Adaptive Management

Action, Monitoring, and Research

This assessment of the causes and consequences of Gulf of Mexico hypoxia, and its analysis of options for dealing with it, is drawn from the assembly and peer review of a massive amount of direct and indirect evidence collected and reported over many years of scientific inquiry. The findings presented are thus well founded and are grounded in those research and monitoring results. There are, however, always uncertainties in scientific analysis. This section identifies areas of further monitoring and research that are needed to reduce those uncertainties in future assessments and to aid decision making in an adaptive management framework.

The complex nature of nutrient cycling and transport within the MARB and Gulf of Mexico make it difficult to predict specific improvements in water quality that will occur for a given reduction in nutrient inputs. Nutrient cycling is affected by atmospheric, watershed, riverine, and marine processes. Many of these processes, such as nitrogen transformations in river reaches, are not fully understood at the local scale at which they occur. Large-scale, multidisciplinary interpretations that integrate knowledge across these hydrologic compartments are difficult.

Further, it is clear that environmental responses to management actions in the MARB likely will be slow, possibly requiring decades of data to demonstrate statistically that remedial actions have helped the recovery of oxygen concentrations in the Gulf and have improved water quality in the Basin. For example, the nitrogen balance in the soil zone and ground water will adjust relatively slowly to changes in nitrogen inputs and outputs, slowing any change in the flux of nitrogen to the Gulf. At the same time, the flux of nutrients to the Gulf most likely will respond quickly and dramatically to large variations in precipitation and runoff—further complicating measurement of reductions in nutrient flux.

A comprehensive program of monitoring, interpretation, modeling, and research to facilitate continual improvement in scientific knowledge and adjustments in management practices should be coupled to whatever initial nutrient management strategies are chosen (see Figure 6.1). This adaptive management scheme involves continual feedback between interpretation of new information and improved management actions.

Monitoring and Research in a Modeling Framework

The adaptive management framework includes monitoring programs that use integrated models of the hydrologic and ecological systems for interpretation of system change. Whole-system monitoring will enable comprehensive interpretation of processes and linkages that affect nutrient concentrations and transport within the MARB and development of hypoxia in the Gulf. These coordinated monitoring efforts must be able to:

- detect environmental trends to evaluate the effectiveness of management actions, to enable effective adaptation of strategies over time;
- observe physical, chemical, and biological processes and their roles in the cause-and-effect relationships between nutrient inputs and resulting environmental quality; and
- differentiate among trends caused by changes in climate, streamflow, nutrient and landscape management measures, and other concurrent factors.

An effective research strategy is also integral to the adaptive management framework. Coordinated research efforts improve monitoring designs, support the interpretation of monitoring output, and increase the predictive power of models and other assessment tools used in the management process.

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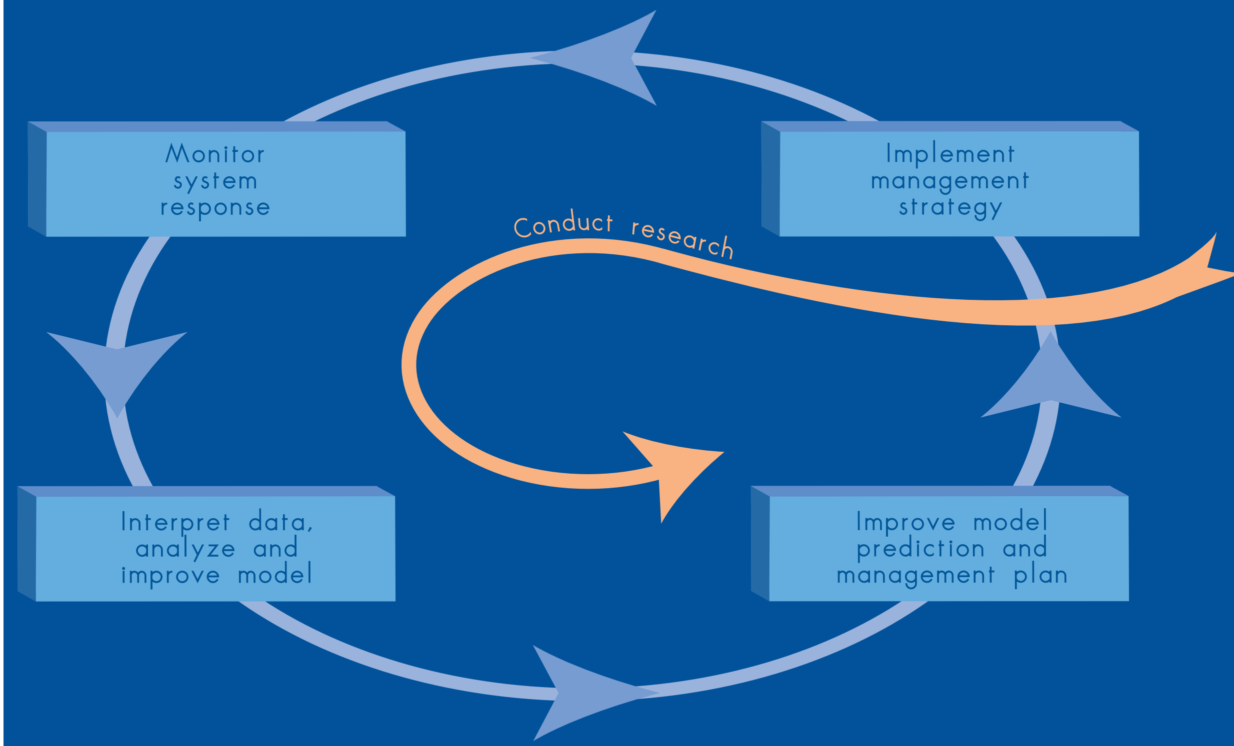
For a system as large and complex as the MARB and the northern Gulf of Mexico, monitoring and research should be integrated using holistic models that simulate our understanding of how the overall system functions and how management practices can best be implemented. Such holistic models include a suite of conceptual, functional, and numerical formulations; integrate research findings; and are tied to monitoring programs designed to both provide input variables and verify model outputs. River monitoring data should be integrated with offshore ecological and oceanographic data on appropriate time scales. An effective modeling framework would include models that simulate:

- transport and transformation of nutrients (nitrogen, phosphorus, and silica) from natural, urban, and agricultural landscapes to ground water and surface waters;
- inputs and outputs of nutrient flow throughout the landscape to improve estimates of nutrient mass balances;
- biogeochemical cycling and water quality effects of those nutrients on river ecosystems within the drainage basin;
- oceanographic and climate influences on those nutrients and their impacts on Gulf productivity as they leave the Mississippi–Atchafalaya River system;
- impacts of increased nutrient flux on productivity in the northern Gulf of Mexico ecosystem, including commercially and recreationally important fisheries; and
- three-dimensional coupling of biological and physical processes in the Gulf ecosystem influenced by the Mississippi River discharge.

Within this larger modeling framework, important research and monitoring needs have emerged from this assessment. Monitoring gaps are found in environmental programs of the MARB and Gulf, as well as in programs that monitor management measures. Research needs include improving the quantitative understanding of the biogeochemical cycling of nutrients within the watershed and the Gulf and its relationship to the dynamics of organic carbon flux in the Gulf; the roles of long-term change in climate, hydrology, and population in year-to-year and long-term trends in nutrient loads and hypoxia; and the social and economic impacts of various management and policy alternative strategies.

FIG. 6.1 Adaptive Management Framework



Source: Herb Buxton, U.S. Geological Survey

The adaptive management concept connects monitoring, analysis, and management actions with continuous feedback for improvement. New understandings from research should be interwoven throughout the process.

Monitoring Needs

A comprehensive monitoring program requires both measurement of environmental response in the MARB and the Gulf of Mexico and tracking indicators of programmatic progress toward mitigating excessive nutrients.

Environmental Responses in the Gulf

Essential components of an environmental monitoring program in the Gulf of Mexico include efforts to:

- Document the temporal and spatial extent of shelf hypoxia, and to collect basic hydrographic, chemical, and biological data related to the development and maintenance of hypoxia over seasonal cycles. A triad of mid-summer shelf-wide hypoxia surveys, monthly transects off Terrebone Bay, and instrumented arrays at stations in the core of the hypoxic zone would provide an optimal combination of spatial and temporal scales of measurement and would be consistent with the existing long-term data. Establishing multiple vertical and horizontal instrument arrays oriented cross-shelf and along-shelf will better define processes that control the temporal and spatial development of hypoxia.
- Improve the collection of ecological, production, and economic information related to fishery and nonfishery species.
- Facilitate synthesis and interpretation of these data through an integrated database.

Environmental Responses in the MARB

Essential components of an environmental monitoring program in the MARB include efforts to:

- Document the flux of nutrients, carbon, and selected other water quality constituents from the MARB to the Gulf of Mexico systematically on at least a monthly basis and more frequently at high flows—at least 25–30 times annually. Additional monitoring sites in the main channel of the Mississippi River are needed to evaluate the extent of nutrient retention/loss within the lock-and-dam system, and to clarify the extent of nutrient retention in the lower Mississippi. There is a need to re-establish monitoring of nutrients, carbon, and selected other water quality constituents in the major sub-basins (the 42 interior basins) throughout the MARB and to establish monitoring in selected small basins within some of the 42 interior basins where the effects of changes in land management practices on nutrient concentrations and yields will be easiest to detect and quantify.

- Monitor nutrients from atmospheric wet deposition in the MARB, and expand the current limited monitoring of nutrients in atmospheric dry deposition. This information is needed to determine if nutrient management strategies affect precipitation chemistry.

- Establish a periodic inventory of effluent reporting conducted through the National Pollution Discharge Elimination System (NPDES) to systematically improve current estimates of nitrogen and phosphorus loads discharged to streams from municipal and industrial point sources.

- Improve measurements for soil nitrogen and nitrogen loss.

Programmatic Measures

Ongoing programs are taking action to improve water quality conditions within the MARB and Gulf of Mexico. Coordination of current and future programs to improve water and ecological conditions can increase their overall effectiveness in achieving goals. Some major measures of progress of ongoing programs include inventories of:

- changing patterns in other nutrient inputs to the Basin, such as fertilizer use and manure application and disposal;

- acres of land leased annually through the Conservation Reserve Program and the Conservation Reserve Enhancement Program;

- acres of created or restored wetlands implemented through the Wetlands Reserve Program, the Emergency Wetlands Reserve Program, the Clean Water Act section 319 program, and the various environmental restoration and related authorities, such as the Coastal Wetlands Planning, Protection and Restoration Act, the Environmental Management Program and other Corps of Engineers programs, and the Partners for Wildlife Program;

- acres of riparian buffers implemented through the Conservation Buffer Initiative and the Clean Water Act section 319 program; and

- actions to reduce nutrient runoff stimulated by the Environmental Quality Incentive Program and the Clean Water Act section 319 program.

Research Needs

The research needs outlined below fall into two categories: (1) immediate priorities that are essential for designing near-term management actions, and (2) longer-term priorities that fill critical gaps in understanding as well as guide efforts to mitigate and control the effects of hypoxia and excess nutrients.

Immediate Research Priorities

Ecological Effects of Hypoxia. A better definition of the past, current, and potential impacts of hypoxia on both commercially and ecologically important species and ecosystems is needed. New retrospective analyses over longer temporal and spatial scales, based on data from marine sediment cores should improve the historical perspective. Better understanding of other factors that affect the ecological health and fisheries of the northern Gulf of Mexico is needed to uniquely identify the role of hypoxia and to design effective management actions.

Contemporary effects. Additional data sources have yet to be examined exhaustively, most notably the SEAMAP database, which includes long-term fishery-independent data on nektonic species' composition in the northern Gulf of Mexico ecosystem. Model analyses of trophic structure and ecosystem dynamics—which will help identify affected fishery resources, and assess potential future impacts—are also needed.

Historical perspective. The northern Gulf of Mexico ecosystem may have already undergone significant ecological change prior to initiation of the first in-depth scientific investigation in the mid-1980s. Thus, the system is likely in a transitional state as nutrient loading approaches new plateaus. Further research and assessment of these longer-term trends are needed. New retrospective analysis over longer temporal and spatial scales, based on data from marine sediment cores should improve the historical perspective.

Watershed Nutrient Dynamics. There is a need to better understand the dynamics and timing of movement of nitrogen and other nutrients from the edge of the field in agricultural landscapes to small streams and tributaries. Additional information is also needed on the geographic distribution and design criteria for targeting wetland creation and restoration efforts and to determine if other strategies (e.g., riparian buffers) and mixtures provide the best nitrate reduction for the least cost.

Research Priorities

Immediate Research Priorities

Ecological Effects of Hypoxia
- *Contemporary effects*
- *Historical perspective*

Watershed Nutrient Dynamics
- *From "edge-of-field" to streams*
- *Wetlands creation*

Agricultural Practices
- *Watershed/farm-scale studies*
- *Experimental policies and practices*

Longer-Term Research Priorities

Nutrient Cycling and Carbon Dynamics
- *Soil organic nitrogen*
- *In-stream, in-river, and Gulf sediment denitrification*
- *Nutrient cycling in the northern Gulf of Mexico*
- *Atmospheric deposition*

Long-Term Changes in Hydrology, Climate, and Population
- *Large-scale climate effects*
- *Flood events*
- *Mississippi–Atchafalaya River delta management and restoration*
- *Point-source and urban nonpoint-source controls*

Economic and Social Impacts
- *Economic values of river and lake water quality improvements*
- *Economic values of Gulf water quality improvements*
- *Economic trade-offs in agricultural systems*

From edge of the field to streams. There is a need to better understand the dynamics and timing of movement of nitrogen and other nutrients from the edge of the field in agricultural landscapes to small streams and tributaries. This is especially true as it relates to tile drains and other practices that move nitrogen and other plant nutrients through the soil drainage system.

Wetlands creation. Additional information is needed on the geographic distribution and design criteria for targeting wetland creation and restoration efforts. There is also a need to determine which other strategies (e.g., riparian buffers) and mixtures provide the best nitrate reduction for the least cost. It is important to understand and quantify the potential for changes in the production of the greenhouse gas N_2O that could occur from wetland creation and restoration efforts.

Agricultural Practices. While improvements in agricultural practices have been achieved in recent years and the efficiency of nitrogen use has increased substantially, there is a need to better quantify the effects of on-farm practices and methods that intercept agricultural nutrients between the field and ground water and adjacent streams.

Watershed/farm-scale studies. There is a critical need to scale up from experimental plots to watershed/farm-scale studies falling into two classes. The first class includes studies to better quantify and demonstrate the effects of on-farm practices, such as precision farming, altered lateral spacing of drainage tiles, controlled water table levels, use of fall and winter cover crops, altered timing of fertilizer application, and exploring alternatives to traditional crop rotations. The second class includes studies on better means to intercept agricultural nutrients between the field and ground water and adjacent streams through riparian buffers, wetlands, and other means.

Experimental policies and practices. Measuring and quantifying the effectiveness of recent policies and voluntary actions to reduce nutrient inputs should be coordinated on a basin scale. There is a need to better quantify and understand the impacts of current and proposed policies (e.g., nutrient trading, fertilizer-use insurance) that increase incentives to reduce nitrogen loss. Additionally, there is a need to evaluate how future policies or practices might best be implemented and administered under various institutional frameworks.

Longer-Term Research Priorities

Nutrient Cycling and Carbon Dynamics. Research is needed to improve understanding of nutrient cycling and carbon dynamics, particularly variations across the Basin and the relationship of site-specific actions to Basin-scale effects.

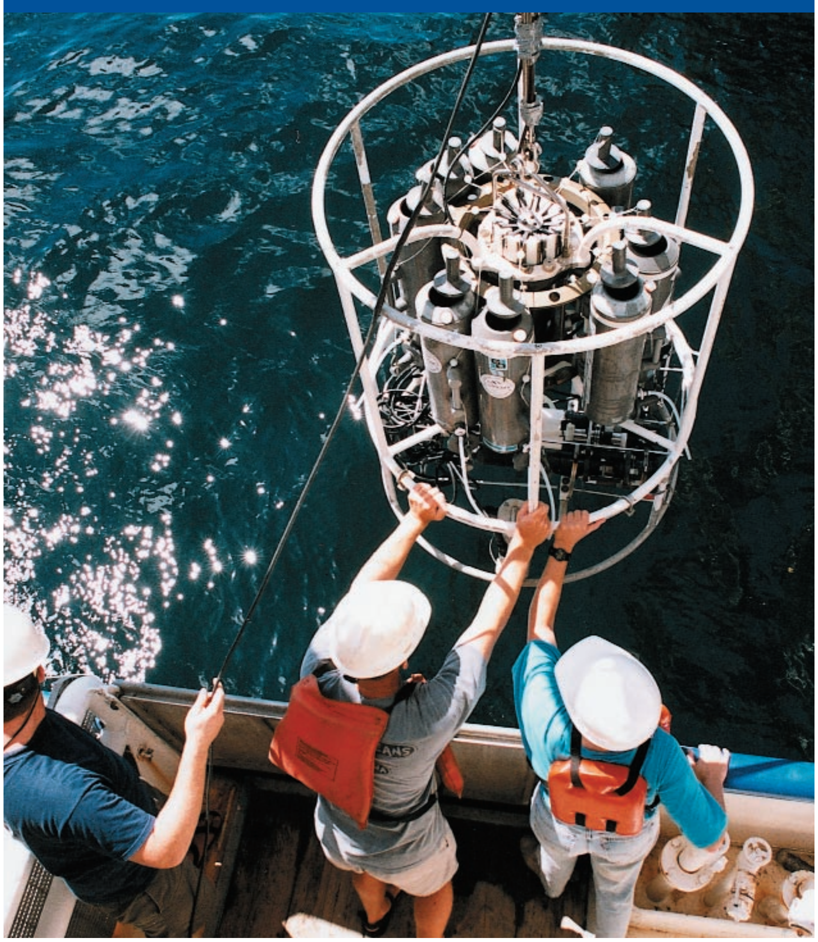
Soil organic nitrogen. Scientific investigations indicate that the soil zone is a huge storage reservoir of nitrogen. Both inputs to and outputs from this reservoir have increased dramatically in recent decades. Research is needed to better understand mineralization and immobilization processes, to develop better means to measure the amount and forms of nitrogen in the soil reservoir, and to develop strategies to minimize leaching of nitrate from the soils to the streams.

In-stream, in-river, and Gulf sediment denitrification. There is a need to better quantify denitrification and nutrient retention rates in small and large streams and in Gulf sediments, and to compare these rates to those achieved in riparian buffers and wetlands.

Nutrient cycling in the northern Gulf of Mexico. Further refinements of the relationships among nutrient fluxes, nutrient ratios, and nutrient cycling on the continental shelf in the Gulf are necessary. Such refinements would improve simulations of subsequent effects on primary productivity, species composition, development of hypoxia, and higher trophic-level productivity in the Gulf ecosystem.

Atmospheric deposition. Additional research on atmospheric deposition of nitrogen in the Gulf is needed to improve understanding of various cycling mechanisms involving different forms of nitrogen.

Scientists deploy conductivity, temperature, and depth (CTD) instruments, along with dissolved oxygen sensors, to sample water conditions in the Gulf.



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Long-Term Changes in Hydrology, Climate, and Population. Additional research is needed to more clearly identify, understand, and predict the effects of long-term changes in hydrology, climate, and population.

Large-scale climate effects. The relationship between large-scale climate patterns (e.g., long-term trends and changes in variability of precipitation) and their potential impacts on river flows, nutrient flux, and flow dynamics on the continental shelf need further evaluation. Changes in precipitation, temperature, and flow patterns may have significant long-term influence on the rate and pattern of nitrate flux within the basin, and on the physical constraints of nitrate assimilation in the northern Gulf. The potential effects of future global climate change on such large-scale climate patterns should also be taken into consideration.

Flood events. Episodic events, such as the Great Mississippi River Flood of 1993 not only have caused significant damage to life and property, but also have transported abnormally high quantities of nitrogen and phosphorus to the Gulf. Studies are needed to evaluate the potential role of flood prevention and control methods that seek to distribute and retain more floodwater within the Basin and thus increase nitrogen retention, while protecting against flood damage.

Mississippi–Atchafalaya River delta management and restoration. Studies are needed to improve understanding of nutrient cycling in the deltaic plain in order to guide possible changes in management activities, such as the diversion of floodwaters to delta backwaters and coastal wetland restoration.

Point-source and urban nonpoint-source controls. The cost of nitrogen reduction from point sources and from urban nonpoint sources has been analyzed on the basis of existing technologies and human population densities. The potential for additional population and landscape changes to offset reductions achieved in nitrogen loading from the Basin should be carefully evaluated.

Economic and Social Impacts. In the spirit of a "win-win" approach to action plan design and implementation, all potential ancillary social and economic benefits of management actions as well as potential adverse effects should be identified and considered in the design of monitoring and research activities.

Economic values of river and lake water-quality improvements. The benefits of reducing nutrient loads in the freshwater system are considered significant. A great deal of research into these benefits has been conducted. Most studies, however, have been site-specific and have been performed for selected watersheds or water uses. There is a growing need for an aggregated analysis of both direct (e.g., drinking-water protection) and indirect (increased recreation) improvements in water quality, for the Basin as a whole.

Economic values of Gulf water quality improvements. To date only the potential direct economic effects of Gulf hypoxia on commercial fish catch have been attempted. Additional work needs to be done to explore a broader range of ecological impacts, including potential impacts to biodiversity and to nonmarket-valued ecosystem goods and services.

Economic trade-offs in agricultural systems. Better estimates of cost savings to agricultural producers from reduced fertilizer nutrient inputs are needed. Similarly, better estimates of the social costs that could result from nitrogen management or reduction strategies (e.g., from dislocation in land use, agribusiness infrastructure, and farm communities) are needed.