Chapter 5
Summary of Findings and Recommendations

This book responds to questions in three general areas: characterization of hypoxia; characterization of nutrient fate, transport and sources; and the scientific basis for goals and management options. In the sections below, these questions (shown in italics bellow) are addressed very briefly with references to those sections of this book where more detailed science on that particular question may be found.

5.1 Characterization of Hypoxia

I. Characterization of Hypoxia*: The development, persistence, and areal extent of hypoxia is thought to result from interactions in physical, chemical, and biological oceanographic processes along the northern Gulf continental shelf; and changes in the Mississippi River basin that affect nutrient loads and freshwater flow.*

A. Address the state-of-the-science and the importance of various processes in the formation of hypoxia in the Gulf of Mexico. These issues include

i. Increased volume and/or funneling of freshwater discharges from the Mississippi River

ii. Changes in hydrologic or geomorphic processes in the Gulf of Mexico and the Mississippi River basin

As discussed in Section 2.1, the hydrologic regime of the Mississippi River and spatial distribution and timing of freshwater inputs to the Gulf of Mexico relative to the occurrence of energetic currents and waves are critical to vertical mixing intensity, stratification, and hypoxia in the Gulf. Alteration of the hydrologic regime of the Mississippi and Atchafalaya Rivers from the 1920s to 1960s has likely increased the residence time of freshwater on the Louisiana–Texas shelf as well as the area of the NGOM shelf that is conducive to hypoxia.

iii. Increased nutrient loads due to coastal wetlands losses, upwelling, or increased loadings from the Mississippi River basin

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As discussed in Section 2.1, increased nutrient loadings from the Mississippi River basin have triggered hypoxia by stimulating in situ phytoplankton production of labile organic matter in shallow near-shore receiving waters of the Gulf. Nutrients also enter this region of the Gulf by advective transport from deeper offshore sources and from atmospheric deposition. However, advective imports and atmospheric deposition are relatively minor sources of nutrients in comparison with those from the Mississippi River basin. The extent to which coastal wetland losses have changed nutrient processing and loading to the Gulf of Mexico is a subject of continued study but is largely believed to be of secondary importance.

iv. *Increased stratification and seasonal changes in magnitude and spatial distribution of stratification and nutrient concentrations in the Gulf*

As discussed in Section 2.1, increased phytoplankton production, coupled with stratification and suppressed vertical mixing associated with fresh water discharge, has caused hypoxia in bottom waters of the northern Gulf of Mexico. However, historic analyses indicate a great deal of variability in seasonal, interannual, and decadal-scale patterns of primary productivity, phytoplankton biomass, and the amounts of freshwater and nutrients discharged to the Gulf. Therefore, trends for nutrient-driven eutrophication and hypoxia on these timescales have been difficult to interpret.

v. *Temporal and spatial changes in nutrient limitation or co-limitation, for nitrogen or phosphorus, as significant factors in the development of the hypoxic zone*

As discussed in Section 2.1.3, studies of waters overlying the hypoxic region of the northern Gulf of Mexico indicate that N limitation characterizes offshore waters, but inshore productivity appears to be P limited and P and N co-limited. This is particularly true from February to May when peak phytoplankton productivity and biomass formation coincide with peak freshwater discharge and nutrient loading. Inshore primary productivity shifts to an N-limited mode during the drier (lower freshwater discharge) summer and fall seasons, and there are likely to be periods when both N and P are supplied at low levels and co-limit phytoplankton production during the spring to summer transition.

vi. *The implications of reduction of phosphorus or nitrogen without concomitant reduction of the other*

As discussed in Section 2.1, the Study Group finds ample evidence to conclude that N loading from the Mississippi–Atchafalaya River basin is the significant factor driving the timing and extent of hypoxia in the northern Gulf of Mexico. However, P supplies also play a significant role in controlling primary production. Therefore, as discussed in Section 2.1.8, reducing the size of the hypoxic zone requires both N and P discharge reductions.

B. *Comment on the state-of-the-science for characterizing the onset, volume, extent, and duration of the hypoxic zone*

Section 2.1.9 describes modeling approaches that have been used to characterize the onset, volume, extend, and duration of the hypoxic zone. Simple linear and multiple regression models that use nutrient loadings to predict hypoxic zone area have been constructed. Other models have included some consideration of processes and mechanisms.

5.2 Nutrient Fate, Transport, and Sources

II. Characterization of Nutrient Fate, Transport, and Sources: *Nutrient loads, concentrations, speciation, seasonality, and biogeochemical recycling processes have been suggested as important causal factors in the development and persistence of hypoxia in the Gulf. The Integrated Assessment (CENR, 2000) presented information on the geographic locations of nutrient loads to the Gulf and the human and natural activities that contribute nutrient loadings.*

A. *Given the available literature and information (especially since 2000), data and models on the loads, fate and transport, and effects of nutrients, evaluate the importance of various processes in nutrient delivery and effects. These may include the following:*

i. *The pertinent temporal (annual and seasonal) characteristics of nutrient loads/fluxes throughout the Mississippi River basin and, ultimately, to the Gulf of Mexico*

Total annual N flux discharged to the Gulf of Mexico, primarily nitrate-N and particulate/organic N, has decreased during the past 25 years, as has the spring (April–June) flux. Neither total P nor SRP fluxes show major annual or seasonal trends during the same period.

As discussed in Section 3.1, the upper Mississippi and Ohio–Tennessee River subbasins contribute about 82% of the annual nitrate-N flux, 69% of the TKN flux, and 58% of the total P flux to the Gulf of Mexico while representing only 31% of the drainage area of the MARB. When the upper Mississippi River basin is further divided, the subbasin contributing to the upper Mississippi River between Clinton, IA, and Grafton, IL (only 7% of the drainage area) contributes about 29% of the total annual nitrate-N flux to the Gulf. Perhaps more importantly, the upper Mississippi and Ohio–Tennessee River subbasins currently contribute nearly all the spring N flux to the Gulf. These subbasins represent the tile-drained, corn–soybean landscape of Iowa, Illinois, Indiana, and Ohio and illustrate that corn–soybean agriculture with tile drainage leaks considerable N under the current management system. The source of riverine P is more diffuse, although these subbasins are also the largest sources of P.

ii. *The ability to determine an accurate mass balance of the nutrient loads throughout the basin*

Estimates of mass balances for nutrient inputs during the period since the *Integrated Assessment* have been recalculated and are discussed in Section 3.2, but the research needs described in the *Integrated Assessment* remain unresolved. Therefore, the Study Group's ability to determine an accurate mass balance of nutrient inputs to the MARB is limited by the available information and understanding. For example, some components of the N mass balance (e.g., denitrification, N_2 fixation, manure N, soil N pool processes such as mineralization and immobilization) are not measured each year. N_2 fixation and manure N are the only two of these components that can be estimated. There are too few data available for the remaining processes to allow calculations. There also is still a disconnect between estimates of inputs to the land (i.e., fertilizer and manure use) and estimates of the proportion of N and P from those inputs that reach the riverine system and contribute to the nutrient flux. Point sources discharge N and P directly to rivers and are estimated by this Study Group to contribute about 22 and 34% of the annual riverine N and P flux, respectively, yet their contributions continue to be estimated from permit limits and are not actually measured. Better point source data are needed to improve mass balance estimates of nutrient loads.

iii. *Nutrient transport processes (fate/transport, sources/sinks, transformations, etc.) through the basin, the deltaic zone, and into the Gulf*

As discussed in Section 3.3, the percentage of annual N and P inputs removed by in-stream processes varies by MARB subbasin and ranges from 20 to 55% for N and 20–75% for P based on model estimates. Denitrification can be a significant pathway for N removal in small streams during low flow, warm periods, thereby enhancing local water quality. However, most nitrate-N is exported to the Gulf during high flows in the period from January to June, when denitrification is not an effective removal process. Although current estimates of denitrification rates in coastal wetlands are higher than the estimates used in the *Integrated Assessment*, current studies still conclude that river diversions to coastal wetlands would remove only small amounts of nutrients relative to the total fluxes. However, better estimates of nutrient and organic matter loss rates (denitrification; long-term burial of C, N, and P; and plant uptake) are needed to better understand observed differences between wetland inputs and outputs in coastal areas.

B. *Given the available literature and information (especially since 2000) on nutrient sources and delivery within and from the basin, evaluate capabilities to*

i. *Predict nutrient delivery to the Gulf, using currently available scientific tools and models and*

ii. *Route nutrients from their various sources and account for the transport processes throughout the basin and deltaic zone, using currently available scientific tools and models*

In Section 3.4, the Study Group singled out three models for discussion: SPARROW, SWAT, and IBIS/THMB. Each is capable of N and P load estimation on the scale of the MARB, yet each has strengths and weaknesses requiring further development. The uncertainty of results from each model reflects the uncertainty of the model structure and algorithms, as well as that propagated by the input data, user parameterization, the calibration process, other user-defined conditions, and the skill of the model user. Even though the capability to predict and route nutrients throughout the MARB has improved since the *Integrated Assessment*, future adaptive management will require a smooth interface between watershed, economic, and Gulf of Mexico hypoxia models that will allow resource managers the capability to assess the effects of policy decisions and management practices on the sources, fate, and transport of nutrients from the MARB to the Gulf of Mexico.

5.3 Goals and Management Options

III. Scientific Basis for Goals and Management Options: *The Task Force has stated goals of reducing the 5-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 km^2 by the year 2015, improving water quality within the basin and protecting the communities and economic conditions within the basin. Additionally, nutrient loads from various sources in the Mississippi River basin have been suggested as the major driver for the formation, extent, and duration of the Gulf hypoxic zone.*

A. *Are these goals supported by present scientific knowledge and understanding of the hypoxic zone, nutrient loads, fate and transport, sources, and control options?*

The Study Group affirms the major findings of the *Integrated Assessment*. Although the 5,000 km^2 target remains a reasonable end point for continued use in an adaptive management context, it may no longer be possible to achieve this goal by 2015. Accordingly, it is even more important to proceed in a directionally correct fashion to manage factors affecting hypoxia than to wait for greater precision in setting the goal for the size of the zone.

i. *Based on the current state-of-the-science, should the reduction goal for the size of the hypoxia zone be revised?*

No. As discussed in the Executive Summary, it is more important to begin to move in a directionally correct fashion than to refine the goal for the exact size of the hypoxic zone.

ii. *Based on the current state-of-the-science, can the areal extent of Gulf hypoxia be reduced while also protecting water quality and social welfare in the basin?*

Social welfare can be protected by choosing policies that incorporate targeting, provide economic incentives and maximize co-benefits. As discussed in Section 4.3, improvements in large-scale integrated economic and biophysical models are needed to better capture system-wide response and effects.

B. *Based on the current state-of-the-science, what level of reduction in causal agents (nutrients/discharge) will be needed to achieve the current reduction goal for the size of the hypoxic zone?*

As discussed in Section 4.2, to reduce the size of the hypoxic zone, the Study Group recommends an adaptive management approach targeting at least a 45% reduction in discharges of total N and total P from the 1980 to 1996 fluxes.

C. *Given the available literature and information (especially since 2000) on technologies and practices to reduce nutrient loss from agricultural, runoff, from other nonpoint sources, and from point source discharges, discuss options (and combinations of options) for reducing nutrient flux in terms of cost, feasibility, and any other social welfare considerations.*

In general, the social costs of reducing nutrients will vary widely with the policy chosen, hence overall cost-effectiveness is largely a function of policy. Policies that target and provide economic incentives are essential to minimize costs. A wide range of policy options are discussed in Section 4.4, while management options are covered extensively in Section 4.5.

These options may include the following:

i. *The most effective agricultural practices, considering maintenance of soil sustainability and avoiding unintended negative environmental consequences*

The cost and reduction efficiency rankings of agricultural management practices will vary by site and region, historic land use and management, crops grown, local soil conditions, distance to waterway, field slopes and configuration, presence of buffers, drainage structures, and so forth. Table 4.8 in Section 4.5.10 provides the Study Group's summary of the evidence comparing the relative effectiveness of nutrient (N and P) reduction options in agriculture. Section 4.5.6 discusses management options for in-field nutrients. A targeted and adaptive management framework will maximize local and regional water quality benefits in the MARB and Gulf.

ii. *The most effective actions for other nonpoint sources*

As discussed in Section 4.5.7, there are significant policy opportunities to reduce atmospheric deposition of N; however, a detailed examination of air pollution control policy options was beyond the

Study Group's scope. Nonetheless, the Group strenuously recommends incorporating water quality benefits and effects on hypoxia in air pollution control decisions.

iii. *The most effective technologies for industrial and municipal point sources*

As discussed in Section 4.5.8, a targeted permit-by-permit approach to industrial point source discharges could yield significant opportunities for nutrient (N and P) reduction since frequently a limited number of permitted facilities are responsible for a large part of the N and P loads. Municipal point sources are also discussed in Section 4.5.8, where the Study Group recommends an analysis to assess the cost and feasibility of tightening limits on N and P concentrations in discharges for large sewage treatment plants.

In all three areas, please address research and information gaps (expanded monitoring, documentation of sources and management practices, effects of practices, further model development and validation, etc.) that should be addressed prior to the next 5-year review.

Recommendations for monitoring and research are found in nearly every section of the book and are included below in the summary of the Study Group's recommendations.

5.4 Conclusion

This book constitutes the Study Group's response to questions posed by the USEPA Office of Water. This Study Group reaffirms the major findings of the *Integrated Assessment*, while pointing out the need for economic incentives to encourage conservation in the Mississippi–Atchafalaya River basin. Although the science has grown, actions to control hypoxia have lagged. The Study Group urges the USEPA and other agencies to act on the recommendations of this Study Group and move ahead with implementing programs, strategies, and policies to reduce the size of the hypoxic zone and improve water quality in the Mississippi–Atchafalaya River basin.

Most of the research and monitoring needs identified in the *Integrated Assessment* have not been met, and fewer rivers and streams are monitored today than in 2000. The majority of monitoring recommendations in the *Integrated Assessment* remain relevant and should be heeded, specifically the CENR's call to improve and expand monitoring of the temporal and spatial extent of hypoxia and the processes controlling its formation; the flux of nutrients, carbon, and other constituents from nonpoint sources throughout the MARB and to the NGOM; and measured (rather than estimated) nitrogen and phosphorus fluxes from municipal and industrial point sources. Echoing the CENR, the Study Group affirms the need for research on the ecological effects of hypoxia; watershed nutrient dynamics; effects of different agricultural practices on nutrient losses from land, particularly at the small watershed scale; nutrient cycling and carbon dynamics; long-term changes in hydrology and climate; and economic and social impacts of hypoxia. A suite of models is needed to simulate the processes and linkages that regulate the onset, duration, and extent of hypoxia. Emerging coastal ocean observation and prediction systems should be encouraged to monitor dissolved oxygen and other physical and biogeochemical parameters needed to continue improving hypoxia models.

Although there are over 90 recommendations in this book, the following major recommendations reflect the Study Group's consideration of the *new* science that has emerged since the *Integrated Assessment*.

To advance the science characterizing hypoxia and its causes, the Study Group finds that research is needed to

- collect and analyze additional sediment core data needed to develop a better understanding of spatial and temporal trends in hypoxia;
- investigate freshwater plume dispersal, vertical mixing processes, and stratification over the Louisiana–Texas continental shelf and Mississippi Sound, and use three-dimensional hydrodynamic models to study the consequences of past and future flow diversions to NGOM distributaries;
- advance the understanding of biogeochemical and transport processes affecting the load of biologically available nutrients and organic matter to the Gulf of Mexico and develop a suite of models that integrate physics and biogeochemistry;
- elucidate the role of P relative to N in regulating phytoplankton production in various zones and seasons and investigate the linkages between inshore primary production, offshore production, and the fate of carbon produced in each zone;
- improve models that characterize the onset, volume, extent, and duration of the hypoxic zone and develop modeling capability to capture the importance of P, N, and P–N interactions in hypoxia formation.

With respect to advancing the science on sources, fate, and transport of nutrients, the Study Group finds that research is needed to

- develop models to simulate fluvial processes and estimate N and P transfer to stream channels under different management scenarios;
- improve the understanding of temporal and seasonal nutrient fluxes and develop nutrient, sediment, and organic matter budgets within the MARB;

To enhance the scientific basis for implementation of management options, the Study Group finds that research is needed to

- examine the efficacy of dual nutrient control practices;
- determine the extent, pattern, and intensity of agricultural drainage as well as opportunities to reduce nutrient discharge by improving drainage management;
- integrate monitoring, modeling, experimental results, and ongoing management into an improved conceptual understanding of how the forces at key management scales influence the formation of the hypoxia zone; and

- develop integrated economic and watershed models to support adaptive management at multiple scales.

To reduce the size of the hypoxic zone, the Study Group recommends at least a 45% reduction in N accompanied by a comparable reduction in P. Five areas offer the most significant opportunities for N and P reductions:

- promotion of environmentally sustainable approaches to biofuel production and associated cropping systems (e.g., perennials);
- improved management of nutrients by emphasizing infield nutrient management efficiency and effectiveness to reduce losses;
- construction and restoration of wetlands, as well as criteria for targeting those wetlands that may have a higher priority for reducing nutrient losses;
- introduction of tighter N and P limits on municipal point sources; and
- improved targeting of conservation buffers, including riparian buffers, filter strips, and grassed waterways to control surface-borne nutrients.