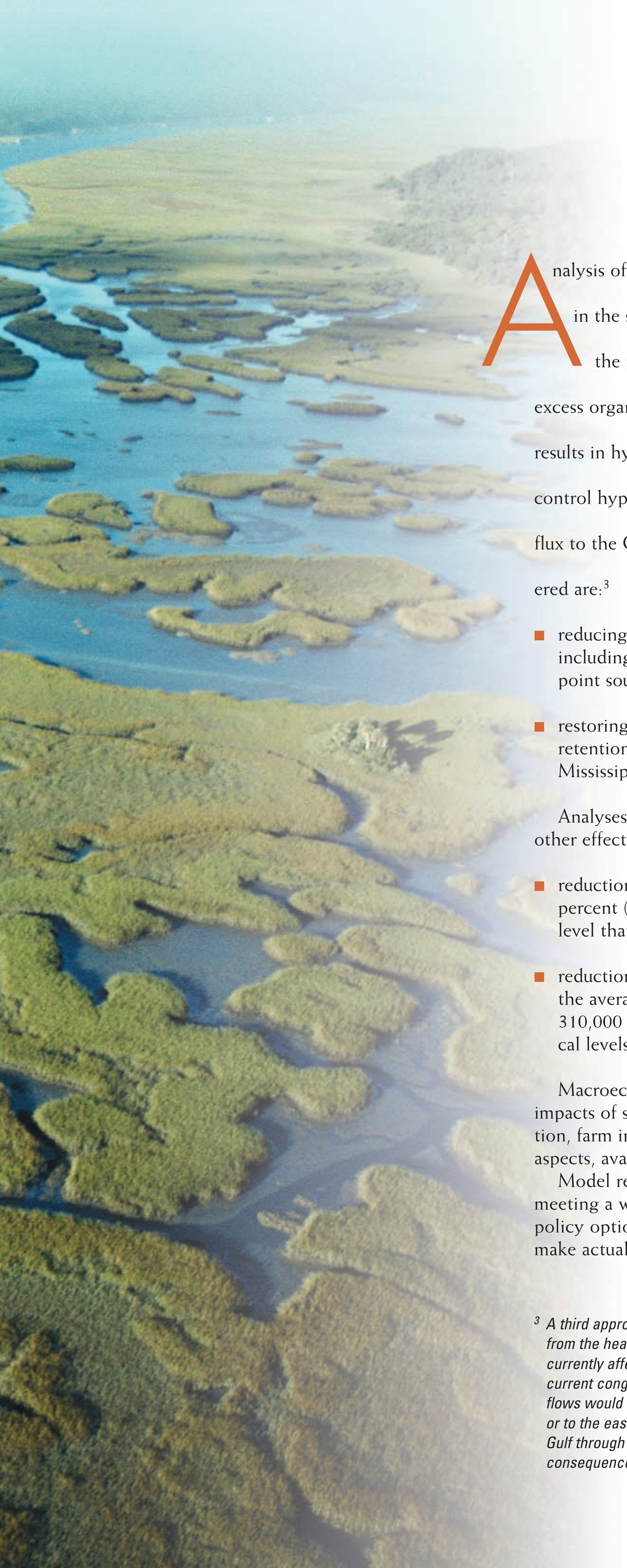
Approaches

for Reducing Nutrient Loads



Analysis of the causes of hypoxia in the Gulf of Mexico, as noted in the second chapter of this report, indicates that nitrogen is the principal nutrient fueling production and deposition of excess organic matter which, when stratified conditions exist, results in hypoxia. Thus, the approaches to reduce, mitigate, and control hypoxia in the Gulf of Mexico focus on reducing nitrogen flux to the Gulf. The two primary approaches that can be considered are:[3]

- reducing nitrogen loads to rivers and streams in the Basin, including losses of nitrogen from farmlands and loads from point sources, atmospheric deposition, and other sources; and
- restoring and enhancing natural denitrification and nitrogen-retention processes to reduce nitrogen loads from the Mississippi and Atchafalaya Rivers to the Gulf.

Analyses of these approaches examined the economic and other effects of achieving nitrogen load reductions at two levels:

- reduction of total nitrogen loads to the Gulf of Mexico by 40 percent (approximately 625,000 metric tons/yr), to the average level that existed during 1955–70; and
- reduction of nitrogen loads by approximately 20 percent from the average level of the 1980–96 period (approximately 310,000 metric tons/yr), midway between reduction to historical levels and no reduction.

Macroeconomic models were used to evaluate system-wide impacts of some broad policy approaches on agricultural production, farm income, consumer prices, and the like. For many aspects, available models offer only rough approximations.

Model results report the broad economic consequences of meeting a water quality goal and are useful for comparing broad policy options. However, the model results cannot be used to make actual policy recommendations for any particular area in

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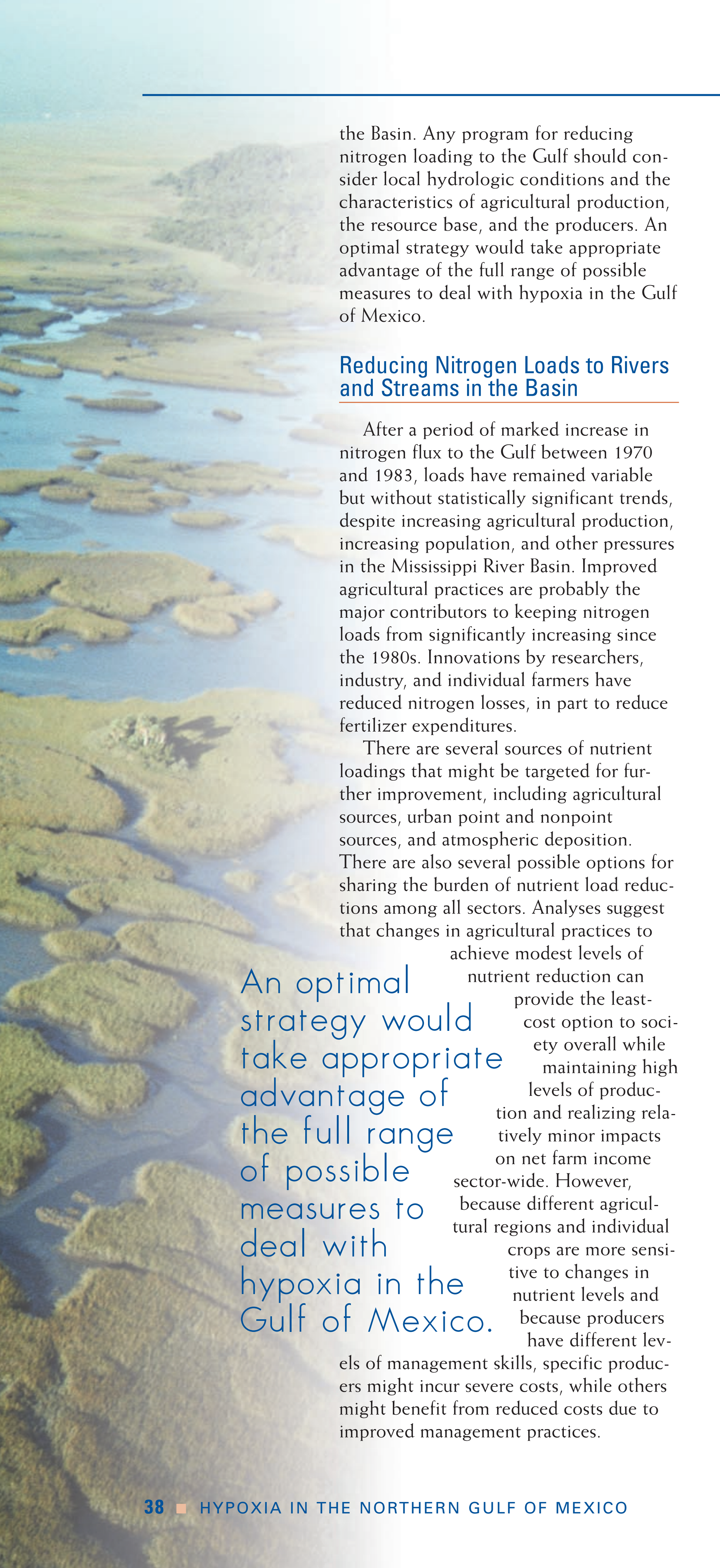
[3] *A third approach, recently raised, calls for diverting nutrient-laden waters away from the heart of the hypoxic zone in the central Gulf to areas that are not currently affected by hypoxia. To do this would require an alteration of the current congressionally mandated 70/30 flow split at Old River, so that additional flows would be passed into the Gulf by the main channel of the Mississippi River, or to the east side of the "Bird Foot Delta," while reduced flows would enter the Gulf through the Atchafalaya River distributary. This option would have multiple consequences and has not been analyzed.*



the Basin. Any program for reducing nitrogen loading to the Gulf should consider local hydrologic conditions and the characteristics of agricultural production, the resource base, and the producers. An optimal strategy would take appropriate advantage of the full range of possible measures to deal with hypoxia in the Gulf of Mexico.

Reducing Nitrogen Loads to Rivers and Streams in the Basin

After a period of marked increase in nitrogen flux to the Gulf between 1970 and 1983, loads have remained variable but without statistically significant trends, despite increasing agricultural production, increasing population, and other pressures in the Mississippi River Basin. Improved agricultural practices are probably the major contributors to keeping nitrogen loads from significantly increasing since the 1980s. Innovations by researchers, industry, and individual farmers have reduced nitrogen losses, in part to reduce fertilizer expenditures.

There are several sources of nutrient loadings that might be targeted for further improvement, including agricultural sources, urban point and nonpoint sources, and atmospheric deposition. There are also several possible options for sharing the burden of nutrient load reductions among all sectors. Analyses suggest that changes in agricultural practices to achieve modest levels of nutrient reduction can provide the least-cost option to society overall while maintaining high levels of production and realizing relatively minor impacts on net farm income sector-wide. However, because different agricultural regions and individual crops are more sensitive to changes in nutrient levels and because producers have different levels of management skills, specific producers might incur severe costs, while others might benefit from reduced costs due to improved management practices.

> An optimal strategy would take appropriate advantage of the full range of possible measures to deal with hypoxia in the Gulf of Mexico.

Ultimately, there are many questions about how these improved practices would be motivated and how the costs would be borne. Differing implementation strategies could impose costs primarily on agricultural producers, consumers, or—if these costs are supported through incentive payments—society at large. How to pursue effective implementation of a solution to Gulf hypoxia across the different nutrient sources and a multitude of state and federal water quality laws and programs will require consideration of a broader range of factors than was attempted in this assessment.

Some reduction in nitrogen loads from municipalities could be achieved by the elimination of combined sewer overflows and the installation of biological nutrient control processes in new sewage treatment plants. While such sources are not the major contributor to the total nitrogen load from the Basin, they discharge directly to major streams, with little opportunity for natural treatment.

Discharges of nitrogen from farms to streams and rivers could be reduced by implementing a wide variety of changes in management practices, such as:

- applying nitrogen fertilizer and manure at not more than agronomically recommended rates;
- switching from fall to spring application of fertilizer;
- improving management of livestock manures, whether stored or applied to the land;
- changing from row-cropping to perennial-cropping systems;
- planting cover crops for fall and winter nutrient absorption;
- switching from conventional to ridge-tilling or other reduced-tillage practices;
- ensuring that the lateral spacing of subsurface tile drainage is not less than 15 meters;
- controlling water tables to promote denitrification within the soil column; and

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The spatial pattern of the manure input to the Basin has changed from a highly dispersed to a highly concentrated distribution as confined animal feedlot operations, such as shown here, have become more common. Improving management practices for storage and application can reduce nitrogen losses to streams and rivers.

- routing soil drainage effluent through wetlands, grass buffer strips, or riparian forest buffers.

Nitrification inhibitors for fertilizers, amino acid feed supplements, and other measures have also been suggested. For some of the above improved management practices, reduction in nitrogen losses to streams are on the order of 10–20 percent of baseline conditions, but others have been shown to reduce losses by as much as 90 percent in specific field studies (see the Topic 4 and Topic 5 reports for details).

As shown in Table 5.1, of these measures, the two with the greatest estimated potential to reduce nitrogen losses from agriculture to streams and rivers are:

- *Improved nitrogen management techniques.* This is estimated to offer the greatest potential reduction of nitrogen loading. Reducing "insurance" rates of nitrogen fertilizer,[4] improving management practices for storage and land application of manure,[5] improving management of runoff from feedlots, applying appropriate credits for previous crops and manure,[5] and using improved soil nitrogen testing methods could reduce nitrogen losses at the edge of fields by about 0.9–1.4 million metric tons per year.[6]
- *Alternative cropping systems.* If 10 percent of the corn–soybean farms in the Basin were changed to include alfalfa or alfalfa-grass mixes as crops, edge-of-field nitrogen losses could be decreased by an estimated 0.5 million metric tons per year.

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[4] *Data on "insurance" application of fertilizer (application at rates above agronomic recommendations) are sparse. "Insurance" application is an economic wager: the producer is gambling that all other factors influencing crop production will be optimal in a given year and that an extra 10–20 pounds of nitrogen fertilizer per acre would result in increased yields. In reality, this is a poor wager. Plant nitrogen is obtained from both soil reserves and applied nitrogen: thus, response is not solely a function of "this year's application," but is a function of the total available nitrogen status. Agronomic recommendations are developed taking these factors into account. Therefore, insurance applications are in most cases wasted, and the extra nitrogen is lost from the field and may lead to increased loadings to the aquatic environment.*

[5] *In practice, according to the Potash and Phosphate Institute, nitrogen use on corn in Iowa in 1996 was within the range of agronomic recommendations, when manure was not used but exceeded agronomic recommendations by more than 30 percent, or about 33 kg of nitrogen/ha (30 lb/acre) when manure was used.*

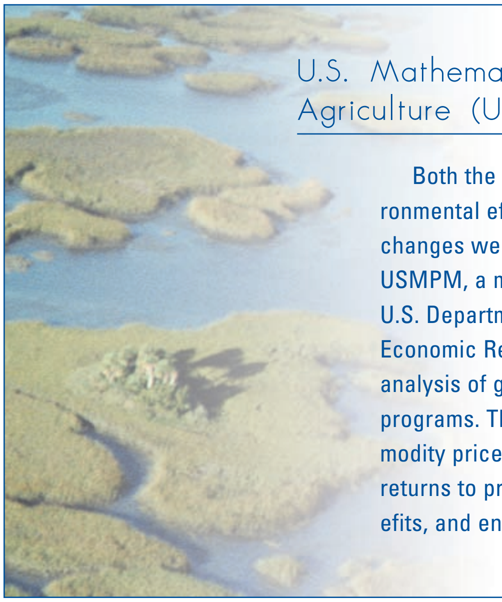
[6] *Note that these estimates of the impacts of changes in agricultural practices are for reductions at the edge of the field; estimated edge-of-field source reductions do not translate to equivalent reductions in nitrogen loadings to the Gulf, because only a portion of nitrogen sources in the Basin reaches the Gulf.*

Estimates of impact are based on field tests and case studies described in the Topic 5 report.

Measures to reduce nutrient loads would generally have net costs. Assuming constant levels of efficiency, large decreases in nutrient use below agronomic rates would lead to reduced agricultural productivity in the MARB and reduced total production as marginally fertile land is retired. The agriculture sector's response to these alternative management strategies was simulated with the U.S. Mathematical Programming Model for Agriculture (USMPM), described below. The model predicts both the economic effects and the changes in nitrogen loading under the various scenarios examined.

The USMPM modeling analysis provided a range of potential results that focusing a variety of nitrogen-reduction strategies in the Mississippi Basin could achieve. The analyses showed that as a result of different approaches to nitrogen reduction, shifts in production could be expected both inside and outside the Basin. Many producers inside the Basin would find that reducing crop acreage would benefit them, whereas many producers outside the Basin would find advantage in expanding their cropped acreage. For example, reducing edge-of-field nitrogen loss by 20 percent (in the most cost-effective manner) could result in a 5.8 percent decline in crop acreage in the Basin with a potential 2.8 percent increase in cropland outside the Basin. This same scenario could also be expected to increase edge-of-field nitrogen losses outside the Basin by about 8 percent due to an increase in production. Modeling analyses indicated that the higher the level of nitrogen loss reductions from agriculture shown in the Basin, the more pronounced shifts in regional production could be expected, and these production shifts could increase nutrient-related problems for other regions. Clearly, the degree and pattern of production shifts that could be realized in response to each alternative strategy would depend on the nature of the strategy selected (the mix of practices used), the size of the region affected, and its location (environmental conditions).

The USMPM modeling analysis predicts that edge-of-field nitrogen losses can be reduced by 20 percent (941,000 metric tons/yr) using various management practices at a total societal cost under economically optimum conditions of $831 million/yr, or $0.88 per kg reduction in edge-of-field nitrogen flux. This result assumes all factors of production are adjusted in the most efficient manner. Although meeting the 20 percent reduction in edge-of-field nitrogen loss could also be achieved by targeting fertilizer reductions only, it would require a 45 percent reduction in fertilizer use, resulting in costs of $2.85 per kilogram of nitrogen reduction. However, smaller reductions would be more attractive on a per kilogram basis: a 20 percent reduction in fertilizer would reduce edge-of-field losses by 503,000 metric tons/yr (about 10 percent) at a total societal cost of $347 million, or $0.69 per kilogram. As part of the economic analysis, the impact of raising the price of fertilizer by increasing fertilizer taxes (an approach designed to spur farmers to find ways to reduce fertilizer use) was evaluated. However, the analysis showed that to achieve a 20 percent reduction in edge-of field losses, such taxes would have to reach 500 percent of current retail price for fertilizer. The resulting cost to individual farmers and society as a whole was predicted to be much greater than other approaches evaluated (see Table 5.3 on page 45).



U.S. Mathematical Programming Model for Agriculture (USMPM)

Both the economic and the environmental effects of agricultural changes were estimated using the USMPM, a model developed by the U.S. Department of Agriculture's Economic Research Service for analysis of government commodity programs. The model calculates commodity prices and quantities, net returns to producers, net social benefits, and environmental emissions recognizing spatial variation and explicitly representing various management practices used by farmers. Adjustments to crop production can be estimated in response to restrictions placed on nitrogen or land use by altering any or all of the following: acreage planted, crop mix, rotations used, tillage practices, and fertilizer application rates (see the Topic 6 report, p. 25ff., for details).

Table 5.1 Potential Approaches to Reducing Nitrogen Inputs

Approach	**Potential Nitrogen Reduction** *(Thousands of metric tons/yr)*
Changing Farm Practices	
Nitrogen management *(Reduction in "insurance" rates of N fertilizer application, improved management practices for storage and land application of manure, improved management of runoff from feedlots, and crediting of nonfertilizer nitrogen)*	900–1,400[a]
Alternative cropping systems *(Perennial crops in lieu of corn and soybeans on 10% of acreage)*	500[a]
Reduction in Point Sources	
Tertiary treatment of domestic wastewater	20

[a] Note that these estimates of the impacts of changes in agricultural practices are for reductions at the edge of the field; estimated edge-of-field source reductions do not translate to equivalent in nitrogen loadings to the Gulf, because only a portion of nitrogen sources in the Basin reaches the Gulf.

Point sources of nitrogen, as well as urban nonpoint sources, also contribute to the total nitrogen load to the Gulf. Nitrate concentrations in urban nonpoint sources are generally not high, compared to urban point sources or Corn Belt cropland. Urban areas constitute only 0.6 percent of the Basin; thus, the contribution of urban nonpoint sources is comparatively small but has not been precisely estimated. Point sources constitute less than 2 percent of nitrogen inputs to the Basin, or about 11 percent of the nitrogen inputs to the Gulf. Higher unit costs for reductions in nitrogen from domestic wastewater partly reflect the fact that these sources are currently regulated and have realized pollution control costs already. Biological nitrogen removal from urban point sources typically costs $40 per kilogram of nitrogen removed. However, in some cases, cost-effective reductions in nitrogen load could be realized.

Atmospheric deposition of nitrogen (wet and dry nitrate, wet ammonia, and organic nitrogen) is estimated to be about 10 percent of the nitrogen input to the Basin. The costs of reducing atmospheric deposition of nitrogen are estimated to be $20–100 per kilogram of nitrogen.

Nitrogen trading among all sectors could offer opportunities to reduce costs overall.

Restoring and Enhancing Denitrification and Nitrogen-Retention Processes

A second general approach to reducing nitrogen flux to the Gulf of Mexico is to place or restore ecosystems that are effective nitrogen sinks along the paths of nitrogen flow from sources to the Gulf. Table 5.2 summarizes the impacts of denitrification options.

Nitrogen transformations in wetlands and riparian soils, surface water, and ground water involve several microbiological processes, some of which denitrify—that is, make the nitrogen effectively unavailable for plant uptake. Wetlands also serve as traps for phosphorus, which limits primary production within the Basin and, under some conditions, on the shelf in the Gulf.

High rates of denitrification are possible, but wetlands and riparian zones can also act as sources of nitrogen under some conditions. Loading rates (flow times nitrogen concentration of inflowing water) dictate the effectiveness of wetlands in reducing nitrogen. The most effective use of wetland restoration and creation would be in watersheds that discharge high amounts of nitrogen. Retention time is also important. Storm events, if significant enough, can cause nitrogen to move rapidly through the system, bypassing effective retention.

Extensive experience with flow-through wetland systems suggests a narrow range centered around 10–25 g N/m^2/yr as a reasonable target for denitrification by wetlands. Assuming denitrification at 15 g N/m^2/yr (150 kg N/ha/yr), 2.1 million hectares (5 million acres, or 0.7 percent of the Mississippi River Basin area) of constructed or restored wetlands would reduce nitrogen load to the Gulf of Mexico by 20 percent. The current national goal is to restore wetlands at a rate of 100,000 acres/yr (about 40,000 ha/yr) (see the Clean


Vegetated buffer areas reduce both surface and subsurface flux of nitrogen to streams and rivers. Riparian buffers can be particularly effective in capturing nutrients (and providing other protection) during floods.

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Water Action Plan, available at <http://www.cleanwater.gov>). The total direct costs for permanent easements and restoration of wetlands to reduce nitrogen load by 20 percent was estimated to be $4.7 billion. Annual costs, including net effects on consumers and producers plus annualized wetland restoration costs, were estimated to be $3.1 billion, or about $8.90 per kilogram reduction in nitrogen flux per year. There would be ecological and wildlife benefits in addition to those that might accrue in the Gulf from using this approach.

Riparian areas are vegetated areas, generally forested or grassed, next to water resources. They have been shown to be effective in removing nitrates from ground water as it passes through the vegetated buffer. Typically, denitrification rates are 2-6 g $N/m^2/yr$. Assuming denitrification at 4 g $N/m^2/yr$ (40 kg N/ha/yr), 7.8 million hectares (19 million acres, or 2.7 percent of the Basin) of additional riparian buffers would be needed to reduce nitrogen load to the Gulf by 20 percent.

A current national goal is to establish two million miles of conservation buffers on agricultural lands (also per the Clean Water Action Plan). Total direct costs for permanent easements and restoration of 27 million acres of riparian buffers were estimated to be $46.3 billion, equating to $18.0 billion annually in changes to consumer and producer surpluses plus annualized restoration costs, or about $26 per kilogram reduction in nitrogen flux per year.

Table 5.2 Potential Approaches to Increasing Denitrification

Approach	Potential Nitrogen Reduction *(Thousands of metric tons/yr)*
Creating and restoring 5–13 million acres of new wetlands	300–800
Creating and restoring 19–48 million acres of riparian bottomland hardwood forest buffers	300–800
Diverting rivers in coastal Louisiana	50–100

Separation of the Mississippi River from its floodplain and coastal estuaries may be an important factor in supplying nutrients to the Gulf. The river once spread out over the Delta during flood periods. Today, however, with the exception of such locations as the Bonne Carre Spillway and the Atchafalaya Basin, the river is mostly shunted directly to the sea. Through enhanced water management strategies, it may be possible to increase the amount of water reaching inland and coastal wetlands, and thereby increase nitrate removal from the water and reduce coastal land loss. Using a denitrification rate of 10 g N/m^2/yr based on studies at Caernarvon, Louisiana, and other locations, diverting 13 percent of the total river flow over 1.2 million acres (500,000 hectares) would remove 50,000 metric tons of nitrate per year. However, without upstream controls, the system might become nitrogen-saturated, or it might release nitrogen in a different form, in a different season, or in a different location. A recent study (Turner 1999) compared nutrient concentrations entering and leaving the Atchafalaya River basin, a major floodway used to divert floodwaters from the Mississippi and Red Rivers to the Gulf during the annual high-water season. This study found that nitrate concentrations remained essentially unchanged from upstream to downstream monitoring stations. However, enhanced water management strategies within the floodway could improve the potential to remove nitrate from waters flowing through this area. Other studies have shown that harmful algal blooms may result when large quantities of Mississippi River water are diverted into coastal areas.

The construction and restoration of wetlands and riparian zones in the Basin to reduce nutrients would contribute to several important national goals, including those for drinking-water protection, adding to the nation's disappearing wetland habitat, improving river ecosystems, enhancing terrestrial wildlife in river corridors, and mitigating the effects of floods. This restoration of wetlands is in keeping with recommendations by the National Research Council's Committee on the Restoration of Aquatic Ecosystems (NRC 1992), which called for a national program of wetland restoration that would contribute to an overall gain of 10 million acres by the year 2010. Well-placed wetlands and riparian buffers generally support larger populations of wildlife because of the diverse habitats they provide. The restoration of riparian vegetation improves the ecological condition of streams and rivers and protects the aquatic communities that depend on them. Roots of riparian vegetation stabilize the stream bank and prevent both bank erosion and downstream sedimentation. The National Research Council also called for restoration of about 640,000 kilometers (400,000 miles) of streams, rivers, and floodplains across the nation (NRC 1992).

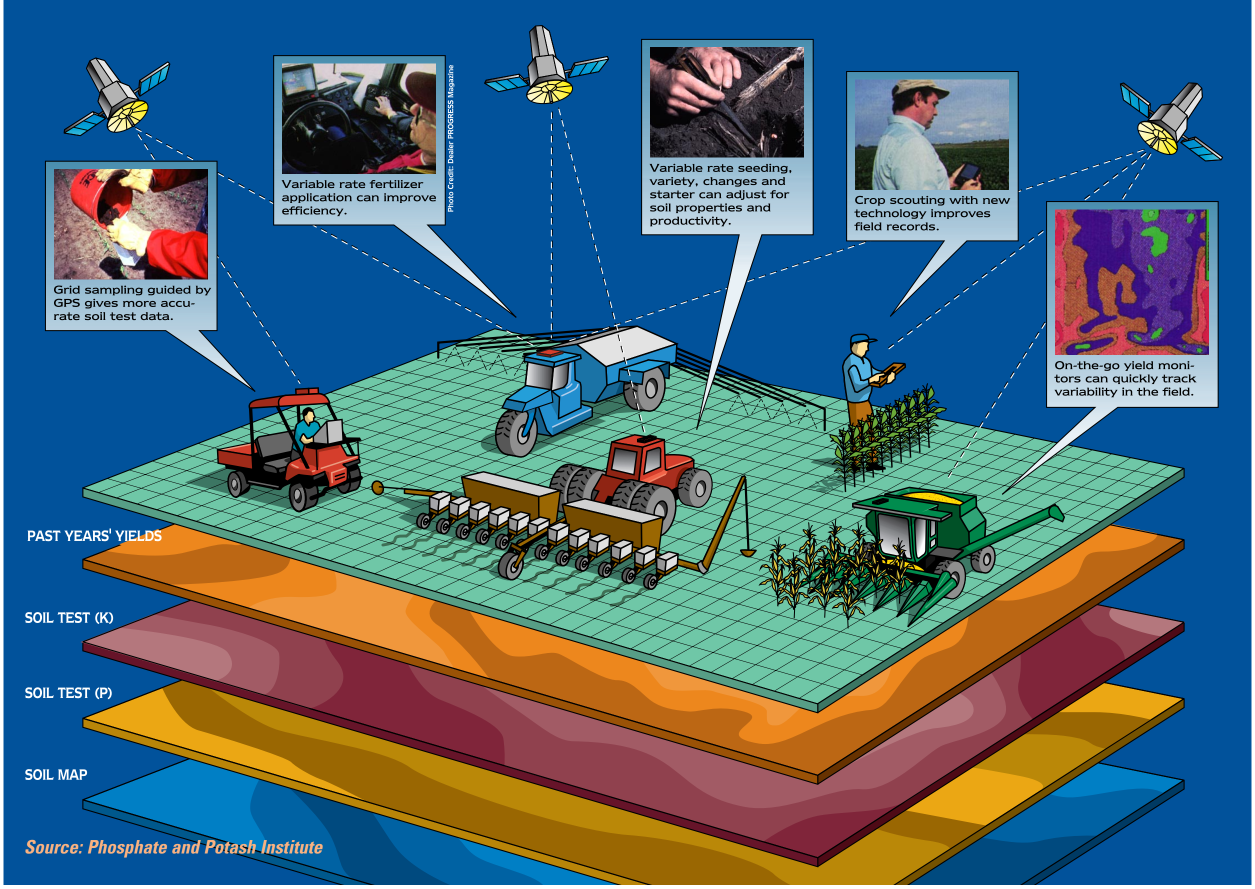
Cost-Effective Strategies

Various potential components of a program to reduce nitrogen loads to the Gulf via the MARB system were analyzed to evaluate their cost-effectiveness; their impacts on the economy, farmers, and consumers; and the reductions in loads (Table 5.3).

Direct costs, including changes in consumer and producer surpluses and easement and restoration costs for wetlands, were estimated using the USMPM. All of the nutrient-reduction approaches will also produce environmental benefits within the drainage basin. These include the values associated with restored wetlands, reduced soil erosion, reduced nitrogen contamination of drinking water, reduced vulnerability to floods, enhanced wildlife habitat and improved recreational water quality. Other potential benefits of nutrient-reduction activities include more efficient use of organic and inorganic fertilizers (see Figure 5.1) and the energy associated with them, lower overall fertilizer costs, decreased health risk from contamination of public and private drinking-water supplies, and improved aquatic habitat in streams, lakes, rivers, and estuaries. Good estimates for the economic value of these benefits are only available for a few categories, such as wetlands and erosion. When these estimated benefits are factored in, the net costs of wetlands and farm practices become close: 20 percent edge-of-field nitrogen-loss reduction was estimated to have a net cost of $0.80 per kilogram ($0.36 per pound), while 5 million acres of wetlands would have a net cost of $1.00 per kilogram ($0.45 per pound).

An optimal strategy would take appropriate advantage of the full range of possible approaches to deal with hypoxia in the Gulf. Implementation mechanisms, including incentive payments, voluntary stewardship and technical assistance programs, more stringent requirements for regulated facilities or various combinations of these approaches, have advantages and disadvantages in various circumstances and locales; however locale-specific considerations were beyond the scope of this assessment. Since, generally, the costs per pound of nitrogen kept out of the river system and Gulf, or removed by biogeochemical processes in restored wetlands or riparian areas, are in the same order of magnitude, these regional or site-specific circumstances may drive the choice of the preferred mix of actions to address hypoxia—no single approach is clearly far more economical or costly.

FIG. 5.1 High-Tech Tools for Site-Specific Crop Nutrient Management



Source: Phosphate and Potash Institute

Nutrient application can be optimized based on geo-referenced records of soil test values, soil yield potential, and previous yield and application histories.

The benefits of a program to reduce nitrogen loads to the Gulf are difficult to quantify. Although there are known impacts to the Gulf ecosystem, an economic analysis based on past data did not detect a direct relationship between hypoxia and Gulf fisheries. The information to estimate the benefit value for such actions as restoring the ecological communities in the Gulf or improving water quality in the Basin is not available.

Another factor important in assessing the impact of potential actions on restoring damaged resources and on mitigating and controlling hypoxia in the Gulf is the uncertainty around and contribution of time lags. It appears that a substantial quantity of nutrient storage in soils and ground water has built up over many decades. This suggests that continuing loads may contribute to elevated discharges to the Gulf perhaps for decades, even after reduction programs are implemented.

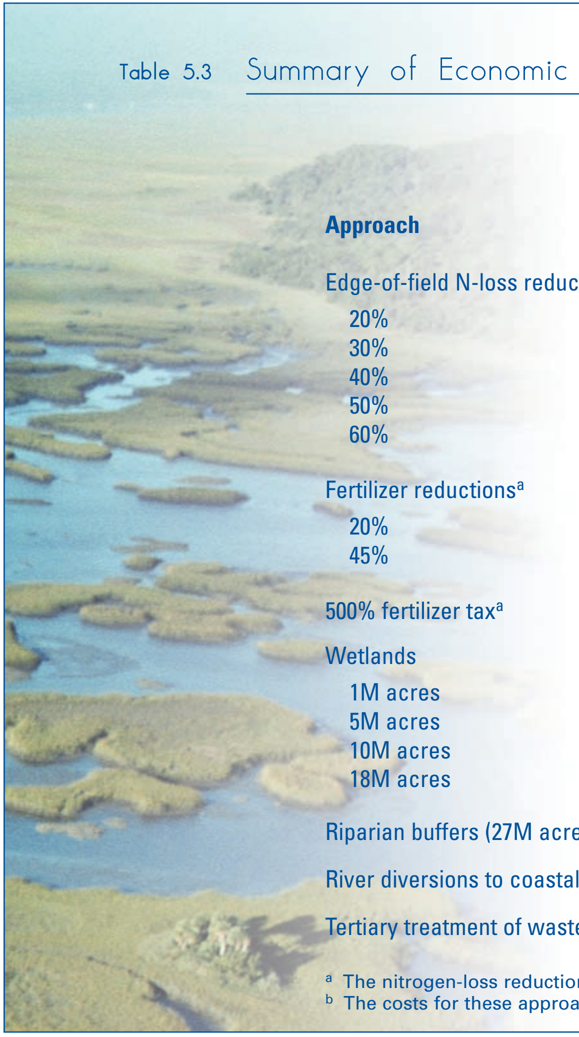


Table 5.3 Summary of Economic Costs of N-Loss Reduction Actions

Approach	**N-Loss Reduction** *(Thousands of metric tons/yr)*	**Net Cost within Agricultural Sector** *($/kg N loss)*	**Net Cost, incl. Environmental Benefits** *($/kg N loss)*
Edge-of-field N-loss reductions, through economically optimum actions[a]			
20%	941	0.88	0.80
30%	1,412	1.90	1.80
40%	1,882	3.37	3.25
50%	2,352	5.20	5.08
60%	2,822	7.48	7.37
Fertilizer reductions[a]			
20%	503	0.69	0.67
45%	1,027	2.85	2.81
500% fertilizer tax[a]	1,027	14.54	14.50
Wetlands			
1M acres	67	6.06	- 2.19
5M acres	350	8.90	1.00
10M acres	713	10.57	2.81
18M acres	1,300	11.93	4.27
Riparian buffers (27M acres)	692	26.03	
River diversions to coastal wetlands[b]	75	~6	
Tertiary treatment of waste water[b]	20	~40	

[a] The nitrogen-loss reduction effects of these approaches are estimated at the edge of the field.
[b] The costs for these approaches include engineering and construction costs only.