Executive Summary

Hypoxia occurs when dissolved oxygen concentrations are below those necessary to sustain most animal life. Since 1993, mid-summer bottom-water hypoxia in the northern Gulf of Mexico has been larger than 4,000 square miles. In 1999, it was 8,000 square miles, which is about the size of the state of New Jersey.

The Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 calls for an integrated assessment of causes and consequences of hypoxia in the Gulf of Mexico. The Act also calls for a plan of action to reduce, mitigate, and control hypoxia. While this integrated assessment is intended to provide scientific information for that Action Plan, it does not include recommendations for action, nor is it the only source of information that will be used to develop that plan.

Key Findings

Hypoxia in the northern Gulf of Mexico is caused primarily by excess nitrogen delivered from the Mississippi–Atchafalaya River Basin in combination with stratification of Gulf waters (Figure E.S. 1). Hypoxia results when oxygen consumption, primarily through decomposing organic material, exceeds oxygen production through photosynthesis and replenishment from the atmosphere. Organic matter can be supplied from external sources, such as river inflow, or can be produced within the system through algal growth stimulated by nutrients.

Sediment cores from the hypoxic zone show that algal production and deposition, as well as oxygen stress, were much lower earlier in the 1900s and that significant increases occurred in the latter half of the twentieth century. During this period, there have been three major changes in the drainage basin affecting the river nutrient flux. First, landscape alterations, such as deforestation and artificial agricultural drainage, removed most of the river basin's nutrient buffering capacity. Landscape alterations were greatest between 1875 and 1925, with a second peak of drainage development activity during 1945–60. Second, river channelization for flood control and navigation was completed prior to the 1950s, except structures that have maintained Atchafalaya flows at 30 percent of the combined flow of the Mississippi and Red Rivers since the mid-1970s. Third, major increases in fertilizer nitrogen input into the Basin occurred between the 1950s and 1980s, along with a large increase in nitrogen removal in harvested crops.

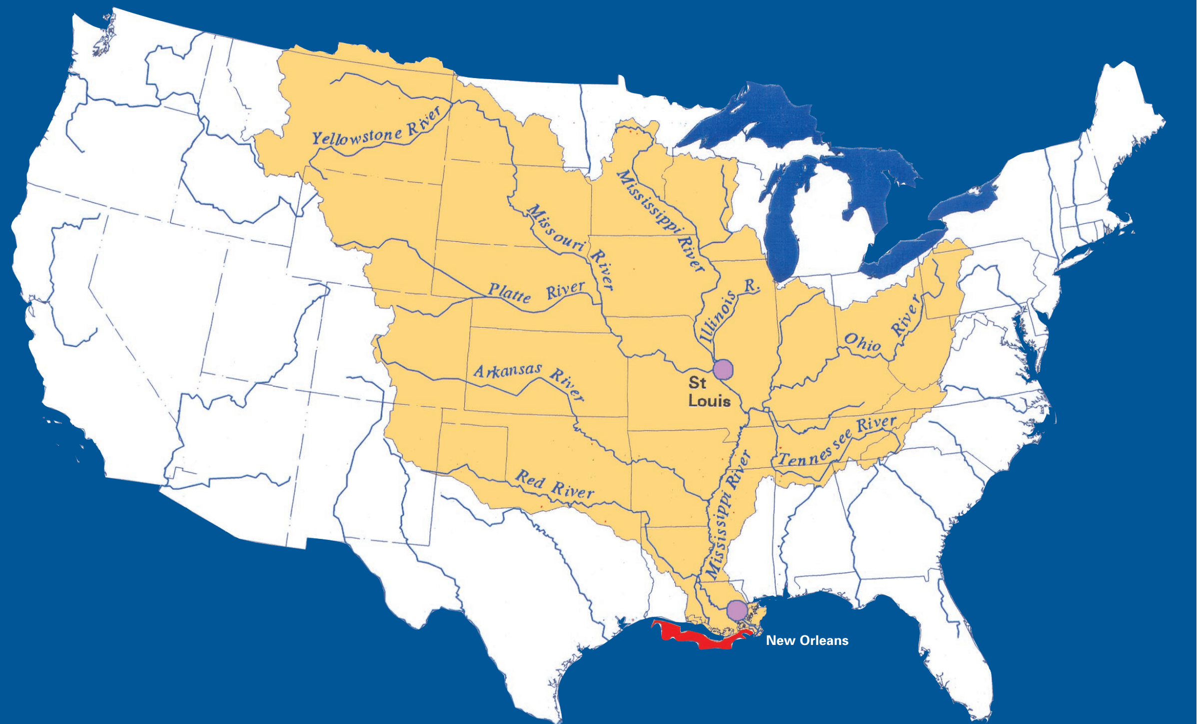
Since 1980, the Mississippi and Atchafalaya Rivers have discharged, on average, about 1.6 million metric tons of total nitrogen to the Gulf each year. Total nitrogen load has increased since the 1950s, due primarily to an increase in nitrate nitrogen. Nitrate flux to the Gulf of Mexico has almost tripled between the periods 1955–70 and 1980–96. Other forms of nitrogen, as well as organic carbon and phosphorus, have probably decreased over the twentieth century. No trend in dissolved inorganic nitrogen or total nitrogen flux has been observed since 1980, but these fluxes have become highly variable, depending on river discharge.

About 90 percent of the nitrate load to the Gulf comes from nonpoint sources. About 56 percent of the load enters the Mississippi River above the Ohio River, and the Ohio basin adds 34 percent. Principal sources are basins draining agricultural lands in Iowa, Illinois, Indiana, southern Minnesota, and Ohio.

Gulf ecosystems and fisheries are affected by hypoxia. Mobile organisms leave the hypoxic zone for healthier waters, and those that cannot leave die at varying rates, depending on how low the oxygen level gets and for how long. Fish, shrimp, zooplankton, and other important fish prey are significantly less abundant in hypoxic bottom waters.

Comparison of the distribution of fishing effort shows that the industry has shifted shrimping efforts away from hypoxic zones. Brown shrimp catch, the most economically important commercial fishery in the Gulf, declined from a record high in 1990 to below average during the years 1992–97, coinciding with years of greatly increased hypoxia. However, economic analysis of fisheries catch data did not reveal statistically significant effects that could be attributable to hypoxia.

FIG. E.S. 1 Mississippi–Atchafalaya River Basin and Gulf Hypoxic Zone



Source: Donald Goolsby and William Battaglin, U.S. Geological Survey.

The Mississippi–Atchafalaya River Basin is the largest river basin in North America, draining an area of 3.2 million square kilometers, or about 41 percent of the conterminous United States. River flux from the Basin to the Gulf of Mexico affects coastal areas where hypoxic conditions have been observed. This figure shows the extent of the hypoxic zone from a 1999 survey.

Water quality in the drainage basin has been degraded by excess nutrients. Most states in the Mississippi–Atchafalaya River Basin have significant river miles impaired by high nutrient concentrations, meaning that they are not fully supporting one or more resource uses, including aquatic life, fish consumption, and swimming. In some areas ground-water supplies are threatened by excess nitrate.

Potential Futures for Different Load Scenarios

If nutrient loads do not increase, the current size and severity of Gulf hypoxia and Basin water quality impairments would most likely remain the same. Hypoxia would vary annually, depending on the timing and extent of spring and summer stratification, weather patterns, temperature, and precipitation in the Gulf and drainage basin. This variability could alter the extent and severity of hypoxia, including creating new extreme increases or decreases.

Efforts to reduce loads may be offset by increases in population and food production and by climate change. If these other factors increase nutrient loads, hypoxia may expand. Because spawning grounds, migratory pathways, feeding habitats, and fishing grounds of important species are affected by the extent and duration of hypoxia, expanded hypoxia could lead to declines in productivity at higher levels of the food web and additional loss of essential habitat. At some point, fisheries and other species would be expected to decline, perhaps precipitously.

A 40 percent reduction in total nitrogen flux to the Gulf is necessary to return to loads comparable to those during 1955–70. Model simulations indicate that nutrient load reductions of about 20–30 percent would result in a 5–15 percent decrease in surface chlorophyll concentrations and a 15–50 percent increase in bottom-water dissolved oxygen concentrations. Such increases in oxygen concentrations are significant because they represent an overall average for the hypoxic zone, and any increase above the 2 mg/l threshold will have significant positive effects on marine life. Reduced nutrient loads to surface waters in the Basin would also be expected to decrease nutrient concentrations in its rivers and streams. These changes should induce positive changes in trophic conditions and result in Basin-wide improvements in surface-water quality.

Considerations for Taking Action

In many areas, significant efforts to reduce nutrient flux to surface waters are already underway. This assessment is based primarily on conditions observed through the mid-1990s; thus, current activities may be having effects that have not yet been documented. Based on these basin-scale analyses, the primary approaches to reduce hypoxia in the Gulf of Mexico appear to be to: (1) reduce nitrogen loads to streams and rivers in the Basin and (2) restore and enhance denitrification and nitrogen retention within the Basin. Another potential approach might be to divert water from the Mississippi and Atchafalaya Rivers directly to areas of the Gulf not currently experiencing hypoxia. However, such an approach would have multiple consequences, none of which have been analyzed.

While this assessment suggests that changes in agricultural practices could provide many elements of a solution at least cost to society overall, analyses contributing to this assessment identified several possible approaches to sharing the burden of nutrient load reductions among all sectors in the Mississippi drainage. There are no single solutions to managing hypoxia in the Gulf. An optimal approach would take advantage of the full range of possible actions to reduce nutrient loads and increase nutrient retention and denitrification within a framework that encourages adaptive management. Such an approach could be initiated within the existing array of state and federal laws and programs.

In this assessment, a national model of the agriculture sector was used to examine many of the economic effects and the changes in nitrogen loading under various scenarios. While specific actions at local levels will most likely require analyses at higher spatial resolution, the following findings should be considered when developing a plan of action for improving Basin and Gulf water quality and habitat.

Management practices that retain more nitrogen on fields—including applying nitrogen fertilizer at not more than recommended rates, implementing alternative cropping systems, and improving manure management—as well as reducing nitrogen flux from point sources will reduce nitrogen loads to rivers and streams. Reducing nitrogen loss at the edge of the field by 20 percent through a combination of economically optimal improvements in farming practices would be expected to cost producers and consumers (net cost) about $0.40 per pound of nitrogen reduction. For comparison, reduction in fertilizer use alone (without other changes in farming practices) was modeled at several levels. A 45 percent reduction in fertilizer use would be required to generate a comparable (20 percent) reduction of edge-of-field loss at a cost of about $1.30 per pound, while a 20 percent reduction in fertilizer use would be required to achieve a 10 percent edge-of-field loss at about $0.31 per pound. (Note that these estimates of the impacts of changes in agricultural practices are for reductions at the "edge of the field," the location where sediment and nutrients leave the farm. Estimated edge-of-field source reductions do not translate to equivalent reductions in nitrogen loading to the Gulf, as only a portion of nitrogen sources in the Basin reaches the Gulf.)

Other measures to reduce nitrogen loads to rivers and streams, such as reducing urban point and nonpoint sources and atmospheric deposition, could provide important contributions in some instances. Average costs of reducing point sources and atmospheric deposition are about $5–50 per pound. In addition, nitrogen trading among all sectors could offer opportunities to obtain least-cost reductions.

Increasing the acreage of wetlands and vegetated riparian buffers within the Basin would enhance denitrification (a process that removes nitrogen from the system) increase nitrogen retention, and decrease the amount of nitrogen entering streams and rivers. Model analyses demonstrate that the most effective use of restored and created wetlands would be in watersheds that discharge high amounts of nitrogen. At typical denitrification rates for flow-through wetlands, 5 million acres of wetlands would reduce nitrogen load to the Gulf by 20 percent and would cost $4.05 per pound of nitrogen denitrified. An estimated 19 million acres of additional riparian buffers would be needed to reduce nitrogen load to the Gulf by the same amount.

Reintroducing river water to the backwaters, coastal wetlands, and shallow inshore bodies of water on the Louisiana delta could augment efforts to reduce nutrient inputs from the upstream sources and could also help to reduce the rate of coastal land loss. However, diversions have potential deleterious effects, such as eutrophication of embayment estuaries receiving the flows, that must also be considered.

All of these nutrient-reduction approaches are expected to produce other important economic and environmental benefits within the drainage basin. These include those associated with restored wetlands, reduced soil erosion, reduced nutrient contamination of drinking water, reduced vulnerability to floods, improved water quality for recreational uses, and improved fish and wildlife habitat in streams, lakes, rivers, and estuaries. Other potential benefits include more efficient use of fertilizers and the energy associated with them, and lower overall fertilizer costs. However, reliable estimates of the economic value of these benefits are only available for a few categories, such as wetlands and erosion. When only these benefits are included in the analysis, the net unit costs of wetlands creation and improved farm practices are comparable. Accounting for some benefits, reducing edge-of-field nitrogen loss by 20 percent through improved farm practices has an approximate net cost of $0.36 per pound. Reducing nitrogen flux from the river to the Gulf by 20 percent through wetland restoration and creation has an approximate net cost of $0.45 per pound when those benefits are considered.

Adaptive Management: Coupling Monitoring, Research, and Action

The complex nature of nutrient cycling and transport within the Basin and the Gulf of Mexico requires an adaptive management framework. Also, the potentially lengthy period of time required to observe changes resulting from management action calls for an adaptive management scheme. Such an approach provides a comprehensive, carefully targeted program of monitoring, modeling, and research to facilitate continual improvement in scientific knowledge and gradual adaptation of management approaches. This adaptive management scheme will require a long-term commitment to monitoring, research, and assessment and continual feedback between interpretations of new information and management actions. A comprehensive monitoring program is needed to measure environmental pressures and responses, and programmatic progress in the Gulf and in the Basin.

The work synthesized in this assessment significantly advances our understanding; however, specific uncertainties remain. Immediate priorities for reducing these uncertainties include research on the ecological effects of hypoxia; watershed nutrient dynamics, particularly between the edge of the field and stream; and the effects of different agricultural practices on nutrient losses from land. Longer-term priorities include research on nutrient cycling and carbon dynamics, long-term changes in hydrology and climate, as well as economic and social impacts.