HYPOXIA IN THE NORTHERN GULF OF MEXICO
-- RESPONSES TO PUBLIC COMMENTS

This document provides responses to many of the public comments received in the course of developing an Integrated Assessment (IA) of Hypoxia in the northern Gulf of Mexico.

As a foundation for the IA, six topical reports were written by teams of experts. Public comments on the six reports were received from 34 organizations and individuals. Those reports and the public comments received on them, were used to draft the IA. The draft of the IA was also made available for public comment and those comments considered in completing the IA. Public comments on the draft IA were received from 16 organizations and individuals. The reports, the draft IA, and the public comments are available at <http://www.nos.noaa.gov/products/pubs_hypox.html>.

The IA and these responses were prepared by the Hypoxia Working Group under the National Science and Technology Council's Committee on Environment and Natural Resources. The IA, along with other information, will be used by the Mississippi River/Gulf of Mexico (MR/GM) Watershed Nutrient Task Force to develop an appropriate Action Plan to reduce, mitigate and control hypoxia in the northern Gulf of Mexico.

Responses in this document are organized by the following categories:

1. Assessment and Action Plan Process
2. Contributing Factors
3. Nitrogen Concentration and Flux: Trends and Sources
4. Gulf Hypoxic Zone History
5. International and National Hypoxic Zone Comparisons
6. Nutrient Control Practices
7. Adaptive Management, Monitoring and Research
8. Modeling of Management Options and Impact

Most attention is directed to comments received on the IA but comments on the six reports which have not been otherwise resolved are also addressed. These responses are directed to issues raised by the public comments; suggestions about specific wording changes have been addressed separately in drafting and revising the IA. In addition to responses in this document and in the draft and final versions of the IA, public comments were addressed in a public meeting of the MR/GM Task Force and a science meeting in December of 1999 which focused on causal issues raised in the public comments. Finally, a number of comments included suggestions that would more appropriately be considered in the context of developing the Action Plan. The Working Group encourages the MR/GM Task Force to give them full consideration.

A number of comments concerned the process used to conduct the Gulf of Mexico Hypoxia Assessment. These comments focused on such aspects as the steps of the assessment process; public participation during development of the assessment reports; the process for reviewing the reports; and the role of further research, modeling, and monitoring in the assessment process. Therefore, this response to public comments begins with an overview of the assessment process.

In early 1996, concerns regarding hypoxic conditions in the Gulf of Mexico led members of the Committee on Environment and Natural Resources (CENR), under the National Science and Technology Council, to ask that the committee undertake the task of assessing the state of scientific knowledge and understanding of hypoxia in the Gulf. In the fall of 1997, the United States Environmental Protection Agency (EPA) expanded a group formed the previous year and established the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (the MR/GM Task Force) which includes federal, state, and tribal government representatives. The CENR and the MR/GM Task Force have worked closely on issues related to hypoxia. Because of their governmental composition, neither of these are considered advisory committees under the Federal Advisory Committee Act. However, the CENR has conducted several workshops to gather input and all MR/GM Task Force meetings were open to the public and announced in the Federal Register.

In October 1998, Congress passed the Harmful Algal Bloom and Hypoxia Research and Control Act, which the President signed into law as P.L. 105-383 on November 13, 1998. This law calls for the CENR to develop an "IA of hypoxia in the northern Gulf of Mexico that examines: the distribution, dynamics, and causes; ecological and economic consequences; sources and loads of nutrients transported by the Mississippi River to the Gulf of Mexico; effects of reducing nutrient loads; methods for reducing nutrients loads; and the social and economic benefits of such methods." P.L. 105-383 also calls for the development of a plan of action to reduce, mitigate, and control hypoxia in the northern Gulf of Mexico. The Action Plan will be developed by the MR/GM Task Force. The IA does not make specific recommendations for action, nor is it the only source of information that the MR/GM Task Force will consider in developing the Action Plan.

Under the leadership of the CENR, a Hypoxia Work Group (the Work Group) was formed to plan and conduct the hypoxia science assessment. The Work Group is composed of representatives from the Department of Agriculture, the Department of Commerce, the Department of Defense through both the Army Corps of Engineers and the Office of Naval Research, the Department of Health and Human Services through the National Institute of Environmental Health Services, the Department of Interior through the Minerals Management Service and the U.S. Geological Survey, EPA, the National Science Foundation, and the Smithsonian Institution. A plan to develop the assessment was completed and presented to the MR/GM Task Force by the CENR Workgroup in March 1998 (see http://www.nos.noaa.gov/products/pubs_hypox.html to review the plan).

The National Oceanic and Atmospheric Administration (NOAA) was asked to lead the CENR assessment, however oversight was spread among several federal agencies, and the assessment itself was conducted by teams that included academic, federal, and state scientists from within and outside the Mississippi River watershed. The assessment of the causes and consequences of Gulf hypoxia is intended to provide scientific information that can be used to evaluate management strategies, and to identify gaps in our understanding of this problem. While the focus of the assessment is on hypoxia in the Gulf of Mexico, the effects of changes in nutrient concentrations and loads and nutrient ratios on water quality conditions within the Mississippi-Atchafalaya river systems are also addressed.

As a foundation for the IA, six specific assessment reports examining various aspects of the hypoxia issue were developed by six teams with experts from within and outside of government. These teams were not established to conduct new research, but to analyze existing data and apply existing models of the watershed-Gulf system. One team analyzed different approaches for alleviating hypoxia. Each of the reports acknowledged the need and identified specific areas for additional research. While the final assessment finds a compelling case for some action now, it also includes specific recommendations for additional research and monitoring.

Each of the assessment reports underwent extensive peer review by independent experts during development. This review followed standard practice for peer review and effectively provided expert review of the six science reports. To facilitate a comprehensive review, an Editorial Board was also selected by the Work Group based on nominations from the MR/GM Task Force and other organizations. Editorial Board members were Dr. Donald Boesch from the University of Maryland, Dr. Jerry Hatfield from the US Department of Agriculture, Dr. George Hallberg from the Cadmus Group, Dr. Fred Bryan from Louisiana State University, Dr. Sandra Batie from Michigan State University, and Dr. Rodney Foil from Mississippi State University. The Editorial Board worked with the Hypoxia Work Group to select reviewers for the six reports, and served as brokers between the lead authors and the reviewers to ensure that significant comments were addressed.

As was described in the March 1998 Gulf of Mexico Hypoxia Assessment Plan developed by the CENR Hypoxia Workgroup, public input played a critical role in the policy process.   It was public concern and action, in fact, that brought national attention to the problem of hypoxia in the Gulf of Mexico and prompted the CENR to undertake this scientific assessment. The CENR Hypoxia Assessment process was designed to keep the public informed and involved, while ensuring accuracy and objectivity of the information that it provides. Thus, the six reports were developed by specialists, subjected to rigorous peer review, and made available for public comment through a Federal Register notice published May 4, 1999. In response to concerns raised by many stakeholders, the original comment period was extended from 30 to 90 days. The public comment period on the six assessment reports formally closed on August 2, 1999.

Furthermore, each of the MR/GM Task Force meetings, several which have dealt almost exclusively with the science assessments, have been open meetings, advertised both in the Federal Register and through a mailing list, with significant opportunities for attendees to participate.

The six assessment reports, and the public comments received on them, were used to develop the draft IA. This draft was made available for public comment through a Federal Register notice published October 21, 1999 (see http://www.nos.noaa.gov/products/pubs_hypox.html for a copy of the draft). A science workshop was held in December 1999 to clarify several significant science issues raised in the assessments and the public comments. A summary of that meeting is also posted on the NOAA website above. Results of the workshop were incorporated in the final IA.

Following clearance by the CENR, the final IA, along with responses to the major comments received on both the original six science reports and the draft IA, will be available on the NOAA website. These documents will provide a basis for the Action Plan required by section 604(b) of Public Law 105-383. However, the CENR Assessment is not intended to be the only input or basis of information for Action Plan. Other information developed by the MR/GM Task Force members, input from stakeholders, and full public involvement will be sought during the development of this Action Plan.

CATEGORY #1: ASSESSMENT AND ACTION PLAN PROCESS

SUMMARY OF COMMENTS

Comments on the Six Topic Reports:
Comments were received from 16 of the 34 commentors concerning the process implemented to conduct the Gulf of Mexico Hypoxia Assessment (LSU AgCtr, IA FarmBur, UMRBA, TFI, 3 Soc, MO CornGrowersA, CFIndustries, IL AssnDrainageDistricts, AgriBank, IL Gov, IA Gov, LSU AgCtr, MO DNR, IL FarmBur, USDA, IA FarmBurF). These comments focused on such aspects as the steps of the assessment process (which has been discussed in the Introduction); public participation during development of the assessment reports; the process for reviewing the reports; and the role of further research, modeling, and monitoring in the assessment process.

Comments on the Draft IA:
Comments on the Assessment and Action Plan process were received from seven of 16 commentors (NatCornGrowersA, TFI, UMRBA, WI Dpts, 15 AgOrgs, IL Gov, MO DNR). The comments regarding the Draft IA primarily spoke to the issues of timing, the discussion of uncertainties, the inclusiveness of the process, the effectiveness of existing efforts, and the opportunity to consider options in the Action Plan not discussed in the draft IA.

Comments included the following points:

Stakeholder involvement
Some commentors felt that there was insufficient opportunity for stakeholder involvement in development of the IA. Some stated that the comment period did not allow sufficient time for a thorough review of the reports and that the CENR process has been closed to public input. Others commented that the peer-review process has not been rigorous. One commented that the data developed and used in the reports, should be made publically available. Another commented that the USDA should be given the lead role for assembling the IA and the Action Plan. Several called for more consistent terminology, particularly on nutrient inputs to the soil, edge of field nutrient loss to the river, and nutrient loss reductions. Some requested a written response to comments.

Uncertainties associated with the data
Several commentors asked that the IA quantitatively describe levels of confidence and uncertainties in the scientific conclusions. Comments asked why these uncertainties were not more fully developed and stated in the draft IA. One commentor suggested that the science assessment should be supplemented with policy dialogue which includes social and economic

considerations especially to fully account for impact on US agricultural production. One commentor argued that the assessment has failed to establish a factual basis for the hypothesis considered, which is that increased nutrient loadings solely are responsible for increased hypoxia in the Gulf of Mexico, and that the assessment should explain alternative hypotheses and what additional data and analysis are needed. Another comment was that action is premature without further study, and no drastic actions can be justified on the basis of what is presently known especially regarding other factors, the primacy of the role of nutrients, and the probable failure of a plan that concentrates on one contributor among many. Comments requested that Action Plan development be delayed until a stronger scientific framework is established. Several commentors stated that additional science is needed and that research and monitoring must continue prior to preparing an Action Plan.

Incorporating existing accomplishments

A number of commentors made suggestions, not about the IA, but about approaches that should be considered in the Action Plan. Commentors suggested that the Action Plan should celebrate and build on successes that have been achieved in reducing nutrient losses through stewardship and voluntary programs. They argued that those programs, including provisions of the 1996 Farm Bill, must be given the opportunity to work to their full potential. Others requested clarification that scenarios used in the assessment are not recommendations and do not preclude consideration of other actions. They asked that policy makers and the public have opportunity for full dialogue on management options without prejudice or presumption that they are limited to those in the reports.

DISCUSSION

Stakeholder Involvement

Concerns about the involvement of stakeholders raised some of the fundamental dilemmas regarding completing work of this magnitude in a reasonable time to ensure an adequate response to the initial conditions that raised the issue. This is a particularly difficult task given the immense size of the Mississippi basin and the Gulf of Mexico, as well as the range of the potential stakeholders. While many attempts were made to ensure broad participation, there is always room for more.

The primary approach was two fold. First, members of the science panels, peer reviewers and the MR/GM Task Force were sought who would act as representatives of larger groups. Federal agencies covered the spectrum of interest, including five different parts of USDA: Agricultural Research Service, Economic Research Service, Cooperative State Research, Education and Extension Service, and Natural Resources Conservation Service. Additionally, academics and state representatives of both agricultural and environmental agencies were included. While not every group may have felt they had a representative, especially the private interests which are difficult to narrow down to a workable number of representatives, the intent was that the members of these various teams and committees represented a sufficiently broad spectrum. Second, we chose to use a combination of wide distribution of documents, including regular updates to various websites and frequent and long opportunities for public review and comment, and open attendance at MR/GM Task Force meetings, to encourage the exchange of views and information. The Task Force Chair routinely invited Governors, Tribes, and other interested stakeholders to suggest alternative sites and opportunities for exchange. The peer review process was designed, in combination with the editorial board and the science workshop, to provide expert consideration of the contents of the science assessments.

It should be noted that the science used in the IA was not meant to cover new ground; the purpose was to condense the best of what is currently known. Additionally, the Action Plan that will be developed will not be binding as new law or regulation. Actions taken as a result of analyses in the assessment will be subject to the normal administrative procedure in the local, state and federal arenas. The purpose is to stimulate national dialogue, not to restrict it. The MR/GM Task Force is encouraged to seek input on ways to improve involvement and to respond to invitations to speak to groups about their work. The suggestion of a policy dialogue is certainly worth pursuing.

<u>Uncertainties associated with the data</u>

As in any significant environmental decision, the uncertainties regarding the cause and effects of hypoxia in the Northern Gulf of Mexico are important. As stated by one commentor, the many pages of recommendations for additional research and monitoring needs testify to the uncertainty of the conclusions. These uncertainties were addressed by summarizing the state of knowledge to reach a conclusion based on currently available research. This information, while not conclusive, points to directions that will accomplish a variety of public goals. For example, the significant increase in nutrients in the entire system has many negative water quality effects that are not restricted to hypoxia in the Gulf of Mexico. These include eutrophication upstream in lakes and rivers and potential drinking water effects from contaminated groundwater.

Ultimately, it must be recognized that the findings and conclusions in the assessment are inputs to the deliberations on the Action Plan. It should also be recognized that the actions analyzed in the six reports were included primarily to illustrate the best judgement of the research teams, and to clarify the range of possible scenarios. While much has been made of the report's fertilizer reduction analyses, for example, it should be remembered that these are included among other actions illustrating the possible costs and effects of different scenarios. Additional information will be used, along with the IA, to develop the Action Plan.

Finally, the need for additional science is unequivocally recognized. Scientific uncertainty is a fundamental condition for most environmental policy making. The question, which has been strongly raised by several reviewers, is whether there is adequate understanding to proceed and how far and fast should we proceed. If the consensus is that we have tremendous uncertainty of any potential outcome, then we need a much more conservative approach.

In reality, the consensus among the science teams and participants in the December 1999 science workshop is that the increase in the severity or areal coverage of summer oxygen depletion can be explained by increased nutrient concentration in the Mississippi River. Furthermore, there is general agreement that steps to mitigate the problem can be taken now. In fact, many of these steps are already underway under the Clean Water Act and the Farm Bill. Ultimately, a very significant outcome of the work of the MR/GM Task Force will be to highlight additional research and implementation funding needs to ensure that there is an oversight process to examine the effects of current activities and suggest what, if anything needs to be done in addition. Nevertheless, these uncertainties and the informational purpose of the analyses in the six science reports were clarified in the final IA.

<u>Incorporating existing accomplishments</u>

The draft IA was seen by many as too strongly pressing the need for additional action without recognizing the success, and likelihood of continued support for improving practices and controls in the watershed. Efforts already underway within the watershed have some effect on the nutrient loadings. The observed apparent steady state of residual nutrients in the face of increased production and population growth in the basin, demonstrates the success of agricultural practices as well as point source and atmospheric controls to reduce the loads to the river.

However, the lack of detailed information on the success of those existing efforts has constrained our ability to assess the efficacy and success of site specific changes. The data analyzed are complete only through the mid 1990s, and do not capture the full impact of current activities. Impacts of specific management measures have been estimated based on a small number of studies in particular sites and models which have limited spatial resolution. Almost uniformly, the authors have called for better and more current data to capture the results of more recent activity.

RESPONSE

The final IA includes an improved discussion of the review and administrative process, the models used for the various economic and ecological approaches, and the uncertainties regarding the state of the science. While the specific ranges of uncertainty for each statement have not been added, the discussion of uncertainty, particularly regarding the scenarios used for the modeled costs of approaches to reduce nutrient loadings, has been reworked to better express the uncertainties. This discussion was included in the Executive Summary and context of the reports and includes both a general statement and appropriate caveats or boundaries for specific statements made in the body of the text.

Additionally, we expanded the discussion of the significance of existing actions and the shortcomings of the data, regarding the delay between increased activity, monitored results and reports in the scientific and industrial literature. These statements should form the basis of a significant monitoring and research effort to better measure accomplishments in the last decade. We clarified the scenarios used in the IA to better acknowledge the contributions of changing agricultural practices since the data used in the report were collected, and to capture a range of scenarios for conditions in the river system and the Gulf.

We clarified the significance and purpose of the analyses found in the six science reports. These are examples and illustrations of policy approaches and outcomes, and do not dictate or encumber the final contents of the Action Plan.
Wherever possible, an attempt was made to convert units of measurement and other terms to a consistent format.

The MR/GM Task Force is encouraged to consider all the suggestions made with respect to the Action Plan. The Task Force should seek opportunities to participate in public fora with an aim to expand awareness of the current findings, encourage presentation of alternative ideas for both assessment and remediation, incorporate social and economic considerations, and build a consensus for support of the plan.

CATEGORY #2: CONTRIBUTING FACTORS

SUMMARY OF COMMENTS

Comments on the Six Topic Reports:
Comments were received from 22 of the 34 commentors concerning possible contributing factors to hypoxia (USDA, IL Gov, IA Gov, LA Gov, ILFarmBur, MO DNR, WI Dpts, MWRDGC, LSUAgCtr, TFI, PPI, ILFert/ChemA, AmFarmBurF, Agribank, CtrGlblFoodIssues, Wheelabrator, CFIndustries, EcoLaw, ILCornGrowersA, ILAssnDrainageDistricts, KYFarmBurF, 3 Soc)

Comments on the Draft IA:
Comments on possible contributing factors were received from nine of 16 commentors (Boesch, AmFarmBurF, UMRBA, Rabalais, CleanWaterNet, MO DNR, TFI, 15 AgOrgs, and LSUAgCtr)

Several commentors stated that it appeared that the objective of the six reports and/or the IA was to prove that hypoxia in the Gulf was primarily attributable to excess agriculturally applied nutrients and did not adequately consider other contributing factors. This led to their conclusion that many other contributing factors were dismissed or minimized, while the impacts from agriculture were maximized without credible scientific data to support these conclusions.

A number of comments suggested that particular mechanisms which might be significant causative factors, other than nutrient flux from the Mississippi and Atchafalaya Rivers, were not sufficiently analyzed. Included among these were:

terrigenous organic carbon;
atmospheric deposition;
flood control levees and modifications of the Mississippi River channel;
coastal wetland loss;
intrusions of deeper offshore waters; and
short- or long-term climate changes.

DISCUSSION

Intensive study of the hypoxia phenomenon in the Gulf of Mexico began in the mid-1980s. Since then, a wide variety of potential mechanisms have been examined and the applicability of the eutrophication paradigm to the hypoxic zone in the Gulf of Mexico has been validated. Internally produced organic carbon, stimulated by nutrients (from the land, air or sea), externally supplied organic carbon, horizontal stratification, ocean circulation, and river hydrology are not competing hypotheses, but rather interacting factors within the eutrophication paradigm applied to the Gulf of Mexico.

These factors have been discussed extensively in the six reports as well as a wide range of previous work summarized in volumes such as the *1995 Gulf of Mexico Hypoxia Management Conference* (EPA 1997) and the December 1994 and June 1996 special issues of *Estuaries.* The 1995 Gulf of Mexico Hypoxia Management Conference included a paper by Turner *et al.* that outlined several hypotheses and possible factors contributing to development of hypoxia in the Gulf of Mexico. These factors included: channelization of the Mississippi River and its tributaries; coastal wetland loss; intrusions of deeper offshore waters; short or long-term climate changes; terresterial organic loading from the Mississippi River; and increased nutrient concentrations in the Mississippi River since the 1950s.
Turner's conclusion, based on available information, was that only increased nutrient flux from the Mississippi River could explain hypoxic conditions in the Gulf, "in an efficacious and non-contradictory way." The IA finds that "oxygen stress in the northern Gulf of Mexico is caused primarily by excess nutrients delivered to Gulf waters from the Mississippi-Atchafalaya River drainage basin, in combination with the stratification of Gulf waters."

The scientific evidence related to some of these potentially contributing factors is summarized below.

<u>Terrigenous organic carbon</u>
The amount of organic carbon loading in the Mississippi River is not large enough to account for the observed decline in oxygen over the area and volume of the hypoxic zone. Terrestrially originated organic carbon could account for a significant percentage of oxygen consumption only if a high percentage were available to be metabolized, and only if it were conveyed, as if by a pipeline, to the hypoxic zone extending 100-200 km from the points of river discharges. On the contrary, substantial losses of organic carbon from the system occur over this distance due to advection, deposition, and metabolism en route to the zone. Furthermore, in comparison with nitrogen, which can be recycled to support more in situ production well down-current, once organic carbon is oxidized it is effectively removed from the oxygen dynamics of the system. Nitrogen loading results in at least 15 times greater contribution to organic carbon responsible for oxygen depletion in shelf bottom waters than equal amounts of terrigenous organic carbon. Comments by Boesch provide additional information.

Analysis of isotope signatures supports the conclusion that material collected from the bottom of the hypoxic zone is different from the carbon from the river. Organic matter from the hypoxic zone has an isotope signature consistent with a marine, as opposed to terrigenous, origin, although some recent work has raised questions about why this observed difference exists. The terrestrial "signature" of the carbon is localized near the Mississippi River delta and does not occur over the broad region where hypoxia occurs. Also, the increase in carbon accumulation since the 1950s is primarily in the marine origin component and not the terrestrial component. Nutrient ratios of material flux from the Mississippi River also indicate that direct contributions of organic matter account for much less of the sedimented carbon than marine phytoplankton production fueled by Mississippi River nutrients. Sedimenting marine phytoplankton generally have an atomic C:N ratio of 9.5-9.9:1 whereas the C:N ratio for Mississippi River flux is about 2.3-3.7:1 (although it has been argued that it may be more appropriate to look at the particulate organic matter fraction and there the difference is less). Finally, suspended sediment has declined by about half since the 1950s, so oxygen consumption due to decomposition of the allochthonous, or transported, organic matter in suspended sediments has probably declined in importance.

The relative role of terrigenous carbon as a driver of hypoxia was addressed in a December 1999 meeting. Invited scientific experts represented a full range of views. However, after discussion of evidence, they agreed that terrigenous carbon is a relatively small factor driving hypoxia and that nitrogen-driven marine carbon production is approximately an order of magnitude greater. Commentors who initially stressed the potential role of organic carbon, in more recent comments on the IA concur that this may not be a large factor.

Atmospheric deposition

Several commentors noted differences in estimates of the contribution of atmospheric deposition to Gulf nutrient loading – estimates that seem to range from a low of 6.7% of Basin inputs in the nitrogen balance table in the Topic 3 report to a high of 174% of the average total annual flux of nitrate from the Mississippi Atchafalya River Basin (MARB).

Examination shows less difference among data than may appear on casual comparison. The estimates are actually different and discrepancies, when the estimates are carefully understood, are much smaller than they appear. Both reports use indirect data and literature values to construct total N estimates, with greatest reliance on data from the National Atmospheric Deposition Program (NADP) National Trends Network.

The Topic 3 report shows 440 kg N/sq km/yr for total nitrate plus organic N atmospheric deposition (wet and dry) averaged over 1990-96 (Topic 3 report, table 5.1). For the 3.2 million sq km MARB, this amounts to 1.4×10^9 kg N/yr or 1.4 million metric tons/yr input to the Basin. This 1.4 million metric tons is 6.7% of the 20.9 million metric tons/yr input to the Basin as shown in the mass balance table (Topic 3 report, table 6.1).

The largest apparent difference is with respect to Dinnel[1]. This paper states that the "average atmospheric deposition of total nitrogen accounts for approximately 174% of the average total riverine nitrogen flux." The first point to note is that riverine flux is different from, and much smaller than, Basin input. Dinnel estimated annual atmospheric nitrogen deposition of total nitrogen to the Basin to be 200×10^9 mol/yr which is equal to 2.8×10^9 kg N/yr or 2.8 million metric tons per year (since N is 14.0 g/mol). This estimate is based on "NADP data and literature factors for nitrite and organic nitrogen." Thus Dinnel's estimate of total nitrogen deposition to the Basin is twice as large as the estimate from the Topic 3 report.

Dinnel, based on NADP data, estimated wet nitrate deposition as 44×10^9 mol/yr average over the period 1979-93 or 0.62 million metric tons/yr. The Topic 3 report estimated wet nitrate deposition to be 200 kg N/sq km/yr average over 1980-96 or 0.64 million metric tons/yr for the Basin – a value in close agreement with Dinnel's estimate.

Dinnel estimated dry nitrate deposition as 75% of wet nitrate deposition whereas the Topic 3 report estimated it as 70%. Dinnel and the Topic 3 report agree that nitrite is a small factor – Dinnel's estimate is 3-4% of his total estimate. Both agree that organic N is about half of the total wet plus dry inorganic N. Dinnel, based on NADP/NTN data estimated wet NH_4 deposition to be 42x109 mol/yr and that dry NH_4 deposition was 25% of the wet NH_4 deposition. The Topic 3 report estimated direct atmospheric deposition to the hypoxic area although Dinnel did not. At a total of 15 thousand metric tons/yr, as estimated in the Topic 3 report, direct atmospheric deposition is a very small factor in the overall mass balance. The estimate was derived from approximately 500 kg/sq km/yr (5 kg/ha/yr) over an area of 30,000 sq km – roughly twice the size of the hypoxic zone.

The major difference is that the Topic 3 report argues that NH_4 deposition within the Basin is likely to be the result of internal sources and that atmospheric deposition of NH_4, therefore should be considered an internal transport process rather than a Basin input (Topic 3 report, p. 66).

Dinnel, Scott. P. 1977. Estimates of Atmospheric Deposition to the Mississippi River Watershed. Proceedings of the First Gulf of Mexico Hypoxia Management Conference, December 5-6, 1995, Kenner, LA. Report EPA-55-R-97-001. Gulf of Mexico Program Office, Stennis Space Center, MS. Pp. 160-173.

	Deposition (millions of metric tons per year)	
	Topic 3 report	Dinnel
total N deposition to Basin	1.4	2.8
wet nitrate	0.64	0.62
dry nitrate	0.45	0.46
wet NH_4	internal transport	0.58
dry NH_4	internal transport	0.15
organic	both agree ~1/2 wet+dry inorganic N	

<u>Channelization of the Mississippi River and its tributaries</u>

Several comments were received that highlighted the potential importance of flood control levees and modifications of the Mississippi River channel, which were constructed to improve navigation, in reducing overland flow and diminishing natural capacity to remove nutrients from runoff to the Gulf. Other comments noted that the hydrology of the Mississippi-Atchafalaya River Basin has changed enormously over the last two decades.

Evidence indicates that the natural capacity of the MARB to remove nutrients has diminished. Many of the original freshwater wetlands and riparian zones that were found throughout the MARB and that were once connected to streams and rivers of the basin are gone from the landscape. Midwestern states, such as Ohio, Indiana, Illinois, and Iowa, have had over 80% of their wetlands drained. The seven states that are in the upper Mississippi River Basin (Indiana, Illinois, Iowa, Minnesota, Missouri, Ohio, and Wisconsin) collectively have lost the equivalent of 14.1 million ha (35 million acres) over the past 200 years. Similar losses have occurred in lower Basin states. Natural wetlands and riparian zones can improve water quality and reduce nitrogen fluxes down the Mississippi River to the Gulf of Mexico.

Channelization, locks, and dams have affected water and nutrient flux to the Gulf in several ways -- changing the rate of flow, sediment loads and nutrient loads. Suspended sediment has declined by about half since the 1950s. As a result, oxygen consumption in the Gulf due to decomposition of the allochthonous, or transported, organic matter in suspended sediments has probably declined in importance. Changes in the flux of nutrients to the Gulf have been studied extensively and are analyzed in the six reports. The major change affecting hypoxia has been nitrate levels. Denitrification in large rivers is generally small. Channelization has not likely had a large direct effect on denitrification in these rivers. Wetlands along the river and particularly wetlands and riparian zones along tributaries and small streams can effectively remove some nitrate, particularly during flood events. River diversions over coastal wetlands and shallow inshore waters also may have the potential to remove some nitrate. By diverting water from these natural areas of denitrification, channelization may affect nitrate loading. One commentor suggested testing the nutrient enrichment theory by suspending "the diversion of Mississippi River flow into the Atchafalaya River, which consequently goes directly into the center of the hypoxic zone." In fact, rather than "diversion," present efforts by the USACOE are to limit Atchafalaya flow to a maximum of 30% of the combined flow of the Mississippi and Red Rivers at the latitude of Old River and to prevent its natural tendency to carry more. The impacts of such a flow modification would be extensive and no careful study has been done.

Coastal wetland loss

Some comments suggested that nutrient and organic loadings from erosion of coastal wetlands in Louisiana are a potential source of materials that fuel the development of hypoxia in the Gulf of Mexico. Coastal wetland loss in Louisiana is severe, although the rate of loss has diminished since the period from the 1950s to 1970s, when it was greatest. Loss rates exceeded 40 square miles per year then, but have been estimated to be between 25 and 35 square miles per year in the 1990s. However, even at the highest rate, the amount of carbon released from erosion of wetlands is not sufficient to account for the observed decline in oxygen over the area of the hypoxic zone. One commentor provided an estimate of the organic matter flux from coastal land loss. Although this possible source is distributed differently than the organic material carried by the River, its impact on the hypoxic zone is diminished by the same processes outlined in the section addressing organic carbon (see Boesch's comments for details).

Further, if the dominance of nutrients were common between estuarine areas suffering land losses, then the sedimentary record of diatom production would be similar. The deposition/accumulation of biogenic silica (a surrogate for diatom production) is, in fact, strikingly different. Accumulation of biogenic silica is greater in sediments beneath the plume. In addition, carbon isotope signatures in nearshore sediments indicate that carbon emanating from marsh detritus is localized close to shore.

Intrusions of deeper offshore waters

Some comments suggested that intrusions of offshore waters bring low oxygen conditions and nutrients to the hypoxic zone. However, intrusions of the oxygen minimum layer from deeper waters on to the continental shelf have always been found to be physically separate from the nearshore hypoxic region that is the focus of this assessment. The hypoxic zone on the continental shelf is in depths of less than 60 m, while the oxygen minimum zone is in water depths of 400 to 700 m. Further, the dissolved oxygen level, salinity, temperature and respiration rates of water in the oxygen minimum layer differ considerably from the waters of the hypoxic zone.

Upwelling of nitrate from deeper waters may be important in shelf edge (depths of approximately 100 m) cycling of carbon and nitrogen. The Topic 1 report (p. 48) notes that, occasionally, mixing diagrams of riverine nutrients with saline Gulf of Mexico waters are nonlinear in a way that implies another source of nutrients which could be from deeper water intrusion. However, all data indicate that the Mississippi and Atchafalaya Rivers contribute, by far, the major sources of nutrients to the northern Gulf of Mexico.

Short or long-term climate changes

Some comments suggested that climate change, particularly increased precipitation, has increased river flow and nutrient transport, increasing stratification as well as nutrient fueling of hypoxia. One comentor noted that hurricane events caused severe localized flooding, shoreline erosion, disturbed shallow habitats and introduced large quantities of nutrients into the waters of the hypoxic zone in the year preceding increases in the extent of hypoxia but notes that they do not argue that these storms alone directly cause hypoxia.

River discharge, nitrate concentration, and sediment core data provide almost 100 years of record for this system. On that time-scale, there is no indication that climate-scale factors override the impacts of human activities in the basin. Streamflow in the Mississippi River was approximately 30% higher during 1980-96 than during 1955-70 as a result of increased precipitation. The climate record thus indicates a 30% increase in river discharge as compared to the 300% increase in nitrate flux over this period.

Since about 1980, the annual nitrogen flux has become highly variable due, in part, to variable amounts of precipitation. Episodic events such as the 1993 flood can nearly double the annual nitrate flux to the Gulf as a result of increased leaching of nitrate from the soil-ground water systems in the basin. High annual nitrate fluxes associated with flood events can be expected to occur in the future. There are indications that future climates for this basin may be wetter and include more extreme events, leading potentially to increased water and nitrate fluxes.

RESPONSE

In response to the concern that the full panoply of potential contributors to the current state of hypoxia in the Gulf of Mexico had not been given full consideration, the relevant evidence was re-reviewed. In addition, a meeting of experts was convened to reexamine the issue and scientists representing the full range of views were invited. Those present at that meeting reached a consensus that river-derived nitrogen is the most important, manageable driver of the increased organic carbon that consumes oxygen in the hypoxic zone.

Thus, the major conclusion drawn from assessing the state of knowledge with respect to hypoxia in the Gulf of Mexico, that this stress is caused primarily by excess nutrients delivered to Gulf waters from the Mississippi-Atchafalaya River drainage basin, in combination with the stratification of Gulf waters, was supported. However, in response to public comment on other contributing factors, the chapter of the IA dealing with causes was written to include discussion of a wide array of potentially contributing factors.

No change was made to statements in the IA about the role of atmospheric deposition because all the information examined is consistent with those statements. Statements about atmospheric deposition as a research need were revised to emphasize the need for better understanding of the relative magnitude of various cycling mechanisms rather than the overall size of its contribution.

CATEGORY #3: NITROGEN CONCENTRATION AND FLUX: TRENDS AND SOURCES

SUMMARY OF COMMENTS

Comments on the Six Topic Reports:
Comments were received from 22 of the 34 commentors (AmFarmBurF, 3 soc, AminoAcidEdC, CtrGlblFoodIssues, GulfRestN, ILFarmBur, IL Gov, IA FarmBur, IA Gov, KYFarmBurF, LSU AgCtr, MWRDGC, MS RiverPart, MO CornGrowersA, MO DNR, PPI, TFI, USDA, Wallin, Wheelabrator, WI Dpts, and UMRBA).

Comments on the Draft IA:
Comments on nitrogen trends were received from nine of 16 commentors on the draft Inegrated Assessment (Boesch, AmFarmBurF, Goolsby, NCR-195, Rabalais, MO DNR, TFI, IL Gov, and LSU AgCtr).

Comments focused on the reports' primary emphasis on nitrogen as a contributing factor to the Gulf Hypoxic Zone. Some of these comments included assertions that total nitrogen flux has actually decreased over time, rather than increased as concluded by the CENR reports. In addition, questions were raised concerning the relative contributions of nitrogen from nonagricultural sources (point sources, atmospheric deposition, etc.) to total loadings, as well as questions about the overall nitrogen dynamics within the system. The following discussion incorporates new data on nitrogen concentrations and flux collected during 1997-99 to address these questions, comments, and issues. The six Topic reports used flux and concentration data collected only through 1996, where as some of the 1997-99 data was used in the draft IA.

Specific comments were grouped in the following areas:

Nitrogen trends in rivers
According to one commentor, total nitrogen concentrations in the lower Mississippi River are lower now than at the start of the 20th century and much lower than at mid-20th century. Total N concentrations in the Illinois River now are about same as at start of the 20th century. Another commentor stated that the data do not support a three-fold increase in N flux in last 30 years. Others noted that IA and CENR reports acknowledge organic and ammonia N data prior to 1970s, but use only nitrate data. One commentor questioned why nitrogen concentration in the Ohio River has not increased in response to the large increases in fertilizer use in the Ohio River Basin. Several commentors noted the lack of 1999 nitrogen data in the IA to support the discussion presented on the size of the hypoxic zone in 1999.

Nitrogen sources

Some commentors stated that there is no consistent relation between nitrate concentrations in streams and use of N fertilizer. Others suggested that the roles of confined feeding operations, municipal treatment plants, and urban runoff as nitrogen sources are not properly represented. One commentor stated that atmospheric nitrate and ammonia, and municipal/industrial point sources are direct inputs to water. Large removal of nitrogen in harvested crops was not properly recognized in the IA. Another commentor recommended the use of nitrogen residuals as the best indication of potential N loads in rivers.

DISCUSSION

Nitrogen trends in rivers

River-borne nutrients and water-column stratification are the major factors contributing to hypoxia in the northern Gulf of Mexico. The key nutrients in this process are nitrogen, phosphorus, and silica. Of these, nitrogen is the most important nutrient leading to the production of excess algae and subsequent hypoxia in the Gulf. Nitrogen is also the only nutrient that has increased significantly in concentration and loads in the Mississippi River in recent decades. Phosphorus loads have not changed significantly since the early 1970s when records began. Silica loads decreased between the 1950s and 1970s, and have not changed significantly since.

Nitrogen is present primarily in three forms in the Mississippi River and its tributaries – nitrate and ammonium (dissolved inorganic N or DIN), dissolved organic nitrogen (DON), and particulate organic nitrogen (PON). Total nitrogen is the sum of these three forms. For 1980-96 the average total nitrogen flux from the MARB to the Gulf was estimated to be 1,567,900 metric tons per year. Of this amount, about 61% was nitrate, two percent was ammonium (DIN = 63%), 24% was DON, and 13% was PON. Most of the analysis of nitrogen changes (trends) discussed in the IA and six Topic reports focused on nitrate, which comprises most of the DIN. The principal reason for the focus on nitrate rather than total N is that nitrate is the most significant bioavailable form of N transported into the Gulf.

DIN is the principal form of nitrogen used by algae in the near surface waters of the Gulf. Most DIN enters the Gulf as nitrate and is rapidly assimilated by phytoplankton. Subsequent recycling of nitrogen in the surface layer of the Gulf produces ammonia, which is also quickly assimilated by phytoplankton. DON entering the Gulf is largely in the form of amino acids and dissolved humic material. Most forms of DON have to be mineralized to DIN by microbial processes before algae can utilize it, and thus DON becomes available very slowly. The PON discharged from the Mississippi Basin is present in all forms of suspended material and tends to settle in the bottom waters of the Gulf. PON has to be mineralized to DIN and then be transported back into the surface waters of the Gulf before algae can assimilate it. Transport of

DIN from the bottom waters of the Gulf to the surface waters would not occur during stratification. Thus, the DIN entering the Gulf as nitrate from the Mississippi River is the principal form of N utilized by the algae that subsequently contribute to the formation of hypoxia. DIN concentration and flux has changed more than any other form of N and therefore potentially has a much larger effect on algal production and hypoxia than do DON and PON.

Few data were collected on forms of N other than nitrate prior to the mid-1970s. No data on organic N are known to have been collected in the lower Mississippi prior to 1973. However, some data on DON/PON were collected in the Illinois River Basin and at a few locations on the Mississippi and Missouri Rivers in the vicinity of St. Louis during the period 1896-1905. Because of the sparseness of organic N data prior to the 1970s, there was little discussion of either historical organic or total N in the CENR reports or in the draft IA report. However the historical organic N data from the Illinois River basin-St Louis area can be used to improve the IA by providing an estimate of total nitrogen concentrations at the beginning of the century. The following response is based largely on data published in reports by Palmer[2], Leighton[3], Dole *et al.*[4], Goolsby *et al.*[5] (also referred to as the Topic 3 report), Howarth *et al.*[6,7], Maybeck[8], and Meade[9].

Pristine conditions: To provide a baseline for determining long-term changes in nitrogen concentrations in the Mississippi Basin, an estimate of mean concentrations was developed for all major nitrogen species in the Mississippi River before European settlement ("pristine" conditions). These estimates are given below in table 1. Using data on nitrogen concentrations in unpolluted major world rivers published in Maybeck[8] the pristine mean dissolved inorganic nitrogen (DIN) concentration, nitrate plus ammonium, in the Mississippi River was estimated to be about 0.115 mg/l. The mean total dissolved nitrogen (DON + DIN) was estimated to be 0.375

---

[2] Palmer, Arthur W., ca. 1903, Chemical Survey of the Waters of Illinois: Report for the years 1897-1902, University of Illinois, 254 p.

[3] Leighton, M.O., 1907, Pollution of the Illinois River by Chicago Sewage, U.S. Geological Survey Water Supply Paper 194, 369 p. (this report cites data presented in the Palmer report and other sources).

[4] Dole, R.B. 1909. The quality of surface waters in the United States: Part I. -- Analysis of waters east of the one hundredth meridian. U.S. Geological Survey Water-Supply Paper 236. Washington, DC: Government Printing Office. 123 p.

[5] Goolsby, D.A., Battaglin, W.A., Lawrence, G.B., Artz, R.S., Aulenbach, B.T., Hooper,R.P., Keeney, D.R., and Stensland, G.J., 1999. Flux and Sources of Nutrients in the Mississippi-Atchafalaya River Basin: Topic 3 Report for the IA on Hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series No. 17. NOAA Coastal Ocean Office, Silver Spring, MD, 129 p. (Also available at URL: http://wwwrcolka.cr.usgs.gov/midconherb/hypoxia.html)

[6] Howarth, R.W., G. Billen, D. Swaney, A. Townsend, N. Jaworski, K. Lajtha, J.A. Downing, R. Elmgren, N Caraco, T. Jordan, F. Berendse, J. Freney, V. Kudeyarov, P. Murdoch,and Z. Zhao-Liang. 1996. Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: Natural and human influences. Biogeochemistry 35:75-139.

[7] Howarth, R.W. 1998. An assessment of human influences on fluxes of nitrogen from the terrestrial landscape to the estuaries and continental shelves of the North Atlantic Ocean. Nutrient Cycling in Agroecosystems p. 213-223.

[8] Maybeck, M. 1982, Carbon, Nitrogen, and Phosphorus Transport by World Rivers. American Journal of Science, v282, April, 1982, p 401-500.

[9] Meade, R.H. 1995. Contaminants in the Mississippi River. U.S. Geological Survey Circular 1133. 140 p.

mg/l[8]. The difference between the above two estimates would be an estimate of the mean dissolved organic nitrogen (DON), which is about 0.26 mg/l. The particulate organic nitrogen (PON) concentration was calculated from the pre-development annual sediment flux from the Mississippi-Atchafalaya Basin to the Gulf of Mexico (400 million metric tons per year[9]). The N content of the sediment was estimated from the lower Mississippi and Missouri River sediment nitrogen data and was found to be about 0.15% and a mean annual streamflow of 21,990 cubic meters per second was calculated (table 2.2 in the Topic 3 report). From this calculation, the mean PON concentration was estimated to be 0.86 mg/l. The pre-development total nitrogen (TN) concentration was then calculated from the sum of the DIN + DON + PON to be 1.24 mg/l. Other estimates of "pristine" TN concentrations from the literature range from 0.79 to 1.15 mg/l (see table 1). Thus, the TN estimate of 1.24 mg/l may be a little high.

Last 100 years: Published data on nitrate, nitrite, ammonium, and dissolved and suspended organic nitrogen were used to develop estimates of mean annual concentrations of all major nitrogen species for four locations in the Mississippi River. These estimates were derived from data published in Palmer (ca. 1903) and cover the Mississippi Basin for the period 1897-1906. The locations 1) the Lower Illinois River, 2) Mississippi River near Grafton, IL (below Illinois River and above Missouri River), 3) Lower Missouri River, and 4) Lower Leighton (1907), and Dole, (1909), are shown below in table 2. Total N, DON, and PON for the lower Mississippi river site were calculated (see footnotes in table 2 for calculation method). Mean nitrogen concentrations at these four sites for 1980-98 are also shown in table 2 for comparison.

Results in table 2 clearly show that concentrations of total nitrogen have increased significantly at three of the four sites during the past 100 years. Table 2 also shows that essentially all of the increase can be attributed to DIN or nitrate. The total N concentration in the lower Mississippi is estimated to have increased by a factor of 1.3 since 1905-06, and nitrate, the bioavailable form of N, has increased by a factor of about 2.5. In comparison with pristine conditions, the total N concentration in the lower Mississippi River has doubled and nitrate has increased by a factor of more than 10. Mean annual total N concentrations in the lower Illinois River and the Mississippi River at Grafton have also doubled in the last 100 years while nitrate concentrations have increased by factors of three to more than four (table 2). The exception is the lower Missouri River where total N concentrations have decreased slightly due to a large decrease in PON concentration associated with construction of reservoirs on the Missouri River in the 1950s and 1960s. Trapping of sediment in the reservoirs has reduced the discharge of suspended sediment by more than 50%[10], resulting in a similar reduction in PON. However, nitrate concentrations in the lower Missouri have more than doubled and make up for most of the decrease in PON.

---

[10] Meade, R.H. 1995. Contaminants in the Mississippi River. US Geological Survey Circular 1133. 140 p.

Table 1. – Estimates of Nitrogen Concentrations in the Mississippi River Basin prior to European Settlement (Pristine conditions)

Nitrogen species	mg/l	Reference or source
(DIN) Dissolved inorganic N	0.115	Calculated from Maybeck (1982)
Nitrate	0.10	Maybeck (1982). ave. for unpolluted major world rivers
	0.09	Clark *et al.* (in press) median for 82 relatively undeveloped U.S. watersheds
Ammonium	0.015	Maybeck (1982)
(DON) Dissolved organic N	0.26	Calculated from Maybeck (1982)
(PON) Particulate organic N	0.86	Calculated from estimated pre-development sediment flux of 400 x 10^6 metric tons/y (Meade 1985); N content of sediment of 0.15%; 1980-96 mean annual streamflow of 21,990 m^3/s.
Total organic N	1.12	Calculated from dissolved and particulate organic N
Total dissolved N (DIN plus DON)	0.375	Maybeck, 1982
Total N	1.24	Calculated from total dissolved N and particulate organic N
Other estimates of total N	0.93	Howarth *et al.*, 1996 (from Maybeck, 1982)
	0.08-1.15	Howarth *et al.*, 1996 (from Lewis 1986)
	0.79	Howarth *et al.* (1998) for mean discharge=17,313 m^3/s; basin area=3.23 x 10^6 km^2
	0.26	Clark, *et al.* (in press); small US watersheds

Table 2. - Historical and Recent Data on Nitrogen Concentrations in the Mississippi River Basin
(Results in milligrams per liter as N).

Location	Number of Samples	Organic N DON	Organic N PON	Organic N Total	Inorganic N Nitrate-N	Inorganic N NH_4-N	Inorganic N DIN	Total N[a]
Lower Illinois River								
1897-1902	weekly	0.59	0.42	1.01	1.25	0.38	1.63	2.64
1980-98	189	0.45	0.60	1.22[b]	4.09	0.14	4.23	5.46
Upper Mississippi River near Grafton (below Illinois R. & above Missouri R.)								
1899-1900	70	0.48	0.62	1.10	0.59	0.13	0.72	1.82
1980-98	120	0.81	0.63	1.27	2.63	0.11	2.74	4.01
Lower Missouri River								
1899-1900	63	0.30	1.53	1.83	0.51	0.06	0.57	2.40
1980-98	186	0.51	0.69	1.03	1.23	0.05	1.28	2.24
Lower Mississippi River								
1905-06	52	0.40[c]	0.76[d]	1.16	0.56	0.1[c]	0.66	1.82
1955-65	308	0.52[f]	0.69[g]	1.21	0.65[e]	0.1[f]	0.75	1.96
1980-98[d]	104	0.52	0.38	0.92	1.45	0.06	1.51	2.40

[a]Total N calculated as the sum of total organic N + DIN.
[b]DON and PON not analyzed on all samples in 1980-98, thus DON + PON does not equal total organic N for this time period.
[c]Estimated from concentrations in upper Mississippi River and Lower Missouri River.
[d]Estimated as 2 times the average 1980-98 PON concentration.
[e]From Topic 3 report, table 3.4.
[f]estimated
[g]Calculated from 1955-65 daily sediment concentration at Tarbert Landing (4018 samples; mean= 460 mg/l) and estimated sediment nitrogen content of 0.15%; PON = 0.69 +/- 0.41mg/l.

Several comments on the IA and the six Topic reports asserted that total nitrogen concentrations in the Lower Mississippi and Illinois Rivers at the middle of the century were much higher than they are now. This statement is difficult to assess because no actual measurements of total N based on analysis of organic N, ammonium, and nitrate are known to exist for this period. However, data are available to calculate an estimate of nitrogen in the Lower Mississippi River for the period 1955-65. The mean nitrate concentration for this period based on chemical analyses was 0.65 mg/l (Topic 3 report, table 3.4). The mean PON concentration can be estimated from suspended sediment concentrations measured at Tarbert's Landing, LA. The mean PON for 1955-65 was calculated to be about 0.69 +/- 0.41 mg/l based on a mean sediment concentration of 460 mg/l and sediment nitrogen content of 0.15%. No data are available for the DON for this period, but it is reasonable to assume that a range for DON was 0.4-0.5 mg/l based on values measured near the beginning and end of the 20th century (table 2). Similarly, the range for ammonia was probably 0.06 to 0.1 mg/l (see table 2). Using the measured nitrate value, the calculated PON, and the high end of the range for values for DON and ammonia the calculated mean total N for 1955-65 is 1.96 mg/l. These results, shown in table 2, indicate that the concentrations of total N in the lower Mississippi River in 1955-65 were similar to concentrations at the beginning of the 20th century, but significantly lower than mean concentrations for 1980-96.

Since the mid-20th century the sediment flux from the Mississippi Basin to the Gulf of Mexico has decreased by about 50%[11] due to trapping of sediment in the Missouri River reservoirs. As a result, the average PON concentration in the Mississippi River has decreased from a calculated value of about 0.69 mg/l during 1955-65 to a mean of about 0.38 mg/L during 1980-96 (table 2), a decrease of about 50%. However, as concluded in the IA and six Topic reports, the mean concentrations of nitrate in the lower Mississippi River have increased, more than offsetting the decrease in PON. Concentrations have more than doubled since the 1955-65 period, with most of the increase occurring between the late 1960s and early 1980s (see figure 1). Since the early 1980s nitrate concentrations have been highly variable from year to year due to varying climatic conditions, but there is no statistically significant trend (figure 1). The highest mean annual nitrate concentrations occurred in 1982 (1.80 mg/l), 1993 (1.79 mg/l) and 1999 (1.82 mg/l). The year 1999 was somewhat unusual in that both streamflow and nitrate concentrations during the spring and summer were above normal in the upper Mississippi. The streamflow of the Mississippi River at Thebes, above the Ohio River confluence for January-June, 1999 averaged 328,400 cfs as compared with a 1980-98 mean of 284,400 cfs for this period. The mean nitrate concentrations for January-June were 3.4 mg/l versus a 1980-98 mean for the period of 2.7 mg/l. However, drought conditions were developing in the upper Ohio basin, which produced below normal streamflow in 1999, 376,000 cfs vs a 1980-96 mean of 426,300 cfs, for January-June. Nitrate concentrations (1.2 mg/l for Jan-June) were near normal for this period. The combination of above normal flows and nitrate concentrations from the upper Mississippi and below normal flows from the Ohio River produced higher than normal nitrate concentrations and flux in the lower Mississippi River, and may have contributed to the large hypoxic zone measured in July 1999.

The annual flux of nitrate to the Gulf of Mexico for 1955-99 is shown in figure 2. The dark part of each bar represents the nitrate flux for January-June, the period that would have the greatest influence on the development of hypoxia. The top (light) part of each bar represents the nitrate

[11] Meade, R.H. 1995. Contaminants in the Mississippi River. US Geological Survey Circular 1133. 140 p.

flux for July-December. Nitrate flux has not yet been estimated for July-December of 1999. The nitrate flux for January-June 1999 was the fifth highest flux measured for this period since records began in 1955.

Figure 2 clearly shows there has been a large increase in the annual flux of nitrate. The IA and CENR reports stated that the nitrate flux to the Gulf almost tripled from an average of 0.33 million metric tons/yr during 1955-70 to 0.95 million metric tons/yr during 1980-96. The time periods selected for this comparison were somewhat arbitrary, and by selecting different time periods for comparison one can get varying ratios for the increase. However, it is clear that nitrogen fluxes have increased significantly in the past 30 years.

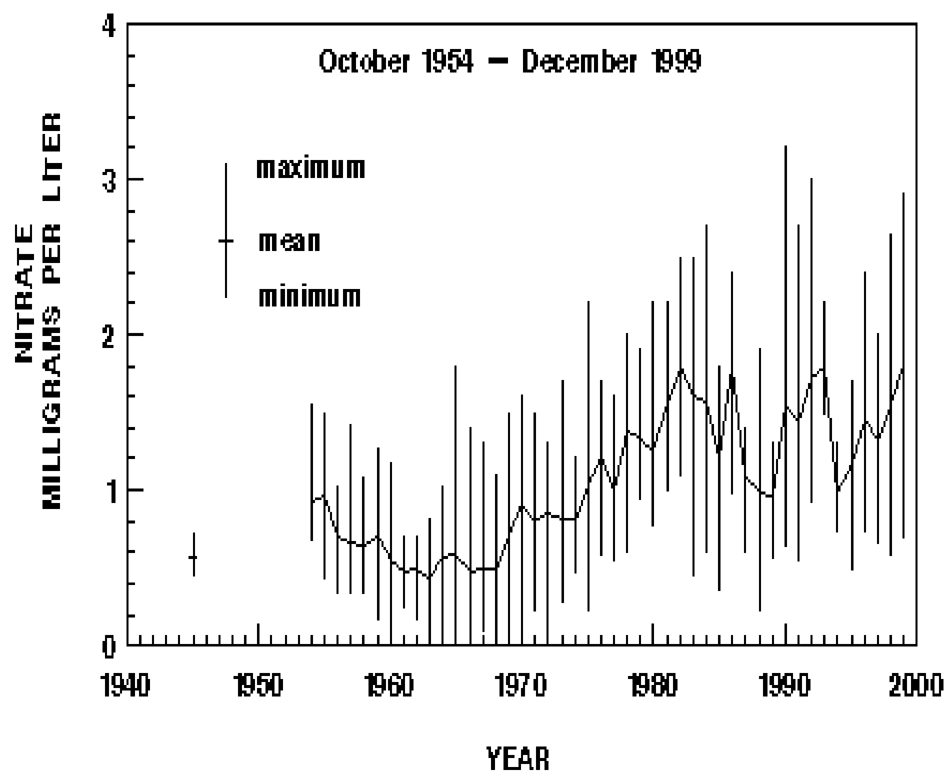


Figure 1. Maximum, minimum, and mean nitrate concentrations in the lower Mississippi River, 1954-99 (from the Topic 3 report, figure 3.4).

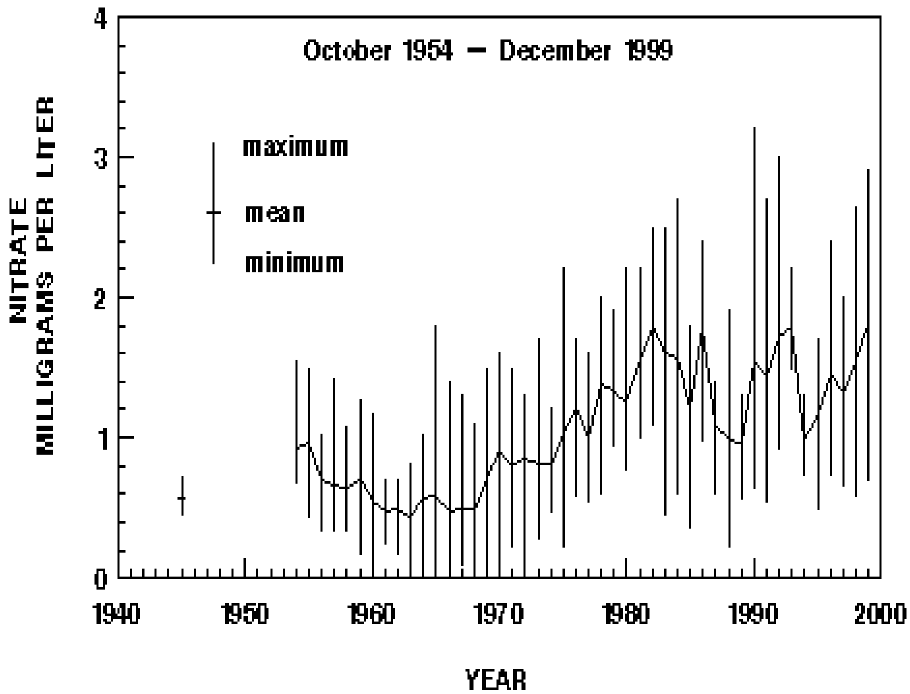


Figure 2. Nitrate flux to Gulf of Mexico for January-June and July-December, 1955-99.

Comparisons to the Ohio River

One commentor questioned why the nitrate concentrations have not increased in the Ohio River basin as they have in the lower Mississippi given the fact that fertilizer use has increased significantly. The reason has not been determined from scientific study. However, there are probably several contributing factors including intensity of nitrogen inputs, subsurface drainage, and climate. The nitrogen inputs per unit area from fertilizer, soil mineralization, manure, etc. are much higher in the middle and upper Mississippi Basins than they are in the Ohio Basin. This is shown graphically in figure 5.10 of the Topic 3 report. Calculations based on data in table 5.7 of the Topic 3 report show that the annual fertilizer N use in the upper and middle Mississippi basins is about 4.2 metric tons/km^2 and 5.5 metric tons/km^2 in just the middle Mississippi Basin, versus 2.2 metric tons/km^2 in the Ohio basin. Annual N inputs from the combination of fertilizer, soil mineralization, and manure are about 4.8 metric tons/km^2 in the Ohio Basin compared to about 12.6 metric tons/km^2 in the upper and middle Mississippi Basin. Fertilizer use has also increased significantly more in the upper and middle Mississippi basin than in the Ohio. There is significantly more subsurface tile drainage in the upper and middle Mississippi Basin than in the Ohio Basin (figure 1.4 of Topic 3 report). Finally, streamflow appears to have increased significantly in the upper Mississippi Basin, but to a lesser extent or not at all in the Ohio basin. All of these factors, and perhaps others, result in more discharge of nitrate to streams in the upper and middle Mississippi Basin than in the Ohio. The result would be an increase in nitrate concentration and flux in the lower Mississippi, and perhaps less or no increase in the Ohio Basin.

Nitrogen sources

The Topic 3 report estimated that about 12.2 million metric tons of new nitrogen are added annually to the Mississippi Basin from fertilizer, legumes, and atmospheric deposition. An additional 8.7 million metric tons of N may become available within the basin annually from mineralized soil, animal manure, and point source inputs directly into streams. Of this nearly 21 million metric tons of N, about 10 million metric tons is removed annually in crops. Most of the remainder is either returned to the soil in organic matter for possible mineralization and reuse by crops in following years or is lost to the atmosphere in gaseous forms. The difference between the nitrogen added by all inputs and the nitrogen removed by crops, lost in gaseous form, or stored in soil organic matter is the amount of nitrogen potentially available for leaching to streams and ground water. On the average, about 1.6 million metric tons of this residual nitrogen, including nearly one million metric tons of nitrate discharges to the Gulf of Mexico via the Mississippi River each year.

A number of factors influence the transport of nitrate to the Gulf of Mexico. These include nitrogen inputs, climate, and crop yields, which largely determine the residual amount of nitrogen in the soil-ground water system. These variables and a number of related variables and mathematical transformations were examined in statistical models to determine which ones could best explain the observed annual time series of nitrate flux to the Gulf. The most important ones appear to be the mean annual streamflow, nitrogen fertilizer use lagged by two years, and the nitrogen residual lagged by one year. The relationship between these factors and annual nitrate flux is shown by the results of four regression models in figures 3a-3d. In figure 3a the annual nitrate flux was regressed against the mean annual discharge. This figure shows the observed nitrate flux and the nitrate flux predicted by the model. The model has an R^2 of 0.58 and explains a considerable amount of the year-to-year variation in nitrate flux but little of the upward trend. It overpredicts nitrate flux prior to about 1976 and underpredicts nitrate flux since about 1980. For figure 3b nitrate flux was regressed against nitrogen fertilizer use two years previous. The observed and predicted nitrate fluxes are shown. This model has an R^2 of 0.60. It explains much of the upward trend in nitrate flux, but not the year-to-year variability, which is driven by climate and other factors. For figure 3c nitrate flux was regressed against the nitrogen residuals lagged by one year. The residual, which is the annual nitrogen inputs minus outputs, incorporates the change in fertilizer use, crop yields, and climatic variation through its influence on crop yields. This model (R^2= 0.66) explains much of the trend and variability in nitrate flux. However, the observed and predicted values do not agree well in all years. Models using lagged values of 0, 2, and 3 years did not improve the results. Figure 3d shows the results from a multiple regression model that used all three predictor variables. This model has an R^2 of 0.89. Lagged fertilizer use explains 68% of the variation in nitrate flux, streamflow explains an additional 18%, and residual nitrogen explains another 3%. The model shows excellent agreement between observed and predicted values except for 1972-74. Streamflow was very high during these three years (see figure 2) and nitrate flux is greatly overpredicted. Results for 1961 are similar, although streamflow was considerably lower. Apparently little excess nitrate was available in the soil-ground water system for leaching during this period.

The models discussed above describe a statistical relationship between the annual flux of nitrate and several variables. However, it must be noted that they do not prove cause and effect. Other variables not used in this analysis may also have a significant statistical relationship to nitrate flux.

Other nitrogen inputs such as manure and legumes changed very little during 1955-96, and thus would explain little or none of the annual variation and increase in nitrate flux. It was assumed in the CENR analysis that soil mineralization was constant over this period, because there were no data to show otherwise. However, the rate of soil mineralization probably has changed due to changes in farming practices and use of commercial fertilizer. Additional research is needed to better understand and quantify the role of soil mineralization in contributing to the nitrate flux of the Mississippi River.

Data on atmospheric inputs are available only since 1984 (see figure 2.5A of the IA). This nonpoint source input contributes to the nitrate load of the river, but it is small compared to fertilizer inputs, and probably adds little to the observed annual variability or increase in nitrate flux.

Data on municipal and industrial point source inputs are available for only two years – 1980 and 1996 (figure 2.5A of IA report). The two values are similar and indicate little change over time. Improved sewage treatment practices since mid-century would remove more solid waste from sewage and should reduce the total nitrogen input from sewage. In general, point source inputs should be relatively constant year-round. As a result, during high-flow events and floods the relative contribution from point source inputs should decrease when compared to nonpoint source inputs.

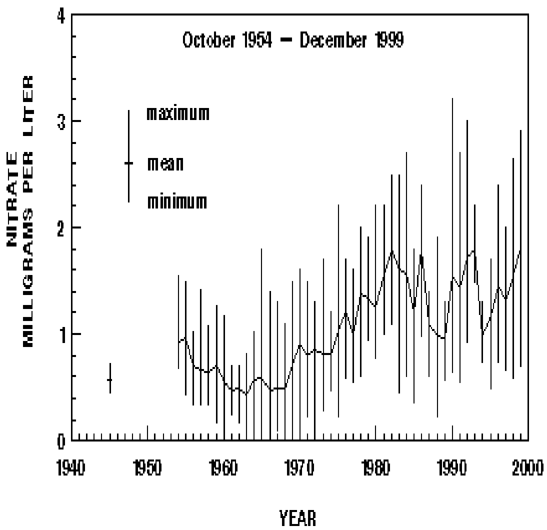
However, as noted in the public comments, the point source estimates may underestimate the short-term effects of bypassing sewage plants during floods, as in 1993 and 1995, and in introducing solid wastes containing organic nitrogen. An upper limit for nitrogen input from human wastes can be obtained by multiplying the total population of the Mississippi basin (70,000,000) by the amount of nitrogen produced in human waste (4.4 kg per person per year[12]).

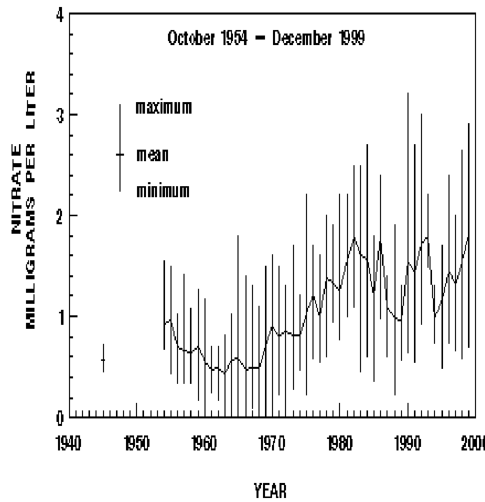
---

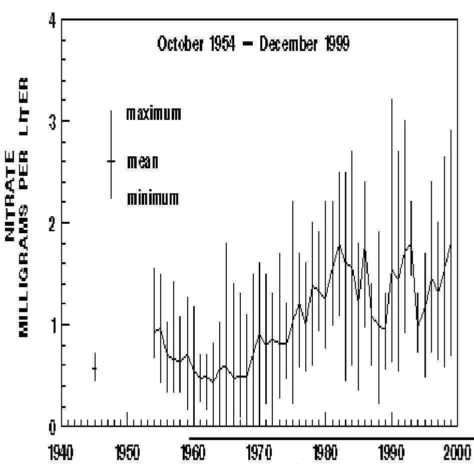
12 Howarth, R.W., G. Billen, D. Swaney, A. Townsend, N. Jaworski, K. Lajtha, J.A. Downing, R. Elmgren, N Caraco, T. Jordan, F. Berendse, J. Freney, V. Kudeyarov, P. Murdoch,and Z. Zhao-Liang. 1996. Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: Natural and

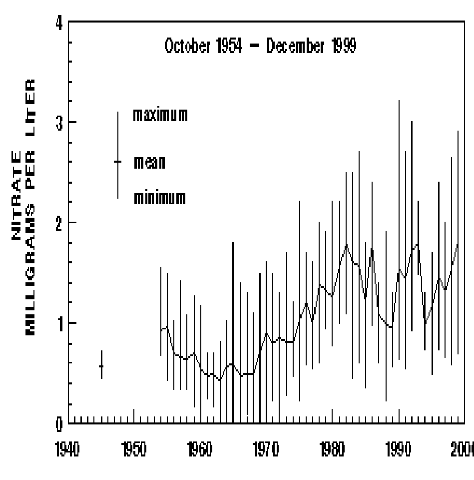
This estimate, which includes many people on septic systems in rural areas of the basin is 308,000 metric tons of N per year, is about 50% larger than the 1996 municipal point source estimate (201,000 metric tons) in the Topic 3 report. Thus, it would appear that on an annual basis, the municipal point source estimates used are reasonable. The short-term effects of potentially bypassing sewage plants during floods such as 1993 are unknown. Also, the effects of urban runoff from residential lawns, streets, etc. on nitrogen flux in the Mississippi River are unknown and needs further evaluation and analysis.

The potential effects of nitrogen releases from confined animal feeding operations during floods are also unknown. The IA considered the annual nitrogen contribution from all animals in the basin. The IA assumed that the animal wastes would be applied to the land surface, and that about half of the nitrogen would be volatilized into the atmosphere. The IA did not consider the effects of a large short-term input of nitrogen from lagoons and animal feeding operations directly into streams during floods. This needs further evaluation.









human influences. Biogeochemistry 35:75-139, pg. 95.

Figure 3. Observed and predicted annual flux of nitrate to the Gulf of Mexico from four regression models. (a) Nitrate flux predicted from mean annual discharge. (b) Nitrate flux predicted from annual fertilizer use two years in the past. (c) Nitrate flux predicted from nitrogen residual (inputs minus outputs) one year in the past. (d) Nitrate flux predicted with multiple regression model from mean annual discharge, fertilizer use two years past, and nitrogen residual one year past.

RESPONSE

The forgoing discussion presents a considerable amount of new information on nitrogen trends, flux, and sources that has become available since the draft IA was written. Some of this information was incorporated into the IA to better support statements and conclusions. Specifically, the information on changes in organic and total nitrogen concentrations since the beginning of the 20th century was incorporated into the IA. This included table 2 and the supporting discussion. Also, the 1999 nitrate concentration and flux data provides information relative to the large 1999 hypoxic zone and some of this was included in the IA. Finally, some of the regression model results showing the relation of nitrate flux to increased fertilizer use, streamflow, and the nitrogen residual were added.

CATEGORY #4: GULF HYPOXIC ZONE HISTORY

SUMMARY OF COMMENTS

Comments on the Six Topic Reports:
Comments were received from eight of the 34 commentors concerning the history of the hypoxic zone in the Gulf of Mexico (USDA, IL Gov, MO DNR, WI Dpts, TFI, IL Fert/ChemA, AmFarmBurF, KY FarmBurF).

Comments on Draft IA:
Comments on the hypoxic zone history were received from three of 16 individuals or organizations (Boesch, Rabalais, IL Gov).

Call for additional history
Several commentors stated that additional historical data are needed to analyze the extent and location of the hypoxic zone.

Hypoxia as a naturally occurring condition
Others questioned whether hypoxia existed historically or whether it is a naturally-occurring condition. One commentor suggested adding additional evidence to show that, although hypoxia occurred before 1900, oxygen stress has worsened since the 1950s.

Primary productivity in the Gulf of Mexico
One commentator stated that the history of primary productivity in the Gulf shows it to have decreased, not increased. This would indicate a reduction in nutrient flux to the Gulf. A few other commentors questioned the productivity calculations.

DISCUSSION

Call for additional history
Direct, regular and systematic measurements of the hypoxic zone began in 1985. Occasional direct measurements of hypoxia can be found from the 1970s. These are described in the Topic 1 report, pp. 95-96. Information about the extent and location of hypoxia prior to that time can be inferred from indications in sediment cores. Core profiles were collected in the eastern end of the hypoxic zone because the higher sedimentation rate in the vicinity of the mouth of the delta, as opposed to the rest of the hypoxic area, makes such analyses possible. The Topic 1 report, chapter 7, describes this information in detail, noting that, “These many, disparate data sources provide a description of ecosystem-level changes that have occurred in the northern Gulf of

Mexico." The IA summarizes this information, showing that the diversity of a family of tiny shelled organisms, ostracods, has decreased; abundance of a mineral, glauconite, formed under low-oxygen conditions has increased; and that the algal community composition, indicated by biologically-bound silica, has changed.

One commentor recognized that the longest record (from the 1700s, based on changes in benthic foraminiferan species at site G27) indicated substantial increase in oxygen stress but argued that the increase was between 1700 and 1920. The data plot (from Topic 1 report, figure 7.10) is reproduced below – a description of the increase shown in this plot as occurring between the 1700s and 1920 is a deceptive description. While the species distribution of benthic foraminiferan species may have changed slightly between 1850 and 1920, the rate of change increased dramatically between 1920 and today. Statistical analysis would not support a significant increase between 1700 and 1920. The commentor also notes that the record at site G50 shows decreasing oxygen stress. That is indeed the case. However, the commentor fails to note that station G50 is outside the zone of persistent hypoxia. The core at that site was collected as a control. The results there are not inconsistent, but in fact totally consistent, with understanding of the hypoxia phenomenon.

Figure 7.10. Changes in benthic foraminiferan species with stratigraphic depth in Pb-210 dated sediment cores from stations in the Mississippi River Blight. A line connecting 3-yr averages is superimposed on the data for C10. (Modified from Rabalais *et al.* 1996, Sen Gupta *et al.* 1996).

Hypoxia is a naturally occurring condition

Neither the IA nor the six reports present data substantiating that hypoxia did not exist historically – the evidence presented indicates that hypoxia and oxygen stress have increased substantially during the last century. Furthermore, neither the IA nor the six reports contend that the Gulf of Mexico is unique with respect to this problem -- there are both similarities and differences with other areas. The Gulf of Mexico is the largest zone of oxygen-depleted coastal waters in the U.S. and the entire western Atlantic Ocean. While hypoxia can occur naturally, and has existed throughout geologic time, its effects, indicated by sediment records, have increased over the past century.

More over, evidence strongly suggests that human activities have accelerated an increase in the extent and severity of hypoxia. The IA recognizes a number of potential contributing factors. Many of these factors, including organic loading from the River, channelization of the delta and loss of coastal wetlands, landscape changes in the basin, and even climate change, have been substantially affected by human activities. Among the potential factors contributing to Gulf hypoxia, only increased nutrient loads can account for the magnitude of the hypoxic zone and its increase over time in a non-contradictory manner. While other factors may contribute to the growth, dynamics, and decay of the hypoxic zone, none of them, alone, can explain its overall size and persistence.

Primary productivity in the Gulf of Mexico

The development of hypoxia is best explained by the eutrophication paradigm. According to this paradigm, organic matter increases in response to increased nutrient flux. In the case of the Gulf of Mexico, the increased supply of organic matter is primarily due to increased phytoplankton production. When the phytoplankton die, they sink to the bottom where their decomposition consumes oxygen faster than it is replenished from higher levels in the water column. Thus the increase in phytoplankton production contributes to hypoxia. One commentator, echoed by others, argued that this paradigm does not apply to the Gulf of Mexico because primary productivity in the Gulf has decreased, not increased. This is an erroneous interpretation of the data.

The very high primary productivity in the vicinity of the delta was not recognized and productivity data from that vicinity was inappropriately contrasted with values from the central portion of the hypoxic zone. Data from the 1950s produced by the National Science Foundation, the National Research Council, and the Scripps Institute of Oceanography, which one commentor felt were ignored, were, in fact, included in the Topic 1 report. Figure 6.1 from that report includes the 1950s data from Thomas and Simmons (1960). All the other data plotted are more recent and almost all indicate higher primary production.

This commentor incorrectly stated that a table included in the comments indicated "a world mean value of 365 g C/m^2/yr," when in fact it showed that only 13% of the world ocean exceeded 250 g C/m^2/yr (10% in the 250-500 range and 3% >500). This commentor referred to several SCOPE volumes alleging inconsistency with the six reports and the IA. In fact, the most recent SCOPE report[13] gives the following description for primary production in the Gulf of Mexico: "We used an average rate of 290 g C/m^2/yr for the Northern Gulf of Mexico which is what has been found on the shelf offshore of Barataria Bay (Sklar and Turner 1981). Flint and Rabalais (1981) reported a primary production value of 177 g C/m^2/yr for the shelf off of Texas. This value was used for the Southwest Gulf. Primary production off Western Florida is lower than that found in the Northern Gulf (Walsh 1983). In the absence of good data for this region, a primary production rate of 177 g C/m^2/yr was also used. When adjusted for area this gives an average of 215 g C/m^2/yr for the entire Gulf of Mexico." Schlesinger[14] estimates total marine primary production to be 51 x 10^{15} g C/yr based on mean production of 130 g C/m^2/yr in the open ocean, 250 g C/m^2/yr in the coastal zone and 420 g C/m^2/yr in the 0.1% of the ocean that it upwelling area. The most recent science report of the Intergovernmental Panel on Climate Change[15] estimates total marine primary productivity to be 50 x 10^{15} g C/yr. Primary productivity data were confused with other data on productivity. One commentor stated that, "According to the assessment reports, and consistent with literature, the rate of primary productivity on the continental shelf and in the hypoxic zone is 122 g C/m^2/yr." In fact, 122 g C/m^2/yr is a figure for total net carbon production in the upper water column at station C6*, not primary productivity (see page 83 of the Topic 1 report). Organic carbon, derived from primary production, is redistributed within the system, and eventually a fraction makes its way to the lower water column and sediments.

RESPONSE

<u>Call for additional history</u>
Additional contemporary and historical data would improve the predictability of the Gulf hypoxia phenomenon. The data currently available demonstrate that oxygen stress has increased substantially over the later part of the 20th century and that hypoxic conditions in the most

---

13 Howarth, Robert W. ed. 1996, Nitrogen Cycling in the North Atlantic Ocean and its Watershed, p. 246.

14 Schlesinger, William H. 1997, Biogeochemistry; An Analysis of Global Change, second edition, Academic Press, p. 302.

15 IPCC 1995, Climate Change 1995, J. T. Houghton et al. eds, Cambridge Press, p. 498.

recent annual survey affect an area off Louisiana shores that is larger than the state of New Jersey. The IA (executive summary) notes that, “A comprehensive, carefully targeted program of monitoring, modeling and research to facilitate continual improvement in scientific knowledge and management practices should be coupled to whatever initial nutrient management strategies are chosen.”

Hypoxia is a naturally occurring condition

The IA acknowledges that hypoxia can occur naturally, but evidence indicates that hypoxia and its effects have increased over the past century. Potential contributing factors have been analyzed in the research literature and in the process of developing the assessment. In response to public comments, a section on potential contributing factors was included in the IA and a meeting of scientific experts was convened to examine various possible causes. No natural phenomenon or phenomena, alone or in combination, can explain the overall size and persistence of the hypoxic zone.

Primary productivity in the Gulf of Mexico

Primary productivity is an important aspect of the eutrophication paradigm but it is an underlying parameter and not mentioned, per se, in the IA. The results presented in the IA (and the six reports) which are related to primary productivity data are correct. No changes were made to the IA on this point.

CATEGORY #5: INTERNATIONAL AND NATIONAL HYPOXIC ZONE COMPARISONS

SUMMARY OF COMMENTS

Comments on the Six Topic Reports:
Comments were received from 10 of the 34 commentors concerning comparisons made between the Gulf of Mexico hypoxia zone and other national and international geographic areas (IA Gov, CtrGlblFoodIssues, Wheelabrator, MO DNR, USDA, AmFarmBurF, KY FarmBur, TFI, MO DCon, LSUAgCtr).

Comments on the Draft IA:
Comments were received from four of the 16 commentors on the draft IA concerning support for findings in other national and international locations (AmFarmBurF, TFI, MO DNR, IL Gov)

Comparisons to international waters
The draft IA fails to provide support for similarities, or recognize dissimilarities, between the Gulf of Mexico and other international seas. Physical differences between the Gulf of Mexico and the Black Sea, Kattegat, Adriatic Sea, and the Sea of Japan preclude comparisons. One commentor agreed that documentation from other smaller seas shows that there is a loss of productivity in the hypoxic zone which ultimately will impact fisheries on a larger scale should hypoxia worsen. It was requested that fertilizer loads in international rivers be compared to those in the MARB. A commentor recommended including discussion on why the Gulf of Mexico rebounds ecologically each year while others worldwide do not.

Systematic examination of other domestic areas
Some commentors felt that comparisons to other areas along the Gulf of Mexico coast would add to our understanding of the factors contributing to hypoxia in the Gulf. It was asserted that the clearing up of Lake Erie was incorrectly attributed to nutrient input reductions when the primary cause was zebra mussels. Additionally, one commentor felt that the assessment incorrectly implies that hypoxia is a man-made problem and provides inadequate discussion recognizing that hypoxia naturally occurs in oceans.

Reaction to hypoxia in other areas
Specific actions taken in the other hypoxic areas should be discussed.

Comparison to worldwide fisheries
Causes of fishery declines worldwide should be compared with fisheries declines in the Gulf of Mexico.

DISCUSSION

The comparisons between the Gulf of Mexico hypoxic zone and other geographic locations around the world were intended to illustrate several of the key factors, both natural and anthropogenic, that drive hypoxic conditions in coastal areas. The intent was to focus on the coastal areas since the most severe hypoxic conditions in the Gulf of Mexico are primarily near the coast. The intent of the IA is neither to imply that all conditions are identical, nor that any similarities between two distinct geographic locations and physical systems necessarily demonstrate the same cause and effect relationships with regard to hypoxic conditions. By using the data and information available at the time the science reports were done, and addressing uncertainties with the existing data, the IA acknowledges what is learned from other systems and what examples have components which are applicable to the Gulf of Mexico.

<u>Comparisons to international waters</u>
Several commentors suggested there is a lack of evidence supporting comparisons to the Baltic, Adriatic, Black Seas, and the Kattegatt. Although the physical, enclosed nature of these waterbodies is different from the coastal Mississippi Atchafalaya River Plume (MARP), there are some similarities that need to be recognized. In all of these systems, freshwater outflow creates a salinity stratification which reduces the mixing capacity between the surface and bottom water. This stratification increases sensitivity to eutrophication-enhanced primary production and subsequent hypoxia. These systems are all suffering from excess nutrient enrichment and have experienced multiple primary and secondary symptoms of eutrophication including increased: algal blooms, chlorophyll *a* concentrations, and primary productivity. Depth distribution and species richness of macroalgae, water transparency, and depth penetration of *Fucus vesiculosus* (bladderwrack) have all decreased. Finally, there has been a reduction of bottom fauna and severe oxygen deficiency in the bottom waters of these systems.

More importantly, these systems are subject to many of the same nutrient sources as the MARB including inputs from agriculture and forest land and atmospheric deposition. In all of these systems, the primary nutrient inputs are human-related and land-based. These similarities make comparison to the Baltic, Adriatic, Black Seas and Kattegatt more valid than comparisons to many other coastal systems in the U.S. For example, the major nutrient source for many North Atlantic estuaries and coastal systems is from offshore coastal waters. Consequently, many of the eutrophic symptoms expressed in the region are thought to be primarily natural conditions, though they may be maintained or encouraged by land based sources. Similarly, the possible natural occurrence of hypoxia problems in the Gulf of Mexico has been exacerbated by human-related nutrient sources.

Encouragingly, studies indicate that efforts to reduce local eutrophication in most Baltic countries are likely to have important positive effects, even when reductions in discharges of nutrients are relatively insignificant in comparison to the total nutrient load. Further information on eutrophication in the Baltic Sea, the Kattegat, the Skagerrak, and the North Sea, including a discussion of the effects of declining water quality on fisheries, can be found in Ambio (May 1990, volume XIX number 3).

<u>Systematic examination of other areas along the Gulf Coast</u>
One commentor noted that a systematic examination of other areas along the Gulf Coast would add to our understanding of the factors contributing to hypoxia in the Gulf. Such an examination was conducted and is reported on in both the National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nation's Estuaries (1999) and NOAA's Estuarine Eutrophication Survey, Volume 4: Gulf of Mexico Region (1997). Information about chlorophyll *a*, epiphytes, macroalgae, oxygen, submerged aquatic vegetation coverage, and algal blooms was collected for 38 coastal areas extending from the Lower Laguna Madre to Florida Bay. Of all regions studied, the Gulf of Mexico has the greatest percentage of estuaries with high eutrophic conditions. While many factors influence the expression of eutrophication in Gulf estuaries, some characteristics are generally associated with higher levels of expression. These include: low tidal energy, low flushing rates with increased nutrient inputs, warm water, and a long algal growing season.

Some have suggested that these natural conditions favor hypoxia even in the absence of human influence. The National Estuarine Eutrophication Assessment explicitly addresses this observation by creating a matrix comparing eutrophic condition, overall human influence, and susceptibility. All of the 17 areas identified as highly eutrophic had high levels of human influence. Of those, only seven were classified as highly susceptible systems. This suggests that, while hypoxia can and does occur naturally, human influence plays a critical role in the frequency and extent of its expression.

<u>Reaction to hypoxia in other areas</u>
Commentors asked for information describing how other countries and regions have reacted to the hypoxia problem. In most cases, countries have responded to the problem only in the last decade and it is too soon after implementation of limitations to expect substantial results. However, some results are evident. By following what happens in these systems, we can modify our response to Gulf hypoxia. An evaluation of the Danish response to eutrophication describes the steps taken to limit nutrient inputs and the observable results to date[16]. This report states that it

16 The Danish Marine Environment: Has Action Improved its State? Conclusions and Perspectives of the Marine Research Programme HAV90. 1998. Peter Bondo Christensen (ed), F. Molenberg, L.C. Lund-Hansen, J. Borum, Ch. Christiansen, S.E. Larsen,. M.E. Hansen, J.Andersen, Jorn Kirkegaard. Havforskning fra Miljostyrelsen. Nr. 652. Ministry of Environment and Energy, Denmark. Danish Environmental Protection

will take 5 - 10 years to see noticeable improvements, an estimate in line with the lag time associated with observation of significant improvements in the Tampa Bay situation (see Tampa Bay National Estuary Program reports[17]).

<u>Comparison to worldwide fisheries</u>
Several commentors noted the lack of discussion comparing causes of fishery declines worldwide with the Gulf of Mexico. Documentation from smaller seas shows that there is a loss of productivity in the hypoxic zone which ultimately will impact fisheries on a larger scale should hypoxia worsen. A recent study quantified the effects of hypoxia on essential fish habitat in the western Gulf of Mexico. Habitat suitability index models were developed for the juvenile red snapper *Lutjanus campechanus* based on habitat factors including water temperature, salinity, and dissolved oxygen. Gallaway *et al.* [18] concluded that, "the step-like expansion of the hypoxic area...offshore of the mouth of the Mississippi River...has reduced habitat carrying capacity for juvenile red snapper in this region by up to 25%, averaging 19%. This environmental change may limit the level to which overfished Gulf red snapper stocks can be rebuilt to historical levels." Because this study directly addressed the potential for fishery declines in the Gulf of Mexico, additional comparisons to other systems were not made.

RESPONSE

In response to the concern that comparisons to Baltic, Adriatic, Black, and Kattegatt Seas were not appropriate, we added more descriptions of the differences among the waterbodies as noted in the references listed above while highlighting the similarities and lessons learned. In addition, the final IA clarifies the use of components of data from both national and international examples.

Agency. 120pp.

17 <http://www.tbep.org/baystate.html>

18 Gallaway, B.J., J.G. Cole, R. Meyer, and P. Roscigno. 1999. Delineation of essential habitat for juvenile red snapper in the northwestern Gulf of Mexico. Transactions of the American Fisheries Society 128: 713-726.

CATEGORY #6: NUTRIENT CONTROL PRACTICES

SUMMARY OF COMMENTS

Comments on the Six Topic Reports:
Comments on nutrient control practices were received from 28 of the 34 commentors (USEPA, USDA, IA Gov, LA Gov, WI Dpts, MWRDGC, LSUAgCtr, GulfResNet, TFI, PPI, ILFert/ChemA, AmFarmBurF, Agribank, MOCornGrowersA. CtrGlblFoodIssues, Wheelabrator, CFIndustries, LakePonBasinF, MSRiverPart, AminoAcidEdC, IlcornGrowersA, MO DCon, IAFarmBurF, NatCattleBeefA, KYFarmBurF, UMRBA, 3 soc)

Comments on the Draft IA:
Comments on nutrient control practices were received from seven of 16 commentors (NCR-195, AmFarmBurF, CleanWaterNet, NRDC, Rabalais, McCartney, and MO DNR).

Comments requested that the six reports and the IA place a stronger focus on a variety of additional nutrient controls, including voluntary and incentive-based programs, as well as public education, technical training, and research. Some commentors focused on analyses of 20% reduction in N use across the MARB and requested additional justification. A number of comments suggested that a complete suite of options for nutrient reductions were not sufficiently analyzed or appropriately presented and that there were errors in the analyses that were conducted. Included among these were:

<u>Predominant form of nutrient transport to the Mississippi River</u>
Some commentors said the relative importance of overland flow, ground water discharge, and tile drains in contributing nitrate to streams was under-represented. It was also noted that a decrease in fertilizer use has been coupled with an increase in tiling, thus resulting in a decoupling of any real success that might come from fertilizer management. Another commentor stated that input-output ratios show that controlling atmospheric deposition and manure use is more effective than controlling fertilizer.

<u>Relative role of Confined Animal Feeding Operations (CAFOs)</u>
Several commentors suggested that the contributions of CAFOs to nitrogen loading were incompletely discussed and need a more in-depth examination. They asked that the difference between feedlot runoff and manure management be clarified. One commentor expressed concern that the concentration of livestock into CAFOs is increasing. Others recommended that analysis of ammonia emissions, manure disposal, lagoon leakage, and lagoon failures be included in the IA.

Failure to fully evaluate the potential for improved nitrogen management in agriculture
Some commentors felt the IA inappropriately concluded that reductions in fertilizer applications have the greatest potential to reduce nitrogen loading to streams and rivers. Specifically, it was suggested that corn yields from insurance fertilizer applications are overestimated and that the positive impacts of whole farming systems are not strongly presented.

Altering flow distributions of the MS and Atchafalaya River outlets to reduce nutrient inputs
Some commentors stated that the IA was predetermined to target agricultural fertilizer use reductions and specifically ignores other options for reducing nutrient loading in the Gulf. One recommended that the IA consider altering flows to the Gulf through the MS and Atchafalaya River outlets as a means to reduce nitrogen loads. Re-plumbing the MS river would reduce nutrient delivery to the hypoxic zone by 33.9%. This commentor suggested that the hypothesis that flow-induced nutrient reductions would reduce hypoxia be tested by altering flow distributions into the Gulf of Mexico.

DISCUSSION

Predominant form of nutrient transport to the Mississippi River
Several commentors asserted that the IA did not fully address the relative importance of overland flow, ground water discharge, and tile drains in contributing nitrate to streams. The central point of these comments was that tiling has increased even as fertilizer use has decreased, thus resulting in a decoupling of any real success that might come from fertilizer management.

Environmental impacts for field-level changes, such as changes in rotations, tillages, fertilizer applications, or retirement from cropping were estimated based on Erosion Productivity Impact Calculator (EPIC) simulations. As explained in the Topic 6 report, appendix 3, the EPIC model does include both surface and sub-surface losses. The term “edge of field” refers to losses over the surface and through the root zone. However, as with any model, there are inherent limitations in EPIC - subsurface flow through tiles is not one of the 200 plus input parameters specifically accounted for. The IA acknowledges the contribution of subsurface drainage to nitrate loads in a separate bullet and notes that maintaining lateral spacing of at least 15 meters between subsurface tile drains minimizes excessive contribution of nitrate to streams.

One commentor stated that the scatter plots shown in the Topic 3 report, Figure 6.1, indicated that controlling atmospheric deposition of nitrate and the use of manure is the most effective way of controlling nitrogen yield. The statements appear to be based on a misunderstanding of these plots. Each of the plots shows total yield from a sub-basin vs. inputs to that sub-basin. Any input variable that was identical for all the basins would have a vertical slope and, by the commentor’s interpretation, would appear infinitely effective independent of how strongly it may be related to nitrogen yield.

Relative role of Confined Animal Feeding Operations (CAFOs)
The context of comments on the contributions of CAFOs to nitrogen loading were mixed with some calling for increased control on CAFOs and others pointing out that CAFOs are already under specific effluent permitting restrictions.

One commentor felt that the difference between feedlot runoff and manure management needed to be clarified and, that while better manure management is a good idea, it is not necessarily linked to feedlots. Feedlot runoff implies a discharge from an animal feedlot or housing area and typically reaches a stream or river via overland flow/runoff. Manure management is the best management practice (BMP) associated with land application of animal manure and often includes changing the rate, time, and method of manure application. The IA addresses the management of these nutrient sources and notes that nitrogen loading can be minimized by improved management of manure, including reducing losses from feedlots, and by limiting the application of fertilizer, including manure, to agronomically recommended rates. The management approach concerns the way manure is managed as well as the need for reducing overall use.

Multiple commentors noted that the concentration of livestock into CAFOs is increasing and one suggested the IA consider moving animals back out onto a large number of smaller farms as an alternative to using CAFOs. This suggestion would essentially represent one option for changing the dynamics associated with the distribution of waste from CAFOs -- eliminate CAFOs entirely and completely restructure the animal production system in the United States. While this option will be forwarded to the MR/GM Task Force for consideration as an option recommended by public comment, no analyses were provided to evaluate the validity of claims that redistribution of animals to smaller farms would indeed be more environmentally effective. Neither were analyses conducted to evaluate the potential impacts of such a large-scale change on community, regional and national economies and social infrastructure. Such detailed analyses would be essential before adopting such a policy change.

Several commentors recommended that the IA include analysis of ammonia emissions, manure disposal, lagoon leakage, and lagoon failures. Neither the Topic reports nor the IA focused in detail on the specific contributions of CAFOs or measures that might be taken to improve management. However, issues associated with animal waste are discussed in detail in appendix 1 of the Topic 6 report. CAFOs can contribute to nutrient pollution through their emissions of ammonia and the often excessive and concentrated application of manure onto the land. Nitrogen loss to the atmosphere is greatest when animal waste is exposed to the sun and/or air, as occurs in open lot and lagoon systems. Ammonia emissions are reduced when manure is stored in underground tanks, and application of manure to land incorporates nitrogen thereby reducing N loss to the atmosphere. While it is understood that leaks from pits and lagoons also contribute to water quality problems, the construction and maintenance of manure storage units was not the focus of analysis. The need for increased attention to manure application and storage were specifically noted in the IA.

Finally, CAFO issues are being examined under the EPA/USDA unified national strategy for animal feeding operations and the Task Force is encouraged to solicit further information from that effort in developing the Action Plan.

<u>Failure to fully evaluate the potential for improved nitrogen management in agriculture</u>

Several commentors considered the IA's identification of reductions in fertilizer applications as being a means with the "greatest estimated potential to reduce nitrogen sources to streams and rivers" to be an inappropriately-drawn conclusion. USDA's Economic Research Service (ERS) analyzed the economic and environmental effects of three strategies for reducing excess nitrogen releases into the Mississippi River basin: reducing nitrogen use, restoring wetlands, and combining wetland restoration with reduction in nitrogen use. The flat percentage fertilizer reduction scenarios used for model runs should not be viewed as absolutes, but rather as surrogates for the levels of effective nitrogen load reductions that might reasonably be obtained from improvements in nitrogen management within the MARB. As such, the IA now discusses improvements to nitrogen management as a broad category that will lead to load reductions to the Gulf. Using additional wetlands to accomplish the targeted reduction in nitrogen loadings would require restoration of five million acres of wetland, a net reduction of 1.3 million planted cropland acres in the MARB.

One commentor asserted that the large variability in edge-of-the-field nitrogen losses make it inappropriate to scale solutions from the entire basin to individual watersheds. Furthermore, drawing such conclusions ignores our lack of fundamental knowledge about the differences between nutrient processes at these scales. This comment is correct. If nutrients were more effectively managed to reflect the variation in environmental (soils, weather, topography, temperature, etc.) and other management decisions, it is likely that nutrient loads to surface waters and to the Gulf would be substantially reduced. Information presented in the IA already reflects improved management practices in the MARB.

Other commentors assert that estimates of corn yield from insurance fertilizer applications are far overestimated.   It was suggested that actual yield does not really increase between "good" and "bad" years due to many other limiting variables. Therefore, they caution that idealized scenarios for response to fertilizer applications are not appropriate as a basis of an Action Plan. These comments are correct and text has been added to the IA indicating that insurance fertilizer applications are a poor wager which most often leads to wasted nitrogen and increased loads to surface waters and the Gulf.   However, the percentage fertilizer reduction scenarios used for model runs were for the whole basin, and do include allowances for different use levels depending on crop grown, soils and climate within the basin. The results from the model are therefore effective at comparing overall, general approaches for achieving load reductions but cannot be used to make local recommendations for achieving the stated goal. It will take a site-by-site assessment of water quality goals (to achieve the overall goal) and the appropriate management actions to implement a policy most efficiently. Wording to this effect has been included in the IA.

Several commentors also propose that the Assessment fails to recognize that individual practices are bundled into whole farming systems and that it ignores studies demonstrating the positive impacts of whole farming systems, particularly organic farming systems, on pollution control. This comment will be forwarded to the MR/GM Task Force for consideration.

<u>Altering flow distributions of the MS and Atchafalaya River outlets to reduce nutrient inputs</u>
One commentor suggested a third approach for controlling hypoxia in the Gulf. Input of nutrient laden water to the Central Gulf could be reduced by altering flow distributions (year around or only during peak flows) at Old River (the location where the Atchafalaya River distributary diverges from the Mississippi river mainstem and where the Red River flows into the Atchafalaya River). This could be accomplished by passing increased flows down the MS River mainstem and reduced flows down the Atchafalaya (except during the largest floods).

As noted in the comments, flow distribution has been set by Congress and would require legislative action to change. Under current operations, the flow distribution at the latitude of Old River is maintained at 70/30 on an annual basis (with an effort made to maintain daily flow distribution near 70/30). Thirty percent of flow passing down the Atchafalaya River into the Gulf is made up of the combined flows of the Red River and the MS River. The proportion of flow entering the Atchafalaya river from the MS River varies depending on the magnitude of flow in the Red River. During most of the year, the majority of flows passing from the MS River into the Atchafalaya river, do so after passing through the Old River hydropower plant.

However, in an effort to consider a wide range of options for reducing the extent and severity of hypoxic conditions, altering flow distributions was discussed briefly in the December 3, 1999 Science Workshop. The general consensus was that such changes in flow distribution would have multiple consequences, not all of which are known. Preliminary work by the USACOE identified potential impacts of modifying flow distributions to put more flow down the mainstem MS river including its effect on:

- water and sediment distribution at the Old River Complex, and thus the Mississippi River and Tributaries (MR&T) Project which provides for flood control downstream of Old River;

- frequency of operation of the Bonnet Carre Spillway with its associated impacts to the Lake Ponchartrain estuarine system near New Orleans;
- shoaling of the mainstem Mississippi River navigation project;
- the ability of the flood control channel in the Atchafalya to carry the design flow for the flood project;
- the need to raise levees along the Mississippi River to pass more flow; and
- the hydropower plant at Old River and the Teche-Vermilion Freshwater Diversion project's ability to serve their customers.

Ecologically, the following are likely to be affected by alterations in flow distribution at Old River so as to reduce flows into the Atchafalaya Basin floodway system:

- cypress forest growth and distribution in the lower Atchafalaya
- distribution of bottomland hardwood forest species
- sedimentation rates of water bodies in lower floodway
- productivity of saltwater and freshwater fisheries
- crawfish production
- fur-animal harvest
- pallid sturgeon (Federally listed endangered species found in the Atchafalaya River at Old River)
- habitat/resources in lower Atchafalaya Basin
- nutrient removal during overflow periods
- hydropower operation which could affect the demand for coal-burning for power.

Additionally, there is no guarantee that diverting nutrients into deeper water would significantly change hypoxia. Even if Mississippi River flows were closed off, Red River flows would continue down the Atchafalaya River. As such, any nutrients in those flows would still flow into the hypoxia zone. An analysis comparing the amount and types of nutrients provided by the
Mississippi River and Red River to the Atchafalaya Basin is needed to determine how Red River flows might continue to contribute to the creation of the hypoxic zone in the Gulf.

RESPONSE

Predominant form of nutrient transport to the Mississippi River

The IA acknowledges the contribution of subsurface drainage to nitrate loads and notes that maintaining lateral spacing of at least 15 meters between subsurface tile drains avoids excessive contribution of nitrate to streams. The term “edge of field” refers to losses over the surface and through the root zone. A footnote in the IA clarifies that estimated edge-of-field source reductions do not account for denitrification between the field edge and major rivers and, therefore, do not translate to equivalent reductions in nitrogen loadings in the Gulf. Finally, the significance of seasonal variability to surface or overland runoff has been put into better perspective by adding the caveat “under some conditions.”

Relative role of Confined Animal Feeding Operations (CAFOs)

The wording in the IA was changed to reflect the difference between feedlot runoff and manure management. The bullet that formerly began with "decrease feedlot runoff" was rephrased and merged with the bullet beginning "improved nitrogen management techniques.” That bullet, in part, now reads “...improving management practices for storage and land application of manure, improving management of runoff from feedlots...” Suggestions for alternate management of CAFOs will be forwarded to the Task Force for consideration. A photograph of a CAFO was added to the IA.

Failure to fully evaluate the potential for improved nitrogen management in agriculture

Information presented in the IA already reflects improved management practices in the MARB. Nutrient loads to surface waters and to the Gulf are substantially reduced when management practices reflect the variation in environmental variables (soils, weather, topography, temperature, etc.). Likewise, the EPIC model, which was used to evaluate the economic and environmental effects of three strategies for reducing excess nitrogen releases into the Mississippi River basin, takes environmental variation into account. It will take a site-by-site assessment of water quality goals and the appropriate management actions in order to implement a policy most efficiently.

The opening section of Chapter 5 was amended to include the following statement: “The model results report the broad economic consequences of meeting a water quality goal, and are useful for comparing broad policy options. The model results cannot be used to make actual policy recommendations for any particular area in the basin. Any program for reducing nitrogen losses to the Gulf of Mexico should consider local hydrologic conditions and the characteristics of agricultural production, the resource base, and producers.”

Altering flow distributions of the MS and Atchafalaya River outlets to reduce nutrient inputs

The IA states that there are many options for reducing nutrient loads to the Gulf, but that research, education, and enhanced partnerships in the agricultural sector are likely to offer the least-cost alternatives. The need for any Action Plan to consider approaches to nutrient load reductions that will distribute the costs and benefits equitably among all stakeholders in the MARB is emphasized. In addition, the IA was amended to note the proposal to divert nutrient laden waters away from the heart of the hypoxic zone to areas that are not currently affected by hypoxia.

CATEGORY #7: ADAPTIVE MANAGEMENT, MONITORING, AND RESEARCH

SUMMARY OF COMMENTS

Comments on the Six Topic Reports:
Comments on adaptive management, monitoring, and research were received from 11 of the 34 commentors on the six Topic reports (USEPA, USDA, IA Gov, LA Gov, WI Dpts, MWRDGC, GulfResNet, Agribank, MSRivPart, MO DCon, 3 soc).

Comments on the Draft IA:
Comments were received from five of the 16 commentors on the IA Report (NCR-195, Rabalais, 15 AgOrgs, TFI, CleanWaterNet)

Comments addressed the following areas:

Uncertainties require more research before action is taken
There was universal support for adaptive management, monitoring, and research.
The need for adaptive management because of the complexity of the hypoxia problem, and the implications of "substantial time lags" between management action and measured response were recognized.

Priorities
Several commentors expressed support of the scope and prioritization of the research needs. Commentors called for more monitoring throughout the MARB to better document sources, the nature of the problem, and to document changes in nutrient flux as better management practices are implemented. Commentors also supported the need for additional research regarding nutrient management, the effects of nutrient enrichment, Mississippi River management, and channelization.

Implementation
Several commentors stressed that it is imperative that state and federal agencies follow up on this science assessment with an Action Plan to address the root causes of nitrogen pollution in the MARB. It is critical that research needs identified in the reports be incorporated in agency budget priorities and funded fully by Congress. One commentor suggested that research be conducted by universities, USGS, EPA, NOAA, USDA, and other groups having a sufficiently broad constituency to provide a basis for national and regional policy actions. Some noted that significant actions are already underway through existing USDA conservation, restoration and water-quality improvement programs. Furthermore, it was recommended that the IA include

private sector water quality improvement programs with similar goals to the federal programs. This would encourage future actions to be built on both private and public efforts.

DISCUSSION

Uncertainties require more research before action is taken

The hypoxia problem is complex and incompletely understood. The CENR science assessment process drew on a massive amount of direct and indirect evidence collected and reported over many years of scientific inquiry. The rigorous technical peer-review process that the six Topic reports underwent assures that the information they contain is well founded and grounded in available research and monitoring data, and that they provide a suitable basis for development of an Action Plan. The process for public comment on both the six Topic reports, and the IA, improved the summary provided in the IA report and particularly improved communication of the limitations and usefulness of the scientific information in the reports and communication of research, monitoring and management needs.

While the limitations of available information are acknowledged, there is strong consensus among the scientific community that the information in the Topic reports and the IA provides a sound basis for development of an Action Plan. At the same time, care should be taken that an Action Plan not move beyond the limitations of available information. Any Action Plan should integrate a sound monitoring and research plan into an adaptive management framework, enabling management strategies to evolve as new knowledge is gained. Furthermore, monitoring and research for a system as large and complex as the MARB and the northern Gulf of Mexico, should be integrated using holistic models that represent our understanding of how the overall system functions and how management practices can best be implemented.

Priorities

Knowledge gaps and the importance of research and monitoring were emphasized by many commentors, both through endorsement of research and monitoring needs presented in the science assessment reports and through suggestion of specific needs:

- quantify the effects of practices and measures taken to reduce nutrient loss from agricultural lands;
- define the relationship between fertilizer use, soil nitrogen, mineralization, crop rotations, and movement of nitrogen from fields to streams;
- monitor the extent, severity and impacts of Gulf hypoxia on commercial and non-commercial resources in the Gulf of Mexico;
- quantify natural nitrogen sources and sinks including nitrogen consumption of shallow coastal wetlands and river diversions, the role of suspended organics in River effluent, in-stream nitrogen losses; atmospheric nitrogen pathways; quantity and quality modeling of

changes in flood flows to channel modifications, coastal wetland diversions, and wetland storage;

- model fisheries dynamics, effects of climate change, land loss and carbon reduction, the trophic response of decreased nutrient loading
- continue examination of the historical extent of hypoxia and historical nutrient, sediment and water fluxes; and
- monitor contributions to water quality impairments by confined animal feedlot operations.

These research and monitoring needs are acknowledged as important.

Implementation

An important and common comment was that any Action Plan, including the research and monitoring components, must be incorporated into appropriate federal budget priorities and sufficient funding must be appropriated by the Congress.

Research and monitoring should be conducted by scientists representing the federal, state, tribal, and local governments, universities, industry, and other private organizations already integrally involved in gathering scientific information on this problem, or who can contribute significant scientific expertise. This will maintain continuity of existing monitoring, coordination, and expertise; as well as provide new scientific perspectives. There is an essential need to assure that monitoring and research results are objective and of high scientific quality. Essential to achieving these goals is formal coordination and integration of monitoring, research, and management activities, including integrated data-management, interpretation, and information-sharing activities.

Significant management activities for conservation, restoration, and water-quality improvement are already being implemented by federal, state, tribal, and local governments, industry and private organizations. All such existing activities should be considered during development of an Action Plan. The effects of many of these activities may not as yet be observed in available monitoring data. Any research and monitoring conducted as part of an Action Plan should emphasize determination of the cause-and-effect relationship between specific historic and proposed management actions and the corresponding improvements in water quality. Such knowledge will improve design of the Action Plan, enable successful adaptive-management practices, and enable achievement of the primary goal – to establish and maintain acceptable water-quality conditions and healthy social and economic conditions throughout the MARB and northern Gulf of Mexico. In the spirit of a “win-win” approach to Action Plan design, potential ancillary benefits of management actions as well as potential adverse effects should be identified.

RESPONSE

The comments itemized above were used to modify the IA report. In general, the modifications are reflected in the language provided above in the Discussion section. Specific comments recommending additional research, monitoring, and management actions were incorporated, in a general way, in the summary of research needs provided in the IA report and also will be forwarded to the Task Force. The Task Force is encouraged to ensure that an important part of the Action Plan provides support for research and monitoring needs and that these are well integrated in an adaptive management framework. A cooperative coordinated effort involving federal agencies, state, local, and tribal governments, and other stakeholders, may be most effective.

CATEGORY #8: MODELING OF MANAGEMENT OPTIONS AND IMPACTS

SUMMARY OF MAJOR COMMENTS

Comments on the Six Topic Reports:
Comments were received from 19 of the 34 commentors on the six Topic reports (USEPA, IL Gov, IA Gov, LA Gov, IL FarmBur, MO DNR, WI Dpts, LSU AgCtr, GulfResNet, TFI, PPI, ILFert/ChemA, AmFarmBurF, MOCornGrowersA, CtrGlblFoodIssues, Wheelabrator, Ecolaw, MS RiverPart, KY FarmBurFed).

Comments on the Draft IA:
Comments on management options were received from seven of 16 commentors (NCR-195, AmFarmBurF, CleanWaterNet, NRDC, Rabalais, McCartney, and MO DNR).

Comments noted that the topic reports (primarily the Topic 2 report) do not provide substantial scientific conclusions that hypoxia impacts Gulf fisheries. In addition, several comments questioned the economic models used in the Topic 6 report.

A number of comments suggested that a complete suite of options for nutrient reductions were not appropriately presented or sufficiently analyzed. Several commentors felt that there were errors in the analyses that were conducted. Particular comments were directed toward the agricultural models and fisheries analyses:

Agricultural modeling
Some commentors contended that the IA does not adequately consider the full suite of actions to reduce hypoxia. Other commentors suggested that the IA does not give a balanced presentation of the analyses conducted in individual topic reports. Some commentors argued that assumptions made in modeling the costs and benefits of nitrogen reductions, including through fertilizer taxes, were erroneous. Commentors expressed the view that the IA does not show the complete effect of fertilizer reduction (since the model does not anticipate the buffering of any price changes that would result from a decrease in MARB productivity relative to the rest of the world). A concern was also raised that no mention was made in the IA of potential impact to rural communities. Other comments (as discussed under “Nutrient Controls,” response category #6) pointed to the limited spatial resolution and lack of direct representation of tile drainage in the models used.

Fisheries analyses
Some commentors asserted that the results of economic analyses which did not demonstrate statistically significant effects due to hypoxia were under-emphasized while others argued that it is more accurate to state that adequate data do not exist (or have not been analyzed) to determine

relationships between hypoxia and shrimp catch. One commentator questioned the wisdom of using either the landings data or CPUE (catch per unit effort) to estimate economic impacts. Commentators also requested that the IA state a clear-cut negative economic impact on shrimp fisheries resulting from east-west migration.

DISCUSSION

Agricultural modeling

The effects of government commodity programs and environmental policies on the US agriculture sector and the environment, including economic costs and benefits associated with nitrogen reductions in the MARB, were analyzed primarily by using the United States Mathematical Programming Model for Agriculture (USMP) developed by the Economic Research Service, USDA. The model predicts how producers will alter production practices (land use, fertilizer application rates, crop rotations, and tillage practices) in response to restrictions or changes in economic incentives. It then estimates how these changes in production practices affect supply and demand for crops and live stock, commodity prices, farm income, and nutrient losses to the environment from soil erosion and nitrogen releases.

Economic data needed to estimate costs to water users and to the environment from nitrogen in rivers, lakes, and streams are not currently available. The IA describes and accounts for some environmental benefits related to nutrient reduction within the drainage basin. The economic assessment does include economic benefits from reduced soil erosion and from increased wetland habitat for wildlife. The IA does not estimate drinking water benefits, benefits to enhanced recreation, or benefits from enhanced flood control.

While the USMP was the primary model used, results from other models were also presented in the six topic reports. One commentor asserted that the IA does not give a balanced presentation of this information, particularly by ignoring information presented in Table 3.3 of the Topic 4 report (based on the HUMUS model), which suggests that the proposed reductions in nitrogen fertilizer applications would result in 56% of the farmers in the MARB losing profits. It should be noted that this table also shows that the welfare of crop producers in the Basin would increase by 1.71%. The table shows edge-of-field N-loss reductions of between 5.4 and 7.7% (weighted for the basin). The modeling in Chapter 6 assumes a goal of 20% N loss reduction, so the adjustments are much more severe than those reported in table 3.3. However, the relative results are consistent with those reported in Chapter 6 (and table 5.3 of the IA). The only difference is that the USMP model cannot estimate the number of producers who lose income. Such information would be useful, but impacts on individual producers cannot be ascertained by either model. It would not be appropriate to draw conclusions regarding individual farmers' performance from such statistics.

Some commentors stated that assumptions about costs and benefits led to erroneous conclusions, particularly about the impact of fertilizer taxes. Empirical evidence from many studies of fertilizer demand show that the demand for nitrogen fertilizer is very inelastic[19] [20], meaning that significant increases in price are necessary to reduce application rates, particularly for the large reductions required in the USMP model to achieve the N-loss reduction goal of 20%. The finding that a 500% tax would be necessary to achieve the 45% reduction in fertilizer that achieves the N-loss goal is consistent with the literature. The IA also reports that, due to its impact on producers, the tax is inefficient compared to other approaches. Other tax approaches suggested by commentators, such as on fall-applied nitrogen, were not considered due to the severe negative impacts of these approaches on producers.

One commentor estimated that the 20% and 45% fertilizer reduction scenarios would result in yield reductions of 1.2 billion bushels of corn in the MARB. This commentor has conducted an inappropriate calculation by taking the total welfare cost from the model and using it to arrive at an estimate of an "implied" reduction in yield that is huge. This would assume that the welfare costs are borne entirely by producers, and that crop prices remain the same. In reality, the costs are borne by consumers (net income to producers actually rises). Second, there is a substantial increase in crop prices, which is why producers benefit. Both these facts are stated in the IA.

The comment that world grain markets would buffer any increase in prices is incorrect. The USMP model does include imports and exports, and the prices reported are world prices. World grain suppliers cannot replace a sudden reduction in U.S. supplies. There is not that much cushion out there.

The economic model used in the assessment does not estimate impacts on rural economies. The Task Force is encouraged to consider impacts on rural economies when developing the Action Plan.

Fisheries analyses

While it is true that the economic assessment in the Topic 2 report based on fisheries data did not detect effects attributable to hypoxia (i.e. the correlation between the extrapolated time series and fisheries data were below levels usually considered statistically significant), failure to identify hypoxic effects does not necessarily mean that they are absent, only that the data available for analysis were inadequate to identify the reasons for variability. The authors of the Topic 2

---

19 Fernandez-Cornejo, J. 1993. "Demand and Substitution of Agricultural Inputs in the Central Corn Belt States." Technical bulletin 1816. U.S. Dept. of Agriculture, Economic Research Service, February.

20 Vrooman, H. and B. Larson. 1991. "A Direct Approach for Estimating Nitrogen, Phosphorus, and Land Demands at the Regional Level." Technical Bulletin 1786. U.S. Dept. of Agricultural, Economic Research Service. March.

report sought to examine the relationship between the estimates of the hypoxic zone area and available fisheries data, primarily on the two main shrimp species in the Gulf because they are part of the benthic community and are commercially important. However, as stated in the IA, since data on the area of the hypoxic zone are only single annual estimates and not available before 1985, the time series was judged too short to establish a credible relationship, and the analysis resorted to an extrapolation back to 1960 (see the Topic 2 report, pp. 19-20, for details).

One commentor questioned the rational of using either landings data or CPUE to estimate economic impacts. While there are problems associated with CPUE as an estimate of economic impacts, it is the best tool currently available. The high variability of CPUE data is acknowledged in the Topic 4 report. Matching that highly variable data to the very short time series available for estimates of the hypoxic area (13 or 14 annual data points) would seem likely to uncover only a catastrophic s effect. The Topic 4 report (pp 38-44) also notes that, despite the insensitivity of the analysis, and in the absence of a model which could reliably explain the variations in CPUE from technology, management, etc., there is ufficient hint of a relationship between hypoxia and CPUE that it cannot be dismissed. If those variations were removed, the effect of hypoxia would likely be clearer.

Commentors also requested that the IA state a clear-cut negative economic impact on shrimp fisheries resulting from east-west migration. Data necessary to evaluate relationships between hypoxia and shrimp catch either do not exist or have not yet been analyzed. Because of this, the studies assessing the economic impact on shrimp fisheries have been equivocal. While the assessment acknowledges the equivocal nature of the findings, it is important to remember that the absence of a more dramatic relationship is not surprising. As stated earlier, the fact that a relationship was not found is not evidence that no relationship exists. Selecting other information (such as oyster harvest from estuaries, not the hypoxic zone) and mixing it with less-than-careful statements about findings from economic analyses, as was done by one commentor, creates a misleading picture. It is more accurate to admit that adequate data do not exist (or have not yet been analyzed) to determine relationships between hypoxia and shrimp catch.

RESPONSE

The agricultural sector's response to management strategies was simulated with USMP. The model predicts both the economic effects and the changes in nitrogen loading under the various scenarios examined. When environmental impacts for field-level changes were estimated in USMP based on EPIC simulations, over 700 data input files were available (see Topic 6 report, Appendix 3 for a discussion of EPIC). One of the primary strengths of this approach is the integration of physical, biological, and economic processes in a systematic modeling framework.

As with any model, there are inherent limitations in the application of USMP, and the outputs are only as good as the data parameters put in. The IA acknowledges that costs and benefits of a program to reduce nitrogen loadings to the Gulf are difficult to quantify, and includes suggestions for monitoring and research to reduce the uncertainties associated with the analysis. The need to better quantify and understand the economics associated with current and proposed policies to reduce nitrogen loss is identified as a research priority by the IA. Furthermore, the need for research exploring a broader range of ecological impacts, including potential impacts to biodiversity and to nonmarket-valued ecosystem goods and services is recognized. While research on impacts to rural communities is not explicitly addressed in the IA, the Task Force is encouraged to give full consideration to that concern in developing the Action Plan.

Likewise, the IA documents the immediate need for research to better define the ecological effects of hypoxia. Collection of ecological, production and economic information related to fishery and nonfishery species must be improved. Current and historical data need to be carefully analyzed to more clearly identify the sources of variability.

The research and monitoring needs identified in the IA are presented in a modeling context. The most effective adaptive management will rest substantially on holistic, integrated models with predictive capability much improved over what is available today.
In response to these public comments, the final version of the IA was modified to more clearly state that the analysis of approaches for reducing nutrient loads was based primarily on models and to note the limitations of those models. The IA states that the model results cannot be used to make actual policy recommendations for any particular area in the Basin. Descriptions of the results of fisheries analysis and agricultural modeling in the executive summary have been simplified to reduce the possibility of readers misunderstanding the significance of those findings.

APPENDIX

Commentors on Six Topic Reports:

Agribank – Agribank
American Farm Bureau Federation – AmFarmBurF
American Rivers – AmRiv
American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America – 3 soc
Amino Acid Education Council – AminoAcidEC
Center for Global Food Issues – CtrGlblFoodIssues
CF Industries, Inc. – CF Iindustries
EcoLaw Institute, Inc. – EcoLaw
Gulf Restoration Network *et al.* – GulfResN
Illinois Association of Drainage Districts – IL AssnDrainageDistricts
Illinois Corn Growers Association – IL CornGrowersA
Illinois Farm Bureau – IL FarmBur
Illinois Fertilizer & Chemical Association – IL Fert/ChemA
Illinois Governor George H. Ryan – IL Gov
Iowa Farm Bureau Federation – IA FarmBurF
Iowa Governor Thomas J. Vilsack – IA Gov
Irma Wallin – Wallin
Kentucky Farm Bureau Federation – KY FarmBurF
Lake Ponchartrain Basin Foundation – LakePonBasinF
Louisiana Governor M. J. "Mike" Foster, Jr. – LA Gov
Louisiana State University Agricultural Center – LSU AgCtr
Metropolitan Water Reclamation District of Greater Chicago – MWRDGC
Mississippi Riverwise Partnership – MS RiverPart
Missouri Corn Growers Association – MO CornGrowersA
Missouri Department of Conservation – MO DCon
Missouri Department of Natural Resources – MO DNR
National Cattlemen's Beef Association -- NatCattleBeefA
Potash and Phosphate Institute – PPI
The Fertilizer Institute – TFI
U.S. Department of Agriculture – USDA
U.S. Environmental Protection Agency – USEPA
Wheelabrator Water Technologies, Inc. – Wheelabrator
Wisconsin Departments of Agriculture, Trade and Consumer Protection and Natural Resources – WI Dpts
Upper Mississippi River Basin Association – UMRBA

Commentors on draft IA:

15 Agricultural Organizations – 15 AgOrgs
American Farm Bureau Federation – AmFarmBurF
Boesch, Dr. Donald – Boesch
Clean Water Network – CleanWaterNet
Goolsby, Dr. Donald – Goolsby
Illinois Governor George H. Ryan – IL Gov
Louisiana State University Agricultural Center – LSU AgCtr
McCartney, Dr. David – McCartney
Missouri Department of Natural Resources – MO DNR
National Corn Growers Association – NatCornGrowersA
Natural Resources Defense Council – NRDC
NCR-195 Regional Committee – NCR-195
Rabalais, Dr. Nancy – Rabalais
The Fertilizer Institute – TFI
Upper Mississippi River Basin Association – UMRBA
Wisconsin Departments of Natural Resources and Agriculture, Trade and Consumer Protection – WI Dpts