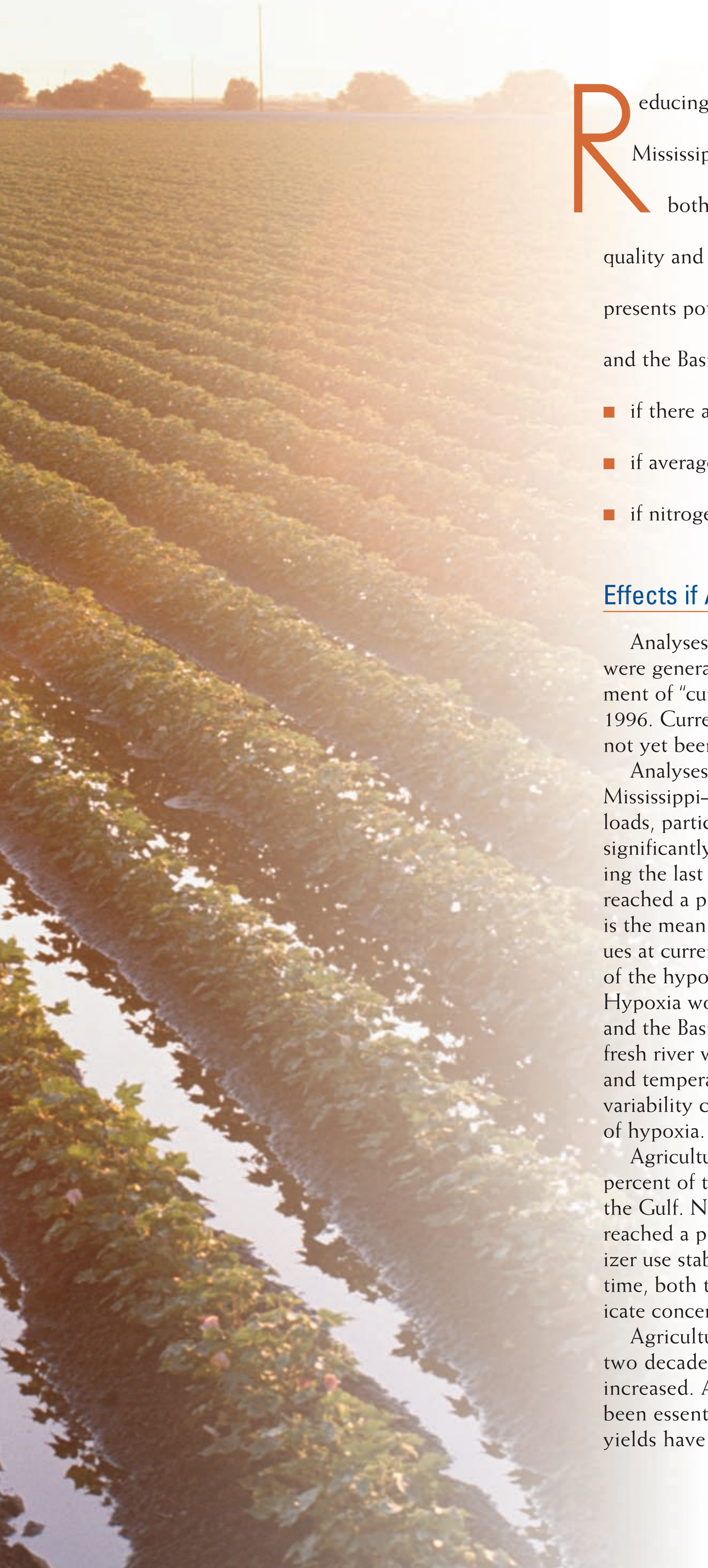
The Effects

of Changing Nutrient Loads



Reducing nutrient loads, particularly nitrogen from the Mississippi–Atchafalaya River Basin, will cause improvements both in the hypoxic conditions in the Gulf and in water quality and land-use conditions within the Basin. This chapter presents potential effects over the next 10–20 years, in the Gulf and the Basin:

- if there are no major changes in average nitrogen loads,
- if average nitrogen loads increase, and
- if nitrogen loads are reduced.

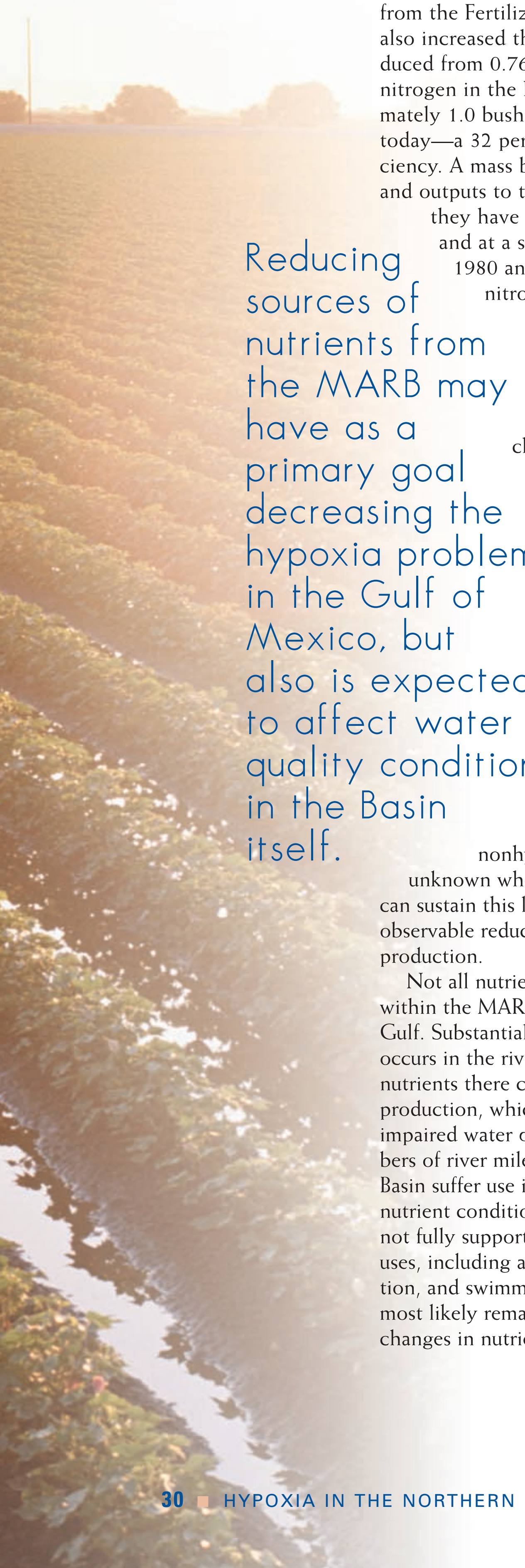
Effects if Average Loads Are Unchanged

Analyses supporting this assessment were based on data that were generally complete through the mid-1990s. Thus, the assessment of "current" activities is up to date only to about 1995 or 1996. Current activities may be having effects for which data have not yet been assessed.

Analyses presented previously in this assessment show that Mississippi–Atchafalaya River Basin nutrient concentrations and loads, particularly nitrogen, to the northern Gulf of Mexico have significantly increased over the twentieth century, especially during the last four decades. However, nitrogen loads appear to have reached a plateau of about 1.6 million metric tons per year, which is the mean load over the period 1980–96. If nitrogen flux continues at current levels, the present range of dimensions and severity of the hypoxic zone on the Louisiana shelf may be maintained. Hypoxia would vary, depending on physical factors in the Gulf and the Basin, such as spring and summer stratification caused by fresh river water flowing over marine waters, weather patterns, and temperature. However, even under these conditions, natural variability could produce new extremes of the extent and severity of hypoxia.

Agricultural nonpoint sources in the MARB constitute about 65 percent of the nitrogen and about 74 percent of the nitrate load to the Gulf. Nitrogen fertilizer use in the MARB appears to have reached a plateau beginning in the 1980s, while phosphorus fertilizer use stabilized in 1980 and then dropped slightly. At the same time, both the rise in river nitrate concentration and the fall in silicate concentration ceased.

Agricultural policies and practices have changed over the last two decades so that both crop production and efficiency have increased. Average fertilizer use per acre of corn in the U.S. has been essentially constant since the late 1970s; however, corn yields have continued to climb, resulting in an increase in the



bushels of corn produced per unit of fertilizer applied. According to comments from the Fertilizer Institute, farmers have also increased the amount of grain produced from 0.76 bushel per pound of nitrogen in the late 1970s to approximately 1.0 bushel per pound of nitrogen today—a 32 percent increase in efficiency. A mass balance of nitrogen inputs and outputs to the MARB indicates that they have been approximately equal and at a steady state since about 1980 and suggests that levels of nitrogen stored in the Basin ecosystem are no longer increasing as they did between 1955 and 1980 (see Figure 4.1).

Reducing sources of nutrients from the MARB may have as a primary goal decreasing the hypoxia problem in the Gulf of Mexico, but also is expected to affect water quality conditions in the Basin itself.

If there are no major changes in average nitrogen loads and the Gulf of Mexico continues to experience a large zone of hypoxia each summer, the area affected is expected to continue to suffer from annual losses of biodiversity, abundance, and biomass. The loss of harvest from the hypoxic region may, or may not, be offset by harvests from nonhypoxic waters. It is unknown whether the northern Gulf can sustain this level of impact without observable reductions in overall fisheries production.

Not all nutrients entering tributaries within the MARB are transported to the Gulf. Substantial processing of nutrients occurs in the rivers and streams. Excess nutrients there can overstimulate primary production, which commonly leads to impaired water quality. Substantial numbers of river miles in most states in the Basin suffer use impairment related to nutrient conditions, meaning that they do not fully support one or more resource uses, including aquatic life, fish consumption, and swimming. This situation would most likely remain the same without some changes in nutrient loading.

Effects if Average Loads Increase

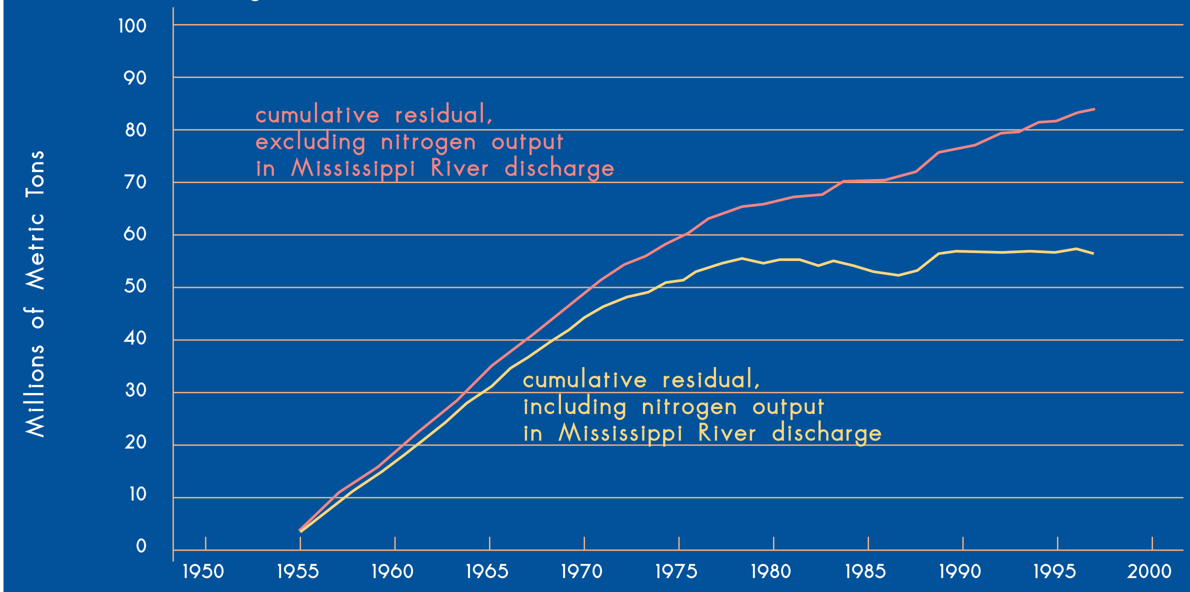
Average nitrogen loads can increase because of anticipated growth in population, food production, and fertilizer use. Changes in climate may also tend to exacerbate hypoxia in the Gulf. Increases in average nitrogen load might be offset by changes that tend to mitigate hypoxia, such as ongoing improvements in farming practices, better targeting of riparian and wetland restoration, and improved riverflow management.

Current pressures that drive hypoxic conditions are likely to intensify. U.S. population and food demand are projected to continue to grow. Over the past decade, the U.S. population has increased by 10 percent (Bureau of the Census 1999); middle series projections predict an 8 percent increase by 2010 and a 17 percent increase by 2020. World population is expected to grow at 1.2 percent per year through 2010 according to the World Bank, and the U.S. has provided a large percentage of the world's food, particularly grain.

The northern Gulf of Mexico is a coastal area that may experience increased freshwater runoff or greater extremes of influx as a result of global climate change. Streamflow was approximately 30 percent higher during 1980–96 than during 1955–70. Part of this increase may be due to long-term climatic variation, and part may be driven by shorter-term climatic cycles. The higher flows in the later half of the twentieth century are attributed to increased precipitation throughout the year and, in particular, to warmer, wetter springs. During this same period, streamflow has increased 30 percent, while nitrate flux has increased 300 percent.

Higher precipitation and streamflow as occurred in the later half of the twentieth century could influence nitrate flux in several ways. More nitrate would be transported with the larger volume of flow unless concentrations decreased more readily than flow volume increased. The higher precipitation could leach more accumulated nitrate from soils in the basin into tile drains and ditches, resulting in higher nitrate concentrations in streams. Higher streamflow would decrease the residence time of water in the river, reducing the rates of denitrification, burial, and uptake by aquatic plants and riparian vegetation.

FIG. 4.1 Cumulative Residual from Nitrogen Mass Balance: 1955–97



Source: Figure 6.4B of the Topic 3 Report for the Integrated Assessment.

Nitrogen inputs to and outputs from the Basin have been approximately equal since about 1980, and the residuals (difference between inputs and outputs) have been variable. The cumulative residual is at a steady state, indicating that levels of nitrogen stored in the Basin are no longer increasing as they did between 1955 and 1980.

The resulting higher runoff in summer would most likely affect water column stability, surface productivity, and oxygen cycling, leading perhaps to an expanded extent of the hypoxic zone.

Understanding the effects of hypoxia in other areas of the world could be useful in projecting effects in the Gulf of Mexico. Experience with other hypoxic zones around the globe shows that initially the higher nutrient concentrations lead to increased production of both organic matter and fisheries (see Figure 4.2). However, as organic matter production increases, changes occur in the food web that lead to both the ecological and the fisheries effects becoming progressively more severe as hypoxia worsens. These changes have been observed in marine ecosystems around the globe, resulting in serious ecological and economic consequences from hypoxia.

Most notable among these affected marine systems are the Kattegat, the Baltic and Adriatic Seas, and the northwestern shelf of the Black Sea. The consequences range from localized loss of target fish catch and recruitment failure (low numbers joining a population, generally due to low reproduction rates) to complete system-wide loss of fishery species. Where oxygen depletion is severe, the food web that supports bottom feeders, such as shrimp and drum, is disrupted, as well as the natural processing of organic matter, nutrients, and pollutants.

In the Gulf of Mexico region, Louisiana leads in production and landings of commercial and recreational marine fisheries. The fishery resources of the Gulf are among the most valuable in the United States, generating $2.8 billion annually. Although possibly due to factors other than hypoxia, catch per unit of effort for brown shrimp, one of the most commercially valuable species in the Gulf, has trended down since the late 1970s.

Other areas that have experienced severe hypoxia, with near-anoxic conditions, experienced greater mortality and had fewer species and lower biomass than areas with intermittent or less severe hypoxia. If experiences in other coastal and marine systems are applicable to the Gulf of Mexico, then the potential impact of worsening hypoxic conditions could be the decline (perhaps precipitous) of ecologically and commercially important fisheries.

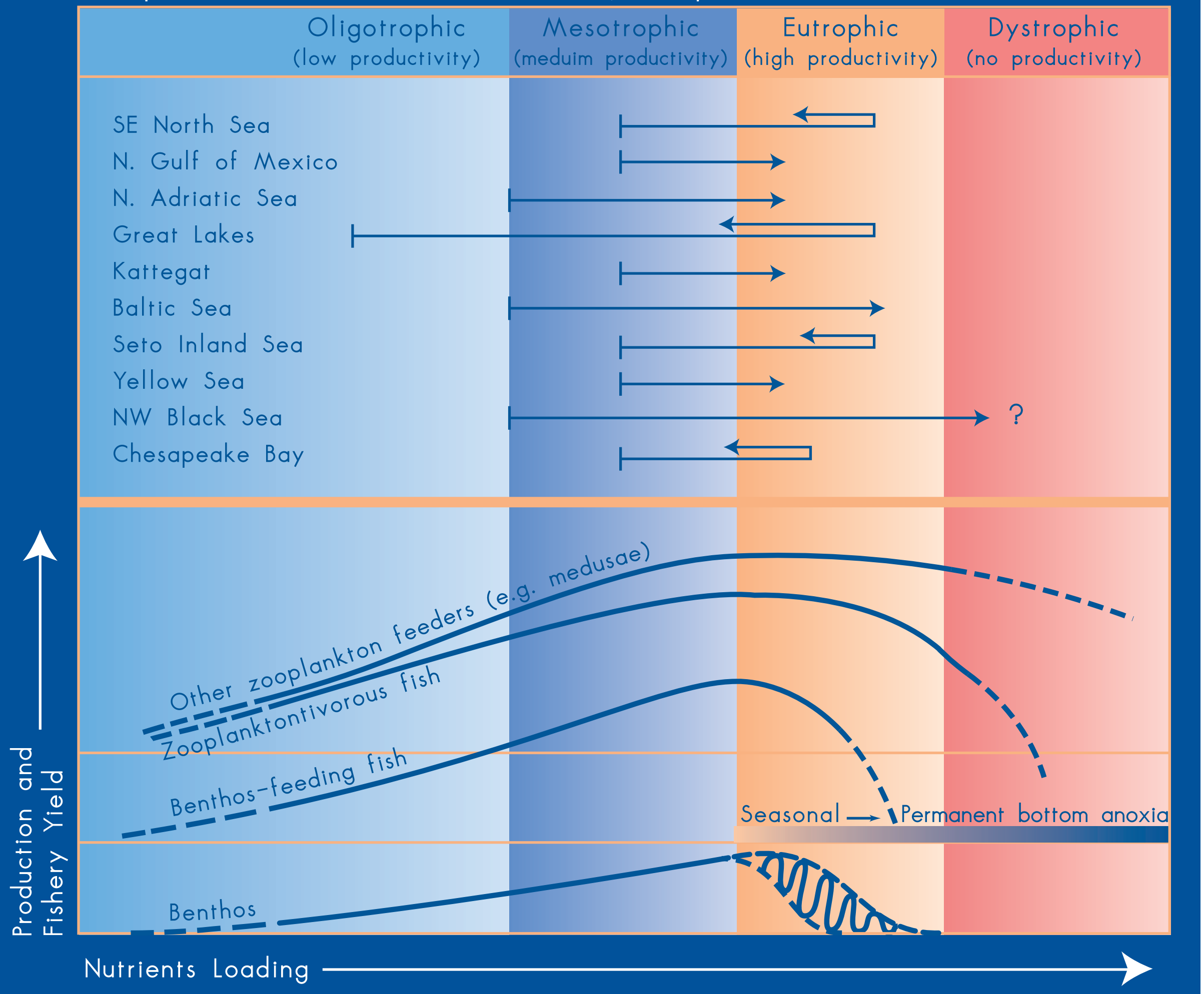
The degree of ecological and economic effects related to hypoxia varies from system to system. For example, both ecological and economic effects of the combined problems of eutrophication and hypoxia have been seen in the Black and Baltic Seas, where demersal trawl fisheries have been either eliminated or severely stressed. Initially in the Kattegat, hypoxia caused mass mortality of commercial and noncommercial species. Now large-scale migrations and/or mortality among demersal fish and the Norway lobster (*Nephrops*) continue, resulting in a changed species composition and reduced growth and biomass. Hypoxia in the Kattegat is believed to be partly responsible for the overall decline in stock size, recruitment, and landings of commercial fish over the last two decades.

Louisiana's commercial and recreational fisheries depend on species that spend part of their life cycles within shallow continental shelf waters that often overlap the hypoxic zone. This is true not only for shrimp but also for the benthic organisms that form the forage base for valuable commercial and recreational species. Because shrimp must move from inshore wetland nurseries to offshore feeding and spawning grounds, hypoxia can block their migration. Spawning grounds, migratory pathways, feeding habitats, and fishing grounds of important species are affected by the extent and severity of hypoxic waters. Expansion of the hypoxic zone could lead to further decreases in productivity at higher levels of the food web and loss of essential habitats.

Increasing nitrogen loads have decreased the silica-to-nitrogen ratio. Decreased silica availability in relation to increasing availability of other nutrients could stimulate blooms of harmful algae, such as dinoflagellates. *Pseudo-nitzschia* spp., a group of diatoms, including some toxic forms, that require silica, have increased in abundance in spite of silica decreases, most likely in response to increasing nitrogen inputs from the Mississippi River.

Although higher nutrient concentrations initially increase the productivity of fisheries, ecological systems worldwide show negative effects as nutrient loading increases and hypoxic or anoxic conditions develop. Each generic curve in the lower half of the figure represents the reaction of a species guild to increasing nutrient supplies. The top half of the figure illustrates trends in various marine systems around the world. Reversals show that trends toward over-enrichment have been turned around in several areas.

FIG. 4.2 Comparative Evaluation of Fishery Response to Nutrients



Source: Redrawn from Caddy 1993.

Effects if Average Loads Are Reduced

Reducing sources of nutrients from the MARB may have as a primary goal decreasing the hypoxia problem in the Gulf of Mexico but also is expected to affect water quality conditions in the Basin itself. Although there are distinct differences between the nature of the responses to such reductions in the two systems, not surprisingly, there are also substantial similarities. In both the Gulf and the Basin, response variables of interest include various nutrient forms, chlorophyll, dissolved oxygen, water clarity, planktonic and benthic biota, and higher organisms. However, the response variable of primary interest for hypoxia is dissolved oxygen in the bottom waters of the Gulf of Mexico.

Depending on the suite of techniques used to reduce loads (i.e., the mix of source reductions, wetland restoration, and river management), a number of costs would be incurred, including those associated with higher material, equipment, and management costs of improved farming practices; loss of productive farmland; and increased treatment costs for municipalities and industry (air and wastewater controls). In addition to reducing risks of precipitous decline in Gulf fisheries from hypoxic/anoxic conditions, these costs would be offset by a number of benefits within the Basin, including improved water and habitat quality, reduced soil erosion, reduced contamination of drinking-water sources by nitrates, improved water quality for recreational use, improved recreational fisheries and wildlife, cost-effective flood damage reduction, and restoration of critical coastal wetlands in Louisiana.

Changes in the Gulf of Mexico

Simulations with a quantitative water quality model (Bierman et al. 1994) indicate that dissolved oxygen and chlorophyll concentrations on the Louisiana continental shelf are likely to be responsive to reductions in nutrient loads from the MARB. However, there are large uncertainties in the magnitudes of these responses for a given load reduction. For nutrient load reductions of 20–30 percent, bottom-water dissolved oxygen concentrations were estimated to increase by 15–50 percent, and surface chlorophyll concentrations were estimated to decrease by 5–10 percent. The ranges correspond to different assumptions for sediment responses and large-scale Gulf of Mexico water quality, and to different hydrometeorological conditions among different years. Although both nitrogen and phosphorus load reductions produced responses in the model, the response, particularly for dissolved oxygen, was somewhat greater for nitrogen reductions.

There has been no statistically significant long-term trend in phosphorus flux to the Gulf for

Thousands of small shrimp boats trawl the northern Gulf of Mexico. Important commercial species in the Gulf, such as shrimp, avoid hypoxic areas, where they would otherwise spend part of their life cycle. Benthic organisms that provide food for other sought-after species are also disrupted in the hypoxic zone.

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the period 1972–96. Over the past half century, phosphorus flux, a large portion of which is associated with sediments, has probably decreased. Nitrogen is the only component of nutrient flux that has increased. For nitrogen load reductions of 30–50 percent (returning to the levels that existed in 1955–70), the model estimates that dissolved oxygen concentrations would increase by 20–75 percent.

There appears to be no evidence that the ecological changes related to hypoxia in the northern Gulf of Mexico at this point are irreversible. Experience has demonstrated that ecosystems can respond positively to nutrient reductions. Examples include Chesapeake, Tampa, and Sarasota Bays. Reductions in loads to Tampa Bay are attributed to improvements in wastewater treatment and in fertilizer loading operations in the Port of Tampa. In Sarasota Bay, reductions occurred as a result of improvements in wastewater treatment and agricultural re-use, and the use of deep-injection wells for wet-weather effluent disposal (Johansson and Greening 1999). There are many examples of small-scale hypoxia reversals associated with improvements in treatment of sewage and pulp mill effluents. In the U.S., the improved water quality in Lake Erie is a good example of positive response to nutrient reductions but is also a demonstration that the time interval for achieving noticeable improvements may be long—on the order of five to ten years after nutrients are reduced. Substantial nutrient reduction targets are being proposed for the drainage area of the Baltic Sea in order to control eutrophication (Jansson and Dahlberg 1999).

Public water supplies are treated, if necessary, to ensure that nitrate levels are below the drinking-water standard of 10 mg/l. People drinking ground water from shallow wells in vulnerable geologic settings (sand, gravel, or karst) in rural agricultural areas, however, are exposed to risks that could be reduced through reductions in nitrogen loading.

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Changes in the Watershed

The most direct effect of actions to reduce nutrient loading to surface waters in the MARB will be to decrease concentrations and to shift the composition of nutrients in its rivers and streams. The changes in nutrient concentrations and composition will induce other changes in trophic conditions and should result in Basin-wide improvements in surface-water quality. The extent of reductions achieved (and subsequently the effects) will depend on site-specific characteristics (climate, soils, cropping history), the types of improvements in management, and the baseline conditions to which the management improvements are being compared.

Aquatic macrophytes (such as duckweed, water lilies, and sedges) have important effects on water quality in shallow waters throughout the Basin. If reductions in nitrogen and phosphorus levels cause an increase in underwater light, submerged aquatic macrophyte distribution would be expected to expand in the upper Mississippi River. The effects on water quality will be beneficial, both locally and system-wide. Increased macrophyte abundance may enhance nutrient retention significantly, leading to lower delivery rates of nutrients to the Gulf of Mexico than would otherwise be predicted for direct effects of source reductions.

Reductions in nutrient concentrations would not be expected to strongly affect sport fisheries because the rivers and streams in the Basin would most likely continue to be highly productive systems. Any decline that might occur in total biomass production would likely be more than offset by habitat and other improvements that would promote game fish over rough fish populations.

All the nutrient-reduction approaches considered—including steps to reduce nutrient losses from farmlands, reduce nutrient discharges from point sources, and increase natural processes to remove excess nutrients from surface waters—are expected to produce environmental benefits within the Basin. These include the values associated with restored wetlands, reduced soil erosion, reduced nitrogen contamination of drinking water, reduced vulnerability to floods, better wildlife habitat, and improved recreational water quality. Other potential benefits of nutrient-reduction activities include more efficient use of organic and inorganic fertilizers 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. All the approaches considered will also have associated costs, including costs for changes in land use; introduction of new technologies, such as precision agriculture and biological nitrogen removal; and implementation of improved management practices. The estimated economic costs of the various approaches to reduce nutrients are described in the next chapter.