliance costs faced by each industrial facility or municipal wastewater treatment plant (WWTP) depending upon size, scale, age, and overall efficiency. This means that the cost of meeting water quality standards may be less for one facility than for another. Trading between point sources provides an opportunity for those facilities whose costs are lower to make additional reductions beyond their obligation, and sell these additional reductions to facilities whose costs are higher.*

Trading can also occur between a point source like a municipal WWTP and a non-point source, such as a farmer. Point sources with high compliance costs can purchase nutrient reduction credits from non-point sources, whose nutrient reduction costs are much lower. Point source facilities are generally controlled by discharge permits mandated by the USEPA, while non-point sources are typically not controlled by regulatory limits.

Incorporating non-point sources, such as agriculture, into trading programs has raised questions of uncertainty about the actual reduction achieved by these sources. For agricultural non-point sources to reduce their nutrient contribution to water bodies, best management practices (BMPs), such as changing tillage practices or crop rotations, reducing fertilizer rates, creating filter strips, or establishing wetlands, are implemented. These practices can frequently improve water quality at a lower cost than upgrading wastewater treatment facilities, but there is a greater degree of uncertainty surrounding the actual nutrient reductions achieved.

To account for this uncertainty, trading ratios or discount factors are applied to nutrient reductions from non-point sources. For this analysis, we used a 2:1 trading ratio; that is, a point source must purchase 2 pounds of nutrient reductions generated by a non-point source for every pound of reduction they require. The BMPs included in our analysis were changing crop rotation and tillage practices, changing fertilizer application rates, and taking land out of production through the Conservation Reserve Program (CRP). A more detailed description of nutrient trading can be found in Greenhalgh and Faeth (2001), Faeth (2000), and at the USEPA website (http://www.epa.gov/owow/watershed/trading.htm).

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* WRI, in a complementary effort, has developed an Internet website, NutrientNet (www.nutrientnet.org), to help reduce the potentially high transaction costs associated with estimating these nutrient reductions and the difficulty buyers and sellers experience in locating each other. The site also provides an online registry to help track these trades as they occur.

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such as wetlands, algal scrubbers, and spray irrigation.

For phosphorus, discharge limits of 1 mg/l/day and <1 mg/l/day[13] were used. The cost curves used for each WWTP depended on the current treatment technology in that plant. For WWTPs that utilize biotowers, trickling filters, lagoons, or biological rotating contactors, chemical treatment was used to reach the 1 mg/l/day P discharge limit. For activated sludge plants, we used a biological phosphorus-removal system. To achieve the <1 mg/l/day phosphorus discharge limit, an additional filtration system was used in both chemical and biological phosphorus-removal systems (Doran, 2001).

These cost curves were used to estimate the following: (1) the nitrogen and phosphorus discharge reductions required by WWTPs in each USGS 8-digit hydrological unit in the Mississippi River Basin to meet the more stringent standards, (2) the cost of achieving these reductions if the total cost was borne by the WWTPs, and (3) the number of nitrogen reduction credits (generated by farmers) that could be traded in each sub-basin. All estimations were based on a 2:1 trading ratio, where 2 pounds of non-point source reductions are required to offset every pound of nutrient discharge from a point source.

The abbreviated definitions for the trading scenarios, along with their credit prices, are listed in Table 2. The credit prices are based on the average cost of achieving nutrient reductions in WWTPs within the Mississippi River Basin, taking into account the 2:1 trading ratio. In this analysis, trading was only allowed between agricultural non-point sources (cropland only) and WWTPs in the Mississippi River Basin.

Greenhouse Gas Trading: As with nutrient trading, GHG trading enables

TABLE 2

Nutrient Trading Scenarios

WWTP Nutrient Discharge Limits Tested	Credit Price	Abbreviation
8 mg/l/day N discharge limit	$2/lb N	N Trading Scenario 1
3 mg/l/day N discharge limit	$5/lb N	N Trading Scenario 2
1 mg/l/day P discharge limit	$5/lb P	P Trading Scenario 1
<1 mg/l/day P discharge limit	$7/lb P	P Trading Scenario 2

sources with high mitigation costs to purchase credits from sources able to reduce emissions at a lower cost.

To simulate the GHG trading market, we used carbon credit prices of $5 per metric ton of carbon ($/t C) and $14/t C. The former price is approximately the current trading price[14] for GHG emissions (Senter International, 2002), while the latter relates to the lower limit of the estimated credit price range before the United States declined to ratify the Kyoto Protocol (AEA, 1998). In our model, farmers receive payments for reducing their overall GHG emissions (including via sequestration) below their current, business-as-usual emission level; in turn, if their emissions increase, farmers must pay for these increases. McCarl and Schneider (2001) use a similar model design in which farmers are paid or penalized depending on the amount of GHGs emitted.

GHG emissions from the agricultural sector incorporated in the model include carbon dioxide emitted in the production process (fuel use, fertilizer production, etc.), the carbon sequestered and stored in agricultural soils (including the CRP[15]), and nitrous oxide released from nitrogen fertilizer use. Methane and other sources of nitrous oxide are not considered. Afforestation also is not included in this analysis; however, this should not significantly impact the sequestration potential as the prices used in this model are not high enough to induce substantial afforestration (McCarl and Schneider, 2001). In this analysis, we assume that carbon sequestered by soils is permanently stored there. Because our model does not account for uncertainty associated with impermanent carbon storage in soil, nor for carbon saturation of soils, the findings from the relevant policy option may overestimate the amount of carbon stored in the soil. The reduction in carbon dioxide emissions from decreased energy use, as well as reductions in nitrous oxide emissions from decreased nitrogen fertilizer use, are also permanent. The GHG trading policy tested here operates at a national level.

Nitrogen Fertilizer Tax: Approximately 50 percent of the nitrogen lost to waterways in the Mississippi River Basin comes from fertilizer and mineralized soil organic nitrogen (Goolsby et al., 1999). Other non-point sources of nitrogen are atmospheric deposition, surface runoff, and groundwater discharge (24 percent), and animal manure (15 percent). In many instances, farmers apply “insurance” fertilizer, hoping that climatic conditions produce a “bumper” crop. In years in which the growing conditions are not ideal, crops do not use this “insurance” fertilizer, and frequently the excess nitrogen is lost to the atmosphere, leaches into groundwater, or moves into waterways via sub-surface or surface drainage. Farmers may also apply fertilizer in the fall to ensure that if there is a wet spring, the farmer can plant as soon as it is dry enough, rather than having to delay planting in order to fertilize. However, during the spring thaw, a portion of this nitrogen leaches into groundwater or runs off into surface waterways.

Our analysis looks at applying a fertilizer tax as a mechanism to reduce the use of fertilizer in the agricultural sector. The tax rate, applied nationally, is equivalent to a 70 percent increase in fertilizer price, corresponding to the actual increase in nitrogen fertilizer prices observed in 2000/2001. During this period, limited availability of natural gas (a major input for the production of nitrogen fertilizer) and the resulting increase in energy prices led to higher nitrogen fertilizer prices. Nitrogen losses included those via surface runoff, in sub-surface flows, and through leaching into groundwater.

Conservation Tillage Subsidies: To reduce soil erosion, tillage subsidies have been used for many years to encourage farmers to convert from conventional and moldboard[16] tillage practices to conservation tillage practices. Conservation tillage also provides climate change benefits, as these practices sequester more soil carbon than conventional and intensive tillage practices. In our analysis, a subsidy payment of $25 per acre was given to farmers changing from either conventional or moldboard tillage to ridge tillage,[17] mulch tillage,[18] or no-till practices.[19] In the past, conservation tillage subsidies were frequently paid on a 75 percent cost-share basis. Subsidy payments vary from $10/acre in parts of the Corn Belt and Great Lakes states to $25/acre for cotton acreage in the southern plains and Appalachian regions (Towery, 2000). In our model, we selected a subsidy of $25/acre, as this amount should provide sufficient incentive for farmers in a majority of regions across the United States to change tillage practices. No restriction is placed on the type of conservation tillage practices implemented or the acreage on which conservation tillage is adopted, and no specific areas are targeted. Once conservation tillage is adopted, it is assumed to be continuous.

Conservation Reserve Program: CRP is a national conservation program instituted in 1985 in the Farm Bill, the legislation governing agricultural programs in the United States, which is revised every six years. The program aimed to take marginal, highly erodible land out of production to reduce soil erosion and improve water quality. Although the focus of the program has remained the same, a number of other criteria have been included over the years. These include wildlife habitat and air quality, which are now prerequisites of the program. At the end of 2002, almost 34 million acres were enrolled in this program (USDA, 2002).

CRP land is not tilled, and typically fertilizer is not applied. Therefore, any increase in CRP acreage will decrease the amount of nitrogen, phosphorus, and sediments lost to waterways. Likewise, GHG emissions from land placed in the CRP also decrease, as there are fewer nitrous oxide emissions from fertilizer applications, no carbon emissions related to tillage operations or the production of fertilizers, and increased sequestration of carbon in undisturbed soils. The 2002 Farm Bill increased the total allowable CRP acreage to 40 million acres. Our analysis uses this increased cap and includes an across-the-board increase in rental rates[20] of 20 percent. The environmental parameters for CRP are based on converting cropping land to pasture.

Combined Strategy of Nutrient Trading with GHG Payments: This option tested a combined strategy involving a nutrient trading program along with payments for reductions in GHG emissions. We capped nitrogen discharges at 3 mg/l/day from WWTPs, with a price of $5/lb N for reduction credits and a payment of $5/t C for reduced GHG emissions from cropped land only. This strategy was implemented only in the Mississippi River Basin.

FINDINGS

The national-level economic and environmental outcomes of the policy options[21] we tested are outlined in Table 3. Maps illustrating the impacts at watershed level can be found at http://hypoxia.wri.org/.

Nitrogen Delivered to the Gulf of Mexico

Each incentive mechanism tested reduced the amount of nitrogen delivered to the Gulf of Mexico, with annual declines ranging from approximately 1 percent to 11 percent. (*See Table 3.*) The greatest reductions were achieved by imposing more stringent nutrient reduction discharge limits on WWTPs and then allowing the plants to use nutrient trading to meet those discharge limits. *(See Figure 2a.)* N Trading Scenario 1 reduces the amount of nitrogen delivered to the Gulf by slightly less than 5 percent, whereas the more stringent N Trading Scenario 2 produces reductions of slightly less than 11 percent. These reductions come from a combination of reduced fertilizer use, increased CRP acreage, and changes in cropping rotations and tillage practices. Similarly, the combined N trading with GHG payments option also reduced nitrogen by just less than 11 percent. The P Trading Scenario 1 produces an approximate 4 percent reduction in nitrogen delivered to the Gulf, while the P Trading Scenario 2 results in almost a 6 percent reduction.

Conservation tillage subsidies result in reductions of around 5 percent. A tax on nitrogen fertilizer and GHG trading at $14/t C led to reductions of around 2 percent to 3 percent. The two options producing the smallest reductions in nitrogen delivered to the Gulf were GHG trading at $5/t C (the current market price) and extending the CRP.

With trading of nitrogen credits, the largest regional reductions in nitrogen delivery to the Gulf come from the Ohio, Arkansas-White-Red, Upper Mississippi, and Missouri River basins. Other than the Missouri River Basin, these areas coincide with the watersheds identified by USGS as delivering the largest portion of nitrogen to the Gulf via waterways. For phosphorus trading, the greatest reductions come from the Arkansas-White-Red, Ohio, Missouri, and Upper Mississippi River basins.

The lowest-cost mechanisms were the market-based incentives, like nutrient and GHG trading. (*See Figure 3.*) However, the most cost-effective solutions were the options based on nutrient trading, which achieved large reductions in the amount of nitrogen delivered to the Gulf of Mexico at low prices.

Farm Income

Not all the options tested in this analysis provided financial benefits to the agricultural community as a whole. (*See Table 3.*) Nitrogen fertilizer taxes and conservation tillage subsidies led to overall decreases in U.S. farm income, while the other options increased farm income. N Trading Scenario 2 and combined N trading with GHG payments produce the greatest boost to farm income. *(See Figure 2b.)*

In the tax option, higher fertilizer prices mean that crop acreage drops, and despite higher crop prices, farm income decreases overall. Untargeted conservation tillage subsidies induce more land into production, leading to increased

TABLE 3 Economic and Environmental Impact of the Agricultural Policy Options Tested in the U.S.

	2010 Baseline	N Fertilizer Tax	Conservation Tillage Subsidy	CRP Extension	GHG Trading	GHG Trading	N Trading 8mg/l/day discharge limit N	N Trading 3mg/l/day discharge limit N	P Trading 1mg/l/day discharge limit P	P Trading <1mg/l/day discharge limit P	Combined N Trading 3mg/l/day- with GHG Payments
		70% tax	$25/acre	cap: 40 mill acre	$5/t C	$14/t C	$2/lb N	$5/lb N	$5/lb P	$7/lb P	$5/lb N and $5/t C
		Percent Change from Baseline									
Farm income ($bill/yr)	82	-2	-4	1	0.4	1	3	5	2	3	5
Cash receipts ($bill/yr)	196	0.9	-1	0.5	0.1	0.3	1	2	1	2	2
Variable costs ($bill/yr)	114	3	0.7	-0.2	-0.1	-0.3	0.1	0.1	0.1	0.2	0.2
Corn Price ($/bu)	2.6	5	-6	2	0.4	2	7	12	6	9	13
N delivered to Gulf of Mexico (mill tons)[a]	2.24	-3	-5	-1	-0.4	-2	-5	-11	-4	-6	-11
GHG emissions (MMTCE)[b]	86	-5	1	-4	-2	-5	-4	-8	-4	-6	-8
P lost to water (mill tons)	0.6	-3	-2	-2	-0.5	-2	-3	-7	-4	-6	-7
N lost to water (mill tons)[c]	5	-4	-3	-2	-0.5	-2	-4	-8	-3	-4	-8
Soil erosion (mill tons)	1,793	-2	-11	-2	-0.3	-1	-2	-4	-3	-4	-4

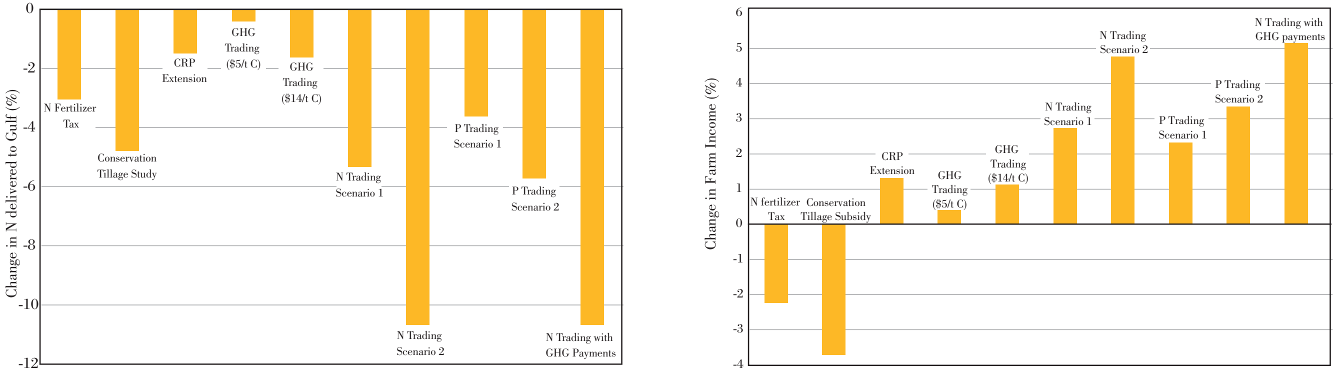
Notes:
All values have been rounded.
a. This is the amount of nitrogen that reaches the Gulf of Mexico from the Mississippi River Basin, taking into account the loss of nitrogen (using nitrogen attenuation coefficients derived from the SPARROW model, Alexander et al., 2000) from the system as it moves through the basin.
b. The baseline GHG emissions incorporate only those covered in the analysis: N_2O emissions from fertilizer use, the CO_2 emissions associated with production (fuel use, fertilizer production, etc.), and CO_2 sequestered by agricultural lands.
c. Refers to the amount of nitrogen that enters waterways in the United States. It does not include the nitrogen transmission losses as it moves through the various basins. It reflects local water quality.

crop production, reduced crop prices, and decreased farm income.

In options featuring nitrogen and phosphorus trading, regional differences emerge. Most regions experience some increase in farm income, with the largest increases found in the Upper Mississippi River watershed, followed by the Missouri River, Great Lakes, and Ohio River basins. Under the phosphorus trading option, there is a small overall decrease in farm income in the Tennessee River Basin. Nutrient trading policies are focused in the Mississippi River Basin, with the increases in farm income arising from sales of nitrogen and/or phosphorus credits as well as higher crop prices. Although the policy is only applied in the Mississippi Basin, farm income elsewhere in the country also increases because of higher crop prices.

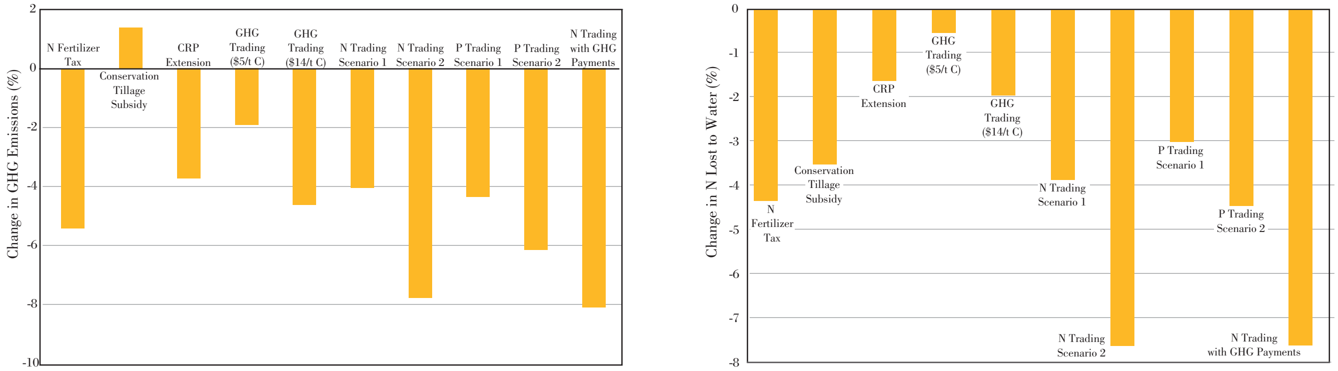
The conservation tillage subsidy is national in scope, but most change occurs in the Mississippi River Basin, as this area offers the greatest opportunities for conservation tillage. However, in this option, the Upper Mississippi, Missouri,

FIGURE 2 Impact of Various Policy Options on the Environment and Farm Income



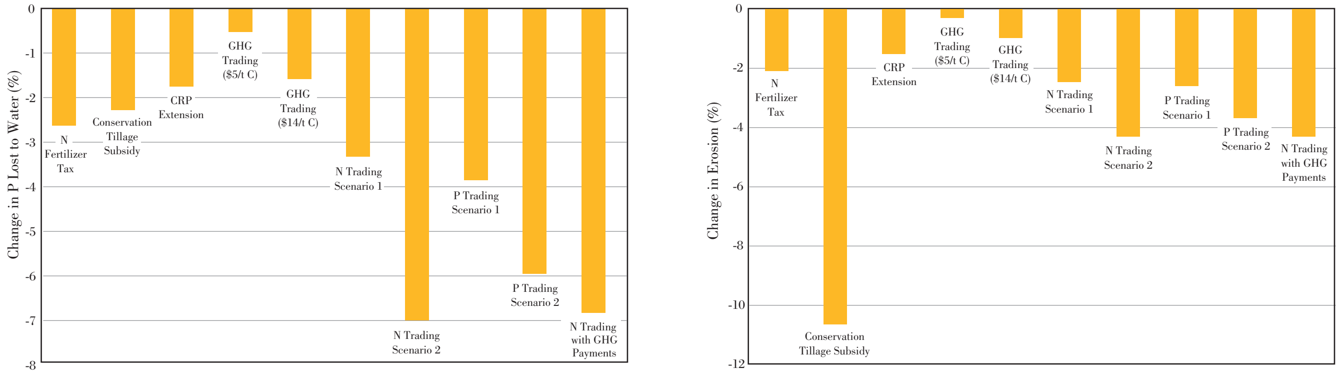
a. Nitrogen delivered to the Gulf of Mexico

b. Farm income



c . Greenhouse gas emissions

d. Nitrogen lost to waterways



e. Phosphorus lost to waterways

f. Soil erosion

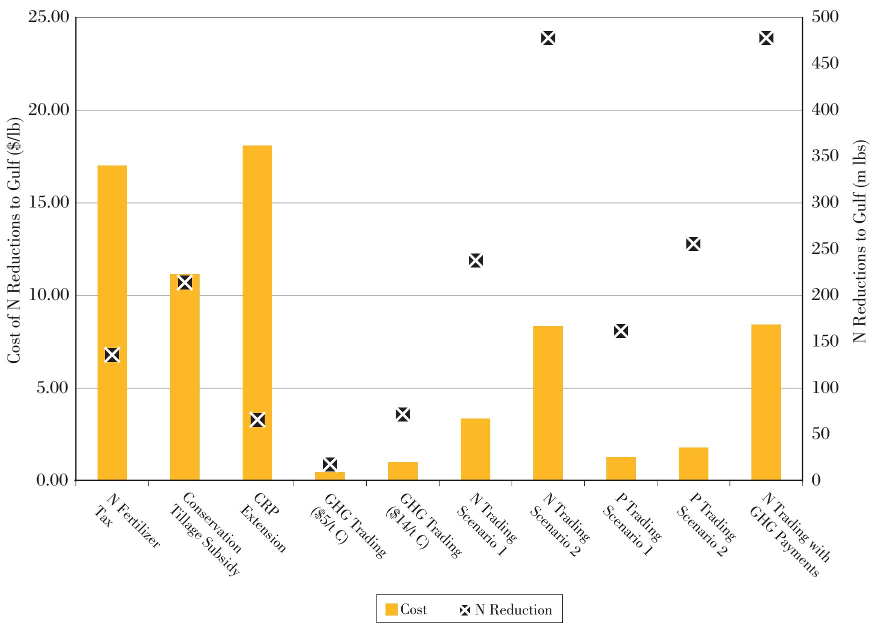
N Trading Scenario 1: 8 mg/l N discharge limit for WWTP at $2/lb N
N Trading Scenario 2: 3 mg/l N discharge limit for WWTP at $5/lb N
P Trading Scenario 1: 1 mg/l P discharge limit for WWTP at $5/lb P
P Trading Scenario 2: <1 mg/l P discharge limit for WWTP at $7/lb P

Great Lakes, and Ohio River basins also are subject to the greatest decline in farm income.

Greenhouse Gas Emissions

At the higher credit price for carbon ($14/t C), GHG emissions from agricultural cropping sources fall by 5 percent. (*See Table 3.*) However, at credit prices currently being offered ($5/t C), GHG emissions decrease by about 2 percent. The option combining N trading (at 3 mg/l/day) with GHG reduction payments ($5/t C) produces GHG reductions of around 8 percent. Other promising policy options for lowering GHG emissions appear to come from either imposing a nitrogen fertilizer tax or promoting nutrient trading. (*See Figure 2c.*) The nitrogen fertilizer tax and nitrogen trading primarily reduces nitrous oxide emissions from fertilizer applications.

FIGURE 3 Cost-effectiveness of Policy Options Tested at Reducing the Amount of Nitrogen Delivered to the Gulf of Mexico



The increase in GHG emissions under the conservation tillage subsidy is mostly due to increases in cropping land (and associated higher energy use) and corresponding decreases in CRP acreage found in the Missouri River Basin.

Under a national GHG trading scheme, GHG emissions are reduced in all areas of the country, with the largest reductions occurring in the Upper Mississippi, Missouri, and Arkansas-White-Red River basins. These declines come from a combination of reduced nitrogen fertilizer use, lower energy use, and increased acreage in the CRP.

With nitrogen trading, which operates only in the Mississippi River Basin, some U.S. regions (mostly outside the Mississippi River Basin) experience small increases in GHG emissions (less than 0.5 percent above baseline). The most significant of these is in California, where, in response to lowered crop production in the Mississippi River Basin, trading results in higher energy emissions from increased cropping acres in conventional tillage. However, if nitrogen trading programs were extended nationwide, a different picture might emerge, involving less incentive for increased conventional cropping and even greater decreases in GHG emissions. Nevertheless, the key issue is whether net GHG emissions decline nationally, since the impact on climate is a global rather than localized phenomenon.

For both nitrogen and phosphorus trading, the greatest decreases in GHG emissions are found in the Upper Mississippi, Ohio, and Missouri River basins. The reduction in GHG emissions comes from a combination of lower nitrous oxide emissions from fertilizer applications, reduced energy use, and increased carbon sequestration.

Nutrient Losses to Waterways

All of the policy options reduce the amount of nitrogen or phosphorus that is lost to local waterways. Phosphorus is the cause of eutrophication in freshwater systems, and nitrogen can impact drinking water quality at the local level. For both N and P Trading Scenarios 2 and combined N trading with GHG payments, nutrient reductions are about double that of any other option. *(See Table 3.)* The worst performer for both nitrogen and phosphorus losses was the GHG trading option at $5/t C. At slightly higher carbon prices, though, nutrients are reduced by around 2 percent. *(See Figures 2d and 2e.)*

On a watershed basis, the greater portion of reductions in nitrogen and phosphorus losses in the nutrient trading options comes from the Upper Mississippi, Missouri, and Ohio River basins. The application of N trading programs in the Mississippi River Basin can result in small increases (around 0.5 percent or less) in phosphorus losses in some watersheds that lie outside of the basin. Under GHG trading programs at $14/t C and $5/t C, the greatest reductions in nitrogen occurred in the Upper Mississippi, Missouri, Arkansas-White-Red River, and Lower Mississippi River basins, while the greatest phosphorus reductions were in the Upper Mississippi and Missouri River basins.

Soil Erosion

Conservation tillage subsidies, as anticipated, reduce soil erosion by slightly less than 11 percent. *(See Table 3.)* The next best options for reducing soil erosion, at around 4 percent, are N and P Trading Scenarios 2 and combined N trading with GHG payments. Surprisingly, the CRP option does not perform as well *(see Figure 2f)*; however, this option is limited in its ability to significantly reduce soil erosion because the increase in CRP acreage is capped at 40 million acres. In addition, some of the additional CRP acreage comes from land tilled using conservation tillage practices, diluting the impact of taking land out of production.

A majority of the decreases in soil erosion produced by a conservation tillage subsidy comes from the Upper Mississippi, Missouri, and Ohio River basins, as well as the Pacific Northwest region. Similarly, with the nutrient trading options, the greatest reductions come from the Upper Mississippi and Missouri River basins.

CONCLUSIONS

What Can Be Achieved?

Reducing the size of the Dead Zone in the Gulf of Mexico to under 5,000 km^2 is an ambitious yet achievable objective for the Gulf Hypoxia Task Force and the residents of the Mississippi River Basin. A projected 20 percent to 30 percent reduction in total nitrogen delivered to the Gulf of Mexico would increase dissolved oxygen concentrations in bottom water by 15 percent to 50 percent, shrinking the area subject to hypoxia (Brezonik et al., 1999). Our analysis shows that nutrient trading, in conjunction with more stringent nitrogen discharge limits for WWTPs, could reduce the amount of nitrogen reaching the Gulf of Mexico by approximately 11 percent annually. This represents a half to a third of the required reductions.

Although WWTPs account for only a small portion of total nitrogen discharges in the Mississippi River Basin, their importance is underscored by the fact that these discharges are more easily regulated than non-point sources. Moreover, a majority of WWTPs either do not have nutrient removal capabilities or do not use advanced nutrient removal technology. With a 2:1 trading ratio for WWTPs purchasing nitrogen credits from agricultural non-point sources, nitrogen reductions could be up to twice as large as those nominally required by the more stringent discharge levels.

In our nutrient trading options, trading was allowed only between WWTPs and the agricultural cropping sector. In essence, our model does not account for industrial point sources, nor for the roughly 15 percent of the Mississippi River's total nitrogen load that comes from the livestock sector. Extending trading options to include livestock operations either as point sources through permitted concentrated animal feeding operations (CAFOs) or as unregulated sources of nutrient loss and industrial facilities would increase the potential for additional cost-effective reductions in nutrient losses. Changing waste management practices for livestock could also have implications for GHG emissions, because approximately 10 percent of U.S. agricultural GHG emissions result from nitrous oxide and methane emissions associated with manure management. The costs of nutrient trading would also be lowered by allowing trading between two point-source facilities. Depending upon the program design, urban sources of nutrient losses could also participate in nutrient trading programs.

Taking a Closer Look at the Co-benefits

Environmental co-benefits should be an important part of any strategy developed to tackle an environmental problem. In the case of water quality, there are strong ties to options for climate change mitigation in the agricultural sector.

With actual carbon credit prices currently at about $5/t C for GHG trading, the agricultural community has very little incentive to take substantial steps toward reducing its GHG emissions. At higher carbon prices, GHG trading can produce more dramatic benefits for both climate change and water quality. Pattanayak et al. (2002) found similar results at higher GHG prices. However, given a low world price for carbon, there may be greater potential for reducing GHG emissions through nutrient trading programs involving nitrogen and phosphorus.

Another option to consider is combining policies like nutrient trading with GHG payments for farmers. This produces water quality benefits similar to the straight nitrogen trading option but also provides small additional benefits in terms of mitigating climate change. In a system where agricultural sources of non-point water pollution are unregulated, it would be possible for farmers to sell both nutrient and GHG reduction credits. On the other hand, if either nutrients or GHGs were regulated, then this would not be a viable policy strategy. Presently, though, agricultural non-point sources are not regulated for either nutrients or GHGs.

Markets for trading carbon and nutrient reductions are both still in their infancy. Focusing resources on the development of domestic nutrient-trading markets could help meet our goal to reduce the size of the Dead Zone in the Gulf of Mexico, improve local water quality, and reduce emissions that contribute to climate change.

Farm income need not suffer in implementing such an environmental strategy. Most of the policy options tested here could be introduced without negatively impacting farm income in most regions of the country. The analysis shows that reductions in nitrogen delivered to the Gulf of Mexico can be achieved in a cost-effective manner. However, there were some exceptions. Options involving conservation tillage subsidies or a tax on nitrogen fertilizer did reduce nitrogen delivered to the Gulf of Mexico, but at a higher cost and with associated declines in farm income that make them less attractive options.

Benefits of Nutrient Trading

Nutrient trading proved to be the most cost-effective and successful option to meet the Gulf Hypoxia Task Force's goals (both coastal and within basin), providing the greatest overall benefits to the environment and the agricultural community. Trading is a highly targeted program in which farmers are paid not according to the practices they implement or changes they make, but instead according to the reductions in nitrogen and phosphorus loss to the waterways they can achieve. To make these reductions, farmers are allowed to utilize practices yielding the greatest reduction for the least cost. Similarly, managers of regulated point sources facing more stringent discharge limits can choose the most appropriate reduction strategy for their facilities.

Giving farmers the flexibility to choose the mitigation option best suited to their operations not only increases cost-effectiveness but may also increase the likelihood of acceptance and adoption of these programs. This would likewise apply to the implementation of GHG trading programs.

Another benefit of nutrient trading is that it reduces in the short term the cost of capital upgrades for municipal WWTPs, which may face increasingly stringent nutrient regulations in the near future. If WWTPs had to meet the 8 mg/l/day nitrogen discharge limit, allowing plants with high capital upgrade costs to purchase reduction credits from the agricultural sector would save approximately $5 billion in capital costs. For the even tighter discharge limit of 3 mg/l/day, the total savings would be in the order of $21 billion.

In the absence of trading, these costs would be borne by all municipal water users in the vicinity of WWTPs. These savings are derived from the cost of WWTPs having to upgrade their plants to meet the more stringent discharge levels (based on cost curves estimated for the Chesapeake Bay). Instituting nutrient trading would ease the financial burden of tighter regulation of WWTPs and provide the agricultural community with an additional source of income. However, the question remains whether point sources should continue to bear the greatest burden for improving water quality. This burden can be relieved to some extent through policy or the design of trading programs, so that non-point sources also receive discharge limits and are responsible for undertaking some form of nutrient reduction.

Nutrient trading also has the advantage of potentially allowing all the contributors of nitrogen to the Gulf of Mexico to be part of the remedy. Municipal and industrial point sources can participate as buyers or sellers in the marketplace, agricultural producers would typically act as the sellers of nutrient credits, and urban sources could enter the market as buyers or sellers. Nutrient markets also leave open the possibility that CAFOs—now that they are required to obtain permits and develop nutrient management plans—could act as either buyers or sellers in the market. These reductions can come from a variety of sources, ranging from nutrient removal technology for WWTPs and CAFOs, to changes in crop management practices, to the establishment of wetlands and buffers.

Nutrient trading presents many benefits for improving water quality. To date, these programs have been slow to materialize or have been rendered unsuccessful due to poor program design. The lack of official federal trading policies and dearth of political will to implement and test such schemes has provided little incentive for innovative groups or government agencies to take on the task of developing trading programs. The new USEPA policy on water quality trading should remove some of this reticence. Another downside has been the absence of a marketplace for these transactions and the difficulty buyers and sellers have in locating each other. The development of websites such as NutrientNet, an e-marketplace for nutrient trading, helps alleviate some of these obstacles. As more pilot trading programs develop across the country, the know-how for and ease of establishing these programs will increase, along with their acceptance.

Regional Impacts of Policy

Programs contained within the Mississippi River Basin can have some negative impacts in other watersheds. However, these impacts typically are rather small and cause very little change (less than 1 percent). In the case of nutrient trading, these small increases in phosphorus losses to waterways occur mainly in the western portions of the United States. For most policies tested in our analysis, the greatest positive financial and environmental impacts tend to be concentrated in the Upper Mississippi, Ohio, and Missouri River basins.

Of all the policy options tested, a nutrient trading strategy not only produced the greatest overall benefits for the environment, but was more cost-effective than the more traditional policy approaches. Trading exploits the synergistic relationships between water quality and climate change and also provides an incentive mechanism for the agricultural community to be part of the remedy for the Dead Zone in the Gulf of Mexico.

RECOMMENDATIONS

1. **The federal and state agencies in the Gulf Hypoxia Task Force should establish and implement a nitrogen cap for the Gulf of Mexico or Mississippi River Basin.**

   An upper limit on the amount of nitrogen entering a watershed can be defined using the assimilative capacity of the aquatic ecosystem and the reductions required to address local water quality concerns, such as drinking water quality or coastal water quality problems. This nitrogen cap could be for the Gulf of Mexico, the entire Mississippi River Basin, or divided between smaller sub-basins with all nutrient sources, both point and non-point source, included in the cap. The TMDL rule is one way to establish a cap on an impaired waterway, and provides the impetus for using nutrient trading to meet this cap. If a cap were set for the Gulf of Mexico, the adoption of nutrient criteria by the upriver states and the subsequent issuance of permits based on these criteria would also be required to ensure action within the Mississippi River Basin itself.

   Nutrient trading, encompassing the entire Mississippi River Basin, is a mechanism that allows each source to cost-effectively meet its cap. In addition, each watershed has the flexibility to identify the most cost-effective nutrient reduction practices to implement. Trading programs can be designed in many ways and are able to take into account the needs of the various sub-basins or the Mississippi River Basin as a whole. Each source can be allocated a nutrient discharge limit and those sources exceeding their limits can trade with sources that can more cost-effectively over-comply with their caps. Programs that target phosphorus and nitrogen will improve water quality in both local waterways and the Gulf of Mexico and will also help reduce greenhouse gas emissions from agricultural sources.

2. **Federal and state agencies should do more to promote nutrient trading programs.**

   Pilot nutrient trading programs exist in many parts of the United States. However, many of these are in their infancy or have not executed many trades. To facilitate the development of successful trading programs, the World Resources Institute, in collaboration with watershed partners, has developed a website, NutrientNet (www.nutrientnet.org), to create a marketplace for nutrient trading. Tools like this, coupled with the USEPA policy on water quality trading, TMDL-type rules, and programs like the Conservation Innovation Grants Program within the 2002 Farm Bill create opportunities for growth of these programs across the country. The success of this cost-effective mechanism to address both water quality and GHG emissions from agriculture depends, to some extent, on support and promotion by government agencies.

3. **Federal and state agencies should develop a coordinated and collaborative approach to planning and implementing watershed conservation measures.**

   Directing and combining resources in specific watersheds will demonstrate how the effectiveness of conservation programs and incentives can be improved. Coordination between agencies leading to more efficient use of program resources will yield greater total ecosystem improvements. These improvements would most likely include improving water quality, reducing greenhouse gas emissions, improving fish and wildlife habitat, and maintaining community viability.

   Without this coordination and collaboration, the important policy and administrative concern of "spreading resources too thin" can arise. Should this be the case, conservation efforts will be too diffused, resulting in little or insufficient ecosystem improvement. Concentrating efforts in those watersheds that contribute the most nutrients to the Gulf of Mexico will result in an even greater cumulative ecosystem response.

   Agency programs that could be involved in funding this approach are the 2002 Farm Bill, the USEPA watershed initiative, Clean Water Act Section 319, U.S. Army Corps of Engineers Vision 2000 program, and U.S. Fish and Wildlife Service natural resource assistance grants. Another example, the Small Watershed Protection and Flood Prevention Program within USDA National Resource Conservation Service, uses a locally led approach to conservation. This program links local, state, and federal partners at the watershed level, providing an additional level of cooperation and funding assistance. Monitoring and research programs should be used to document outcomes and develop technology to better evaluate and estimate ecosystem response.

4. **Agencies should establish coordinated monitoring strategies to determine if watershed and conservation efforts have made a difference.**

   A significant drawback of many initiatives is the lack of a strategy to monitor program impacts. The ability to demonstrate program success, quantitatively and/or qualitatively, will allow for better arguments to policymakers and budgeting bodies about the benefits of continued, increased, or new funding. Similarly, the ability to illustrate how changes in on-farm production and management practices or the application of a new incentive are having an impact will provide stronger motivation for the agricultural community to further adopt these practices and embrace these new incentives.

5. **Farm conservation spending should be targeted.**

   Performance-based payments allow farmers to undertake those practices that are not only most suitable for addressing the environmental problem in question but are also most profitable. The effectiveness of various practices and initiatives in improving the environment differs between regions. Letting farmers choose their preferred conservation option produces the "biggest bang for the buck" and promotes fiscal responsibility. Nutrient trading is one mechanism that can accomplish this. As in the "coordinated approach" recommendation, greater benefits can be achieved by directing conservation spending to those regions or watersheds with the greatest need. Depending on the size of a specific targeted area, a shift in activities to other areas not implementing the policy may need to be considered.

6. **Government agencies and private organizations should explore other opportunities to reduce greenhouse gas emissions in the agricultural sector beyond activities associated solely with carbon sequestration.**

   There has been a general tendency in the agricultural community to concentrate efforts around climate change on carbon sequestration prospects. However, there are uncertainties associated with the permanence of these reductions and the saturation of the carbon pool. This emphasis on carbon sequestration has masked other opportunities. Frequently overlooked are opportunities to reduce emissions of nitrous oxide and methane, two potent greenhouse gases with substantial climate impact. These gases offer possibilities for the agricultural sector to make significant, permanent, and profitable reductions in its contribution to greenhouse emissions. Similarly, mechanisms such as nutrient trading promise to capitalize on opportunities to simultaneously decrease greenhouse gas emissions, increase carbon sequestration, and stimulate water quality improvements. Combining nutrient trading policies with additional payments for GHG benefits, in the right policy context, is another option to consider.

7. **A strategy should be developed to tackle a suite of environmental problems rather than focusing on individual problems as they arise.**

   A common feature of past conservation efforts was to concentrate on environmental problems as they occurred, sometimes unwittingly creating additional environmental problems or failing to take advantage of the potential for co-benefits among policy options. A comprehensive appraisal of all environmental concerns facing a watershed or region will permit identification of co-benefits and assessment of tradeoffs (both economic and environmental) to create an overarching policy or program with optimal impacts for the entire ecosystem.

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NOTES

1. Normal levels of dissolved oxygen are about 5 parts per million.
2. These estimates of percent contribution from the various sources are based on regression results from nitrogen yield models (Goolsby et al., 1999).
3. These estimates of percent contribution from the various sources are based on regression results from phosphorus yield models (Goolsby et al., 1999).
4. Concentrated animal feeding operations are also regulated, but to date, few permits have been issued or enforced.
5. These estimates are based on National Pollution Discharge Elimination System (NPDES)-regulated point sources. Methods and procedures are outlined in USEPA (1998) and Tetra Tech Inc. (1998).
6. Measuring global warming potential (GWP) permits comparison of the climate change impacts of various policies and practices, even those that do not address the same greenhouse gases.
7. Tile drains are concrete, ceramic, plastic pipe, or related structures placed at suitable depths and spacings in the soil or subsoil to enhance and/or accelerate drainage of water from the soil profile.
8. The TMDL program requires states and territories to list impaired waters and then develop limits establishing the maximum amount of pollutants, such as nutrients, that a body of water can receive and still meet water quality standards. This amount is then allocated between all point and non-point sources in the watershed. USEPA has withdrawn the revised TMDL rule from 2000, but the 1992 rule remains in effect and continues to be the basis for the TMDL program.
9. A base year of 2010 is used in the USMP model and throughout this analysis.
10. This includes direct emissions from synthetic fertilizer and indirect emissions when nitrogen enters the atmosphere as ammonia (NH_3) and nitrogen oxide (NO_x) and returns to the soil by atmospheric depositions, which enhances nitrous oxide (N_2O) production.
11. The details of the December 2002 CAFO rule can be found at www.epa.gov/npdes/caforule.
12. Policymakers examining options for the Chesapeake Bay, which experiences hypoxic zones similar to those in the Gulf of Mexico, are discussing possible tightening of discharge limits for wastewater treatment plants to either 8 mg/l/day or 3 mg/l/day. The credit price selected for this analysis reflects a price that is at or below the average price and where the additional nutrient reductions per dollar spent are decreasing.
13. The 1 mg/l/day discharge limit represents a transition point in technology and capital expenditure for phosphorus removal. The credit price selected for this analysis reflects a price that is at or below the average price and where the additional nutrient reductions per dollar spent are decreasing.
14. The carbon prices in the CERUPT scheme in the Netherlands ranges from EUR 3.30/t C to 5.50/t C (~US$3.30 and US$5.50), while the ERUPT scheme expects prices to range from EUR 3/t C to 5/t C.
15. In the model, the Conservation Reserve Program is capped at 40 million acres—the current legislated acreage for this program.
16. Moldboard tillage is a form of conventional tillage where less than a 30 percent cover of crop residues remains on the surface after the completion of the tillage sequence. It is a primary broadcast tillage operation that is performed to shatter soil with partial to complete inversion, usually to depths greater than 20 centimeters.
17. Ridge tillage is a form of conservation tillage where 30 percent or more of the crop residue remains on the soil surface. The soil is left undisturbed from harvest to planting except for nutrient injection. Planting is completed in a seedbed prepared on ridges. Residue is left on the surface between the ridges.
18. Mulch tillage is a form of conservation tillage where 30 percent or more of the crop residue remains on the soil surface. The soil is undisturbed prior to planting and any tillage or preparation of the soil is done in such a way that plant residues or other materials are left to cover the surface.
19. No-till is a form of conservation tillage where 30 percent or more of the crop residue remains on the soil surface. The crop is planted directly into the soil with no primary or secondary tillage carried out since the harvest of the previous crop. Planting or drilling is accomplished in a narrow seedbed or slot.
20. Rental rates are the payments on a per acre basis that are paid to farmers who enroll in the CRP program.
21. Go to http://hypoxia.wri.org/ for details of sensitivity analyses performed for these policy options.

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