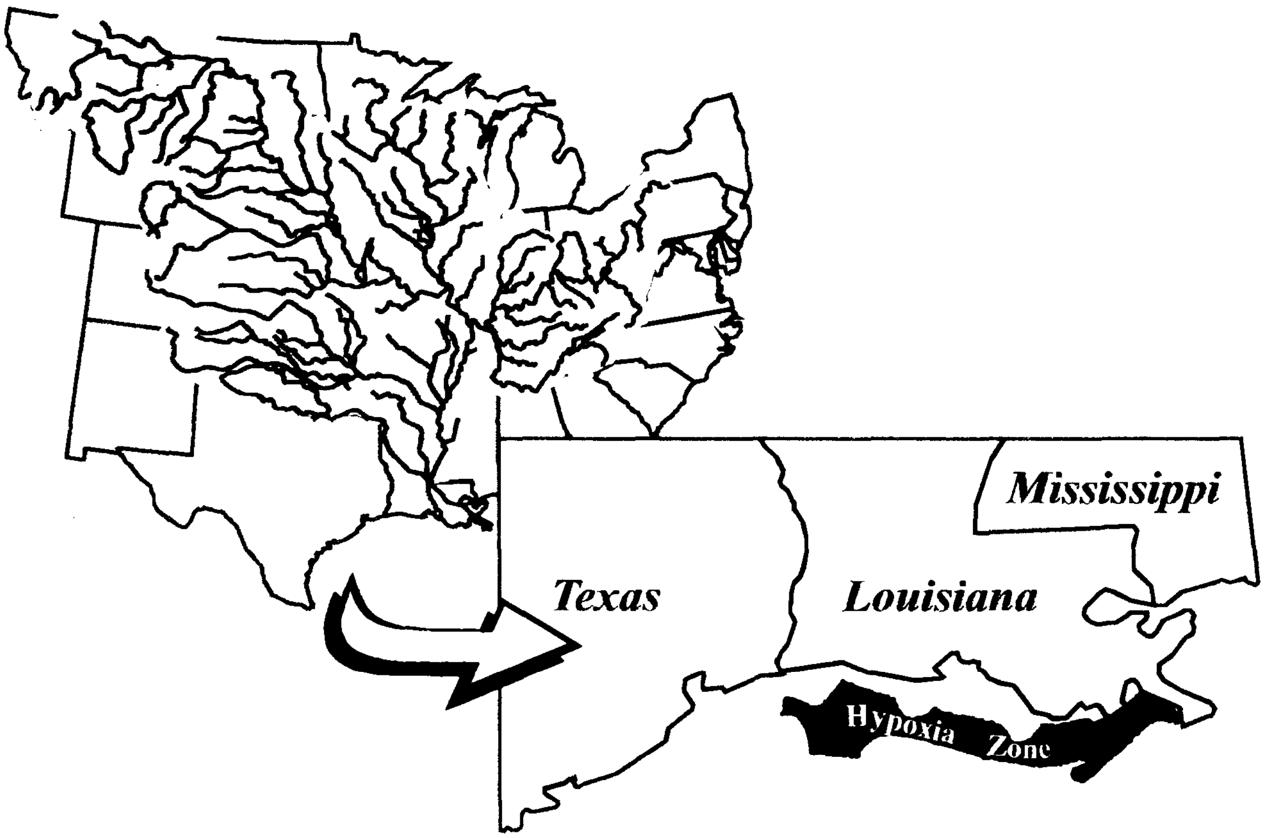
Workshop on Solutions and Approaches for Alleviating Hypoxia in the Gulf of Mexico
February 18, 1998



NWRC Special Report 98-02

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Workshop on Solutions and Approaches for Alleviating Hypoxia in the Gulf of Mexico February 18, 1998

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Suggested ***citation.***

Cordes, C. L., and B. A. Vairin, Editors. 1998. Workshop on solutions and approaches for alleviating hypoxia in the Gulf of Mexico. NWRC Special Report 98-02, U.S. Geological Survey, Biological Resources Division, National Wetlands Research Center, Lafayette, Louisiana. iii + 53 pp.

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Summary

A growing problem in the Gulf of Mexico is the eutrophication that results from excessive nutrient flux from the Mississippi and Atchafalaya Rivers. A result of this nutrient over enrichment is a reduction in dissolved oxygen in the lower water column and bottom waters. Hypoxic conditions (where dissolved oxygen is less than 2 parts per million) result and cover an area of approximately 7,000 square miles of seabed off the Louisiana coast. The "Dead Zone," so called because fish, shrimp, and crabs cannot be caught there, poses a threat to the long-term fishery productive capacity of the Gulf of Mexico.

Fortunately, steps are being taken to deal with the gulf hypoxia issue. The U.S. Environmental Protection Agency, through its cooperative Gulf of Mexico Program, leads a cadre of Federal, State, and nongovernmental agencies and organizations in reducing excess nutrient flows into gulf waters. The U.S. Geological Survey is part of this cadre and has assembled a database related to the monitoring of nutrient levels in the Mississippi River.

Scientists and managers alike agree that the hypoxia problem cannot be solved immediately. There is general agreement, however, that actions taken now should demonstrate that there are means for reducing nutrient loading within the Mississippi River Basin and other coastal rivers whose catchments increasingly suffer from urbanization and eutrophication.

A workshop held at the USGS National Wetlands Research Center on February 18, 1998, identified 13 strategies and/or measures that should be considered for nutrient abatement in the Lower Mississippi River Valley and coastal Louisiana. Some of these actions were evaluated to be more feasible to implement than others, but all of the strategies identified in this workshop were considered to be reasonable approaches for addressing the hypoxia problem in the gulf. The workshop was attended by 35 participants from the Federal and State governments, academia, and private sector. U.S. Senator John Breaux (LA) gave a briefing to participants in which he reaffirmed his commitment to take action on addressing the issue of hypoxia in the Gulf of Mexico.

Introduction

For 20 years, scientists have been reporting on the so-called "Dead Zone" in the Gulf of Mexico along the Louisiana and upper Texas coasts. Recent investigations focused on the very large size of the zone, 7,000 square miles of the gulf with oxygen levels too low (less than 2 parts per million) to support most marine life such as fish, shrimp, crabs and the resources that support them. The primary cause of this phenomenon is the flow of increased nutrients down the Mississippi River into the Gulf of Mexico. To address the hypoxia problem, the U.S. Geological Survey (USGS), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), National Oceanic and Atmospheric Administration (NOAA), and other Federal agencies, as well as the states within the Mississippi River corridor and along the gulf coast, and private conservation organizations, are planning research and management efforts.

The National Wetlands Research Center organized and hosted the facilitated workshop in Lafayette to obtain a broader perspective on the hypoxia issue, to establish relationships with other agencies and organizations concerned with this problem, and to identify strategies or measures to solve the hypoxia problem in the gulf.

Purpose of Workshop

The purpose of the workshop was to identify strategies that could be implemented over the next 5 years and tested on a demonstration basis to reduce nutrient flows into the Mississippi River system and/or Gulf of Mexico. This 5-year target is artificial, but it is intended to keep the focus on implementing actions to reduce nutrient loading in the Lower Mississippi River Valley. The workshop was accomplished by bringing together scientists, resource managers, agricultural specialists, and others familiar with the hypoxia problem. U.S. Senator John Breaux addressed the workshop, expressing deep concern about the hypoxia issue and urging attendees to bring solutions to the table (see Appendix A, List of Attendees).

Workshop Process

Meeting facilitators led a general discussion about the assumptions for the workshop (Appendix B, Agenda). All participants agreed that hypoxia is an important problem and wanted to work together in this workshop to identify solutions. Participants also agreed that the focus should be on a broad outline for alleviating hypoxia in the gulf, not on the technical details related to how solutions would be implemented (Appendix C). Participants further requested that any new programs or projects for hypoxia should be integrated with existing programs, especially with those identified with the Committee on Environmental and Natural Resources (CENR).

The workshop was divided into two parts. The first part included background presentations on hypoxia and the identification of strategies for mitigating the problem of excessive nutrient flows to the gulf. The second part of the workshop involved breakout groups charged with evaluating each of the identified strategies.

Background Presentations

A series of presentations by representatives of the USEPA, USGS, NRCS, Louisiana Universities Marine Consortium (LUMCON), and the State of Louisiana provided workshop participants with background information on the hypoxia problem and actions underway to address this problem in the Gulf of Mexico and on a national scale.

Bryon Griffith (USEPA Gulf of Mexico Program) and Nancy Rabalais (LUMCON) provided an overview of hypoxia and its effects on natural resources in the Gulf of Mexico. These speakers also presented information on the importance of the Gulf of Mexico Program (a multi-agency and constituent organization) in coordinating research and management activities in the gulf. These speakers identified the Gulf of Mexico Program's Nutrient Enrichment Focus Team as being the primary focus group for hypoxia in the gulf. The team was further identified to be primarily responsible for research assessments in the following areas related to the hypoxia problem: characterization, ecological effects and economic consequences, sources of and loading amounts from nutrients, effects of reducing nutrient loads, potential of demonstration projects, and methods to control nutrient loads (Appendix D).

Rick Hooper (USGS) provided information to participants on two USGS programs for water quality assessment: the National Stream Quality Accounting Network (NASQAN) and the National Water Quality Assessment (NAWQA). NASQAN operates 39 stations on major rivers in four of the largest river basins in the country, including 17 stations in the Mississippi basin. This program is designed to estimate the annual mass flux of a broad range of constituents, including nutrients of concern in the gulf hypoxia problem, at each station. These data will be useful in determining source areas for nutrients within the Mississippi River basin. NAWQA performs a more detailed water quality assessment in medium-sized basins (averaging approximately 20,000 square miles); nutrients also are measured in this program. There are 18 study units within the Mississippi basin which are operated on a rotational basis. Data collected by these programs, as well as historic data collected by the USGS, are being used by the CENR Task Group 3 to estimate annual loadings of nitrate, total nitrogen, orthophosphate, total phosphorus, silica, and chloride at eight large basins in the Mississippi and 30 smaller basins for the period of record of the data. Hooper noted that nitrate concentrations in the lower river were approximately 2 mg/L, relatively low compared to concentrations observed at smaller scales in the upper river. Any existing or proposed river diversions to remove nitrate must take into account these low concentrations. Hooper further noted that while it is relatively easy to monitor inputs to and outputs from the river basin, the transformations controlling the delivery of nitrate from the terrestrial environment into the river system were poorly understood quantitatively at this large scale. Process research is needed to better determine the transport to the river, and the exchange between the river and its alluvial aquifer where denitrification could take place (Appendix E).

Hiram Boone (NRCS) reviewed the actions that are under way in the agricultural community to reduce nutrient loading to the Gulf of Mexico. He emphasized that NRCS field personnel were working closely with farmers who have voluntarily reduced application rates of fertilizer to row crops. Boone reported that NRCS has set a goal of 2 million miles of vegetated buffers by the year 2002. These buffer strips are designed to intercept nutrients moving from agricultural areas into receiving water bodies. A key to the success of these programs is to identify farmers in the watershed who, because of their commitment to reducing the use of chemical fertilizers, serve as models for others to follow. Boone reported that this approach is working well (Appendix F).

Charles Villarrubia (Louisiana Department of Natural Resources) provided an overview of the Caemarvon freshwater diversion project and its relationship to nutrients and hypoxia. The Caemarvon demonstration project diverts up to 8,000 cubic feet of water per second into a marsh area in southeastern Louisiana. To date, this project has resulted in the regeneration of 400 acres of wetlands and has improved conditions for oyster beds in the area. Villarrubia reported that such diversions are feasible and may represent a means for reducing nutrient loading to the gulf (Appendix G).

Identification of Strategies for Alleviating Hypoxia

A major activity of workshop participants involved identifying strategies for alleviating the hypoxia problem in the gulf. Participants were encouraged to identify strategies that could be implemented and tested with demonstration projects in the Lower Mississippi River Valley (below Cairo, Illinois) and the coastal region of Louisiana. They identified 17 initial strategies, which after a discussion session were reduced to 15 by combining closely related strategies. Workshop facilitators then directed the participants in a voting process for ranking the strategies in decreasing order of preference for discussion purposes. During the breakout session, these strategies were further revised and combined into 13. Lower ranked strategies were, in some cases, dealt with very quickly at the end of the day when everyone was tiring. Hence some of the writeups are abbreviated.

Strategies

1. Develop an integrated data management, analysis, and modeling system for assessing nutrient loads and habitat degradation in the Mississippi River system on a spatial and temporal basis.
2. Evaluate hydraulic approaches and the effectiveness of river and stream diversions on reducing nutrient loads through biological and physical uptake mechanisms and/or transformations.
3. Monitor the effectiveness of U.S. Department of Agriculture (USDA) conservation programs and applied conservation practices on the reduction of nutrients in the Lower Mississippi River Valley.
4. Design a conceptual framework that follows nutrients from their sources to the gulf.
5. Identify and determine the effectiveness of existing fertilizer abatement and/or habitat restoration programs in the Lower Mississippi River Valley.
6. Investigate river restoration and floodplain management as a means to reduce nutrient loads in the Gulf of Mexico.
7. Target nutrient reduction as a major goal for habitat restoration, preservation, and protection.
8. Educate stakeholders about existing research data pertaining to the hypoxia problem in the gulf.
9. Identify actions to deal with nutrient loads and contributions from the Upper Mississippi River Basin (north of Cairo).
10. Verify the effectiveness of Hydrogeomorphic Methods (HGM) as an approach to evaluate possible nutrient removal methods.
11. Reduce point-sources of nutrient loads and obtain data for inland systems specifically for nitrates.
12. Delineate and compare the relative contributions of various nutrient sources to water quality problems and hypoxic conditions in the Gulf of Mexico.
13. Don't solely use short-term research results for long-term management decisions; develop long-term research programs to explore methods to reduce and monitor nutrient flow.

Breakout Groups

Participants were divided into two groups, with each group responsible for describing in more detail the strategies assigned. The 13 strategies were divided between the two breakout groups. Seven specific questions were identified to guide the breakout groups in this exercise as they addressed each of the 13 strategies. These questions were:

What would a pilot or demonstration project be and what might be accomplished? For those proposed strategies that could not be interpreted as pilot demonstration projects, the question was taken to mean "What does the strategy mean, and what work would be done?'

How would the effects of the pilot or demonstration project be documented? This question was considered essential because the public has become impatient with agencies and organizations that conduct studies but do not take actions to fix the problem.

What might the impacts be of the pilot or demonstration project if implemented broadly? Some successful pilot projects may have broad application throughout the Lower Mississippi Valley for reducing nutrient loadings. Others might be effective on only a small part of the watershed.

What is the feasibility of doing the pilot or demonstration project? This question involved potential barriers, such as policy constraints or excessive time requirements, to the implementation of demonstration projects for reducing nutrient inputs to the Gulf of Mexico.

What are the risks and other external considerations of the pilot or demonstration project? This question was intended to capture information on political sensitivities and the need to involve key players or stakeholders outside of the government and academic sectors.

What are the costs of the pilot or demonstration project? This question involved rough estimates about both staffing and operational costs.

What other partners or organizations should participate in the pilot or demonstration project? This question was included to ensure that any new efforts stemming from this workshop would be fully integrated with other ongoing or recently completed work on hypoxia in the Gulf of Mexico.

The two breakout groups used slightly different approaches to developing the strategies previously identified. Group 1 discussed each question for each strategy one at a time, reaching a degree of agreement. Within the time allocated, Group 2 placed the strategies in order to be discussed; then participants noted their contributions for each of the seven questions on “sticky” notes and posted them on the appropriate strategy sheet for others to read. This second group did not attempt to reach a consensus on the answers, preferring to address agreement and fine tuning when the draft version of the workshop report was sent out for review.

Participant responses regarding the seven key questions for each strategy identified for alleviating the hypoxia problem were synthesized and integrated by workshop facilitators and planners. Because of time constraints, participants were not able to address each strategy in as complete a manner as they wanted. Therefore, the following summary of synthesized accounts for each strategy are not considered to represent a maximum response by workshop participants. Nevertheless, these accounts do present a broad overview of strategies for solving the problem of hypoxia in the Gulf of Mexico.

Strategy 1. Develop an integrated data management, analysis, and modeling system for assessing nutrient loads and habitat degradation in the Mississippi River system on a spatial and temporal basis.

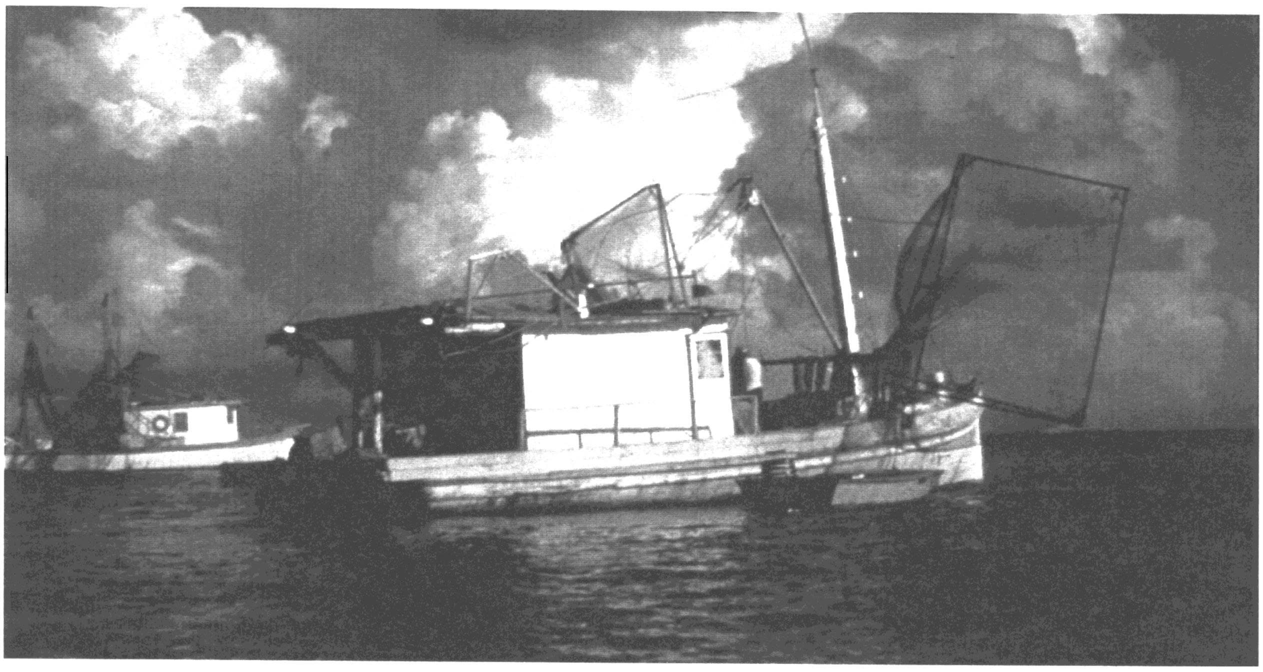
This system includes the entire Lower Mississippi River Valley watershed, including the coastal/nearshore Gulf of Mexico region of Louisiana. This integrated system of data, analytical processes, and modeling outputs will include information that is referenced in time and space. Geographic databases should include climate, soils, land use patterns, Best Management Practices (BMP’s), nutrient sources, remediation actions/projects, etc. Before such an integrated system is conceptualized, various existing databases should be reviewed and/or tested in a pilot demonstration project. The integrated data analysis/modeling system for the Lower Mississippi River Valley watershed should be tested initially with data for a sub-watershed. The early application of the system should be to assist with setting up pilot demonstration projects for nutrient reduction. Later applications of the system would include analyses from these pilot projects and extrapolation of their results to include the Lower Mississippi River Valley. The system should be useful for locating and planning new nutrient reduction projects, for tracking and evaluating the effectiveness of existing projects, and identifying critical sites where nutrient loadings may be occurring. Researchers should be able to access the system for specific data sets, etc. The system could serve as a prototype for other large river basins.

The benefit of an integrated data management, analysis, and modeling system is that it would serve to put into use the myriad of data already collected. The system would serve as a “central coordinating mechanism” to assist with identifying existing and planned demonstration projects for nutrient reduction.

The impact of a pilot data management system on the overall objective of nutrient reduction in the Lower Mississippi River Valley would be documented through user success in better understanding and managing nutrients in the region. If the system contributes to the efficient siting and establishment of new nutrient reduction projects and programs, it would be an important asset to Federal and State agencies. By having a system capable of managing temporal and spatial data and compatible with a range of field-scale (up to watershed scale) models, nutrient loading and gulf hypoxia can be more clearly evaluated.

The integrated system of data, analysis and evaluation capabilities, and modeling outputs could be further designed to include a public outreach component for addressing the nutrient management issue. Public interaction and involvement with nutrient management and the gulf hypoxia problem are important to the ongoing and proposed scientific and management efforts to solve this problem. The feasibility of developing the integrated system is very high since existing technologies, methods, and data are available.

System development is not without risk, however. One risk is that development costs could be high, and the existing databases may be too incomplete for



system application on a broad scale. There is also a risk associated with data acquisition for the system. Some required data sources may be unavailable for inclusion in the system. The system's format for data acquisition may also be incompatible with the format used for other databases. Finally, there is a potential credibility problem involved with developing such large integrated data management systems. Often, such developments are questioned by the public as to their utility for solving problems in the public's interest. However, these risks can be minimized by limiting the size of the first demonstration project and ensuring that the project can be successfully completed.

Initial costs for system development and demonstrations are expected to be in the area of $100,000 to $250,000 for a watershed of 20,000 to 50,000 acres. This cost could increase, depending on the number of existing sources tested and resolution of the data required. The total costs will be related to the scale, and complexity of the system and to the number of modeling components and hypotheses that are to be evaluated. Linking a watershed-scale data management/modeling system with river transport models and gulf eutrophication models will require additional funds. This linkage between nutrient loads and patterns in the Lower Mississippi River Valley and hypoxic conditions in the gulf is considered to be necessary to successful management of hypoxia.

Strategy 2. Evaluate hydraulic approaches and the effectiveness of river and stream diversions on reducing nutrient loads through biological and physical uptake mechanisms and/or transformations.

River and tributary diversions are considered a potentially important strategy for reducing nutrient flows into the Gulf of Mexico. Investigations (monitoring) of eutrophication in shallow and coastal gulf waters, marsh ecology, water quality, and seasonal timing of water diversion should be added to monitoring protocols for existing diversion projects. Whereas demonstration water diversion projects could be accomplished over shorter periods, long-term monitoring would be required to assess the nutrient reductions resulting from river and tributary diversions and the effects of such diversions on riverine and wetlands ecology.

The Atchafalaya River is associated with a long-term record of monitoring data. Available data show the system to be removing particulates but not taking up dissolved nutrients. The transformation of nitrates to ammonia that results in a somewhat higher discharge from the Atchafalaya River vs. the Mississippi River is not of overall benefit to offshore plankton. Demonstration projects in this channelized river must be carefully designed to be able to detect reductions in nutrient loadings to the Gulf of Mexico.

Participants recommended that the pilot or demonstration project involve the addition of a carefully designed nutrient monitoring program to an existing water diversion project. Evaluation of increased eutrophication in shallow or coastal waters near the Atchafalaya River's outfall, resulting from the diversion, would also have to be an element of the monitoring protocol.

The monitoring design for documenting the success of a diversion project in removing nutrients from the water column must be carefully planned to include monitoring stations both within and outside the diversion area. This approach should result in high quality data sets to assist decision-making in regards to the interconnections and cumulative impacts of river diversion on wetland hydrology, ecosystem health, and ecological effects on both plant and animal communities in the project area.

Diversion of the Mississippi River or tributary waters into vegetated areas for the purpose of reducing nutrient loads to the gulf is considered to be a very feasible strategy when coupled with existing demonstration projects. Risks are considered to be minimal in terms of technical **issues.** However, impacts to oyster-growing areas or to sensitive habitat areas should be considered in any plans to expand existing projects or initiate demonstration projects in other locations in the Lower Mississippi River Valley. The estimated costs for modifying an existing diversion project to include a nutrient monitoring program are between $500,000 and $1,000,000 for a 3- to 4-year effort. The USGS was identified as the organization best suited and equipped to enhance or increase monitoring for nutrients at existing water monitoring stations in the Lower Mississippi River Valley.

Strategy 3. Monitor the effectiveness of USDA conservation programs and applied conservation practices on the reduction of nutrients in the Lower Mississippi River Valley.

The thrust of this strategy is to document the effects of nutrient reduction practices now being implemented in the Lower Mississippi River Valley and coastal Louisiana for natural resources conservation. Resource managers, policy makers, land owners and the general public need to know the effects of Best Management Practices, to determine those practices that contribute to ecosystem health and nutrient balance.

Pilot/demonstration projects should be selected from among the various BMP's and conservation practices that are in place or planned for the purpose of protecting natural resources. For example, a vegetated buffer strip associated with irrigation management and minimal tillage in an agricultural area could be evaluated for its effectiveness at taking up excess nutrients from fertilizer application before the nutrients reach a water course.

The effects of a vegetated buffer strip on reducing nutrient loading to a receiving water course could be documented by measuring nutrient levels on either side of the buffered strip over time. If the strip takes up excess nutrients carried from the agricultural area, then the amount of nutrients entering a river or stream on the other side of the buffer strip would be expected to be reduced when compared to a control (nonbuffered) site.

The impacts of implementing a successful demonstration project on a broader scale would be positive. If it could be demonstrated locally that a particular conservation practice can serve to reduce nutrient loading, then widespread acceptance of the practice by other potential users in the region would be strongly encouraged. Success would also benefit the Federal agencies responsible for assisting with implementing such practices, since continuation of such programs would be encouraged by such successes.

Implementing pilot or demonstration projects for nutrient abatement in the Lower Mississippi River Valley is both reasonable and feasible. Opportunities exist among the many programs currently underway. Close cooperation among the agencies involved with demonstration projects is necessary to their success.

Demonstration projects involving USDA conservation practices are not without risks, however. The question of getting reasonable results within the 3- to 5-year period of a demonstration project must be raised. Many factors control nutrient dynamics, and existing BMP's, for example, may not lend themselves to a stringent experimental design. On the other hand, if there is strong buy-in by the agencies with funding levels necessary for quality projects, useful data can be collected.

Costs are difficult to estimate and would vary according to the scale, complexity, and duration of the demonstration project. A simple demonstration encompassing a small watershed could cost $200,000/year.

Organizations participating in such nutrient reduction demonstration projects should include local, regional, and national groups involved with conservation practices in the Lower Mississippi River Valley. Farmers and their representative organizations must be the primary participants because they are key to nutrient management in the region.

Strategy 4. Design a conceptual framework that follows nutrients from their sources to the gulf.

Initially this framework should be a qualitative diagram that shows sources of nutrients within the Lower Mississippi River Valley and the connections between the sources and the Mississippi River and its tributaries to the gulf. A second stage of development moves toward quantification into a static system mode1 that accounts for average flows. Further development would lead to a system dynamic mode1 to define water flows and nutrient concentrations over time. From this stage the design would be expanded to include a system dynamic model for a single sub-basin that would provide data on how effective management practices in the sub-basin were at reducing nutrient inputs. The framework would ultimately be used to track nutrient changes throughout the Lower Mississippi River Valley, to pinpoint sources, to identify nutrient uptake or removal sites, and to identify sites where management opportunities exist for nutrient abatement. The research community would also benefit from this nutrient-tracking system.

Strategy 5. Identify and determine the effectiveness of existing fertilizer abatement and/or habitat restoration programs in the Lower Mississippi Diver Valley.

A number of demonstration programs related to fertilizer abatement and/or habitat restoration are active in the region. Identification of these projects and a synthesis of their effects on nutrient abatement in a given watershed is needed. A demonstration project might involve development of a directory of ongoing planned activities related to nutrient reduction. The initial directory might focus on only a specific sub-basin of the greater Mississippi River Basin. Another idea for a pilot project is preparation of a descriptive document on existing databases for a geographic area or category of Best Management Practices.

Identifying and integrating existing demonstration projects in the Lower Mississippi River Valley is a strategy more related to planning and organizing a broader assessment program for nutrient reduction than it is to conducting a *study ofnutrient levels.* Thus, the effects of a pilot project under this strategy would best be documented by assessing user requests for the pilot-generated product (planning directory, database, etc.).

The impacts of a localized demonstration project applied over a broader region would vary, depending upon the nature of the project. Since the strategy or measure under question involves integration of existing demonstration programs, the impacts of an integrating exercise would be to create a centralized database or directory that could be used for project planning over a broader area. The impacts of such an effort would be positive.

This strategy is very feasible to accomplish, provided that key agencies participated in the information-gathering process. Certainly close coordination among participating agencies is required, and one agency should be identified as lead for the effort.

This strategy is not generally associated with high risks. The effort to integrate existing demonstration projects under a centralized directory of information and data systems is a worthy objective. However, integration of information is not of much value unless there is a clear plan of action for its use.

Costs for a pilot project related to this strategy will vary depending upon the nature of the effort. A limited database constructed for a confined geographic area will likely cost $60,000-$75,000 plus system maintenance costs of $15,000/year.

Partners in the demonstration project should include all Federal, State, and nongovernment agencies involved with the hypoxia issue. Perhaps the NRCS would serve best as the lead agency responsible for integrating existing demonstration projects into a central project management system.

Strategy 6. Investigate river restoration and floodplain management as a means to reduce nutrient loads in the Gulf of Mexico.

Restoration and watershed management activities are planned and ongoing within the Mississippi River Alluvial Valley. Nutrient reduction should be considered a side benefit of such activities. Several opportunities for demonstration or pilot projects exist. For example, portions of the St. Catherine's Creek National Wildlife Refuge on the east bank of the Mississippi River below Natchez, MS, could be reforested and monitored to evaluate the impact of such a restoration project on nutrient reduction. Additionally, opportunities exist for working with private landowners such as the Delta Land Trust to incorporate river restoration into any large scale program for nutrient reduction in the Lower Mississippi River Valley. Other candidate demonstration projects might be selected from ongoing projects on the White, Cache, and Tensas Rivers. If any of these projects are selected for a demonstration project for nutrient reduction, additional water monitoring stations would need to be considered.

Strategy 7. Target nutrient reduction as a major goal for habitat restoration, preservation, and protection.

The importance of habitat preservation, protection, and restoration would be influenced dramatically in the decision-making process if nutrient reduction were taken into account, as a justification for implementation of restoration projects.

Strategy 8. Educate stakeholders about existing research data pertaining to the hypoxia problem in the Gulf.

All stakeholders-including lawmakers and policy makers, administrators and resource managers, fishermen and coastal zone planners, municipalities and agricultural interests, and the general public—must be made aware of what is currently understood about hypoxia. This understanding includes the message that the hypoxia problem will take time to correct. Reduction of nutrients from their sources in the Lower Mississippi River Valley will not mean that the hypoxic zone in the gulf will dissipate quickly. Phytoplankton may be able to recycle nutrients already present in the gulf hypoxic zone for many decades to come. A pilot or demonstration project might involve the preparation of an outreach brochure that summarizes what is scientifically known from research on hypoxia conducted in the Gulf of Mexico. Such a brochure should be targeted to the general public. Other demonstration projects might include special educational modules aimed at transferring research information on hypoxia to schools, to agricultural organizations, city governments, etc. Getting research information into farm organization publications may be highly beneficial. Fact sheets, success stories, press releases, video presentations, etc., are all excellent formats for "getting the word out."

Success could be documented by the number of requests for more information on hypoxia, by the number of information releases, and by the level of positive feedback and political support received.

A well-designed outreach project could be successfully duplicated on a broader scale, perhaps to include the entire Lower Mississippi River Valley. A well-educated public would likely support Federal and State requests for funding for hypoxia abatement.

Since an outreach program designed to convey information about hypoxia is a means of keeping the public aware of an environmental problem, the risks of carrying out such an activity is low. Most citizens would react favorably to such information. Other organizations, especially conservation groups, would likewise welcome information about what has been learned about the hypoxia problem. However, following a successful outreach project, the public and political sectors may expect more and bigger accomplishments immediately. Such false expectations can create problems for research or evaluation programs for nutrient reductions that often require longer periods for quality results.

Costs for a demonstration project under this strategy will vary according to project design and scope. However, the long-term benefits from such an activity will outweigh the associated costs for whatever level of effort is undertaken.

All agencies, organizations, and local groups involved with hypoxia should participate and benefit from a pilot project that involves the education of stakeholders, especially the farming community and the general public.

Strategy 9. Identify actions to deal with nutrient loads and contributions from the Upper Mississippi River Basin (north of Cairo).

The Committee on Environment and Natural Resources (CENR) and the USGS have responsibility now to investigate this strategy.

Strategy 10. Verify the effectiveness of Hydrogeomorphic Methods (HGM) as an approach to evaluate possible nutrient removal methods.

The U.S. Army Corps of Engineers is developing HGM protocols, and the project is in the early stages of research, development, and testing. Implementation of HGM will improve the decision-making process regarding nutrients because the methodology is a science-based approach to evaluating options. Both the USEPA and U.S. Army Corps of Engineers are strongly encouraged to continue HGM development.

Strategy 11. Reduce point sources of nutrient loads and obtain data for inland systems specifically for nitrates.

This strategy was considered to be outside the purview of this workshop. The reduction of point sources is considered to have broad policy impacts and to be a regulatory function under the appropriate Federal and State agencies.

Strategy 12. Delineate and compare the relative contributions of various nutrient sources to water quality problems and hypoxic conditions in the Gulf of Mexico.

This strategy is related to strategies 1 and 2 above. Strategy 1 involving development of an integrated data management and modeling system would be useful for estimating the relative contributions of various nutrient sources or geographic locations to nutrient loading levels in the Gulf of Mexico.

Strategy 13. Don't solely use short-term research results for long-term management decisions; develop long-term research programs to explore methods to reduce and monitor nutrient flow.

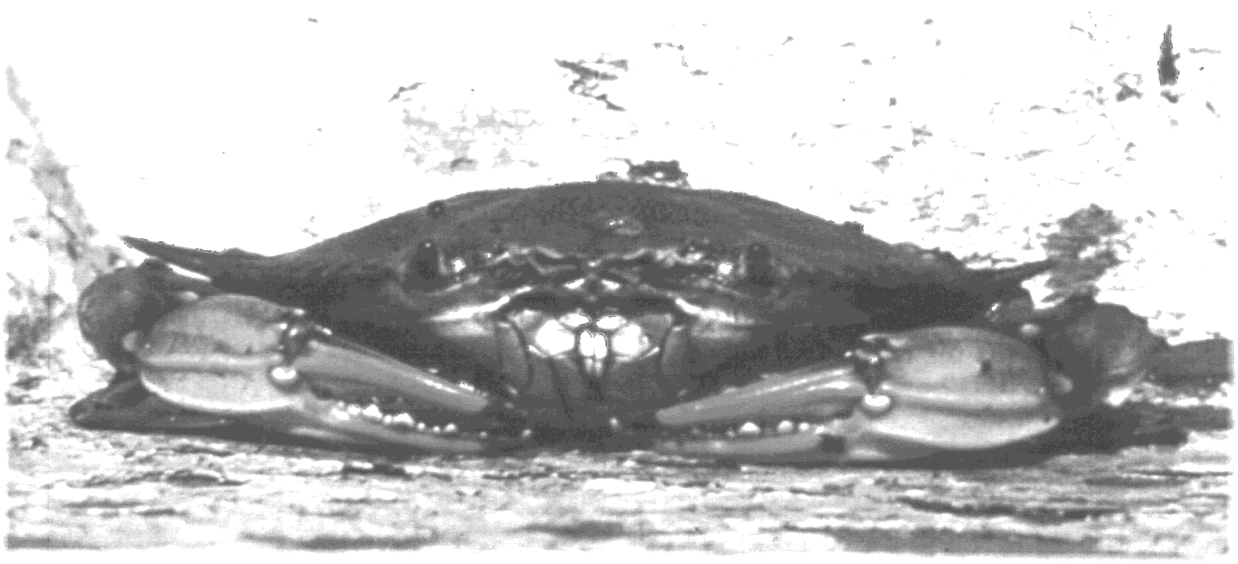
Monitoring and modeling nutrient loads within the Lower Mississippi Valley and in the offshore waters of the gulf need to be continued on a long-term basis. Otherwise, it will not be possible to relate nutrient reduction projects in the watershed to decreases in the gulf hypoxia zone along the Louisiana and upper Texas coasts.

During the breakout sessions two policy recommendations were offered. These were:

1. When agency demonstration projects are implemented to reduce nutrient loads, the impacts of surface runoff reaching the Mississippi River or one of its tributaries should be taken into consideration; and
2. When USDA-administered conservation practices (Best Management Practices, stream buffers, wetlands restoration, etc.) are applied in pilot watersheds, a provision should be included to evaluate the success of a representative sample of such practices on nutrient reduction.
3. Increase agency effort (primarily USGS) to monitor water quality and nutrients in the Lower Mississippi Valley.

Follow Up

Workshop participants received a draft copy of this report and returned comments that were incorporated into this final report.



Appendix A

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Appendix B

Agenda

8:30 a.m.	Welcome and Outline of Workshop Activities/Objectives	Bob Stewart (USGS)
8:45 a.m.	Overview of Gulf of Mexico Hypoxia Problem	Bryon Griffith (EPA) Nancy Rabalais (LUMCON)
9:00 a.m.	Review of USGS Water Resources Division Monitoring in the Mississippi River System	Rick Hooper (USGS)
9:15 a.m.	Existing Actions/Measures for Reducing Nutrient Loading to the Gulf of Mexico (Agricultural Programs)	Hiram Boone (NRCS)
9:30 a.m.	Coffee break	
9:45 a.m.	Freshwater Diversions, Nutrients, and Hypoxia: Preliminary Observations from Caernarvon	Charles Villarrubia (LA DNR)
10:00 a.m.	General Session: Identification of Other Actions/Measures for Reducing Nutrient Loading to the Gulf of Mexico Examples: 1. Divert Mississippi River and/or tributary waters into adjacent forested wetlands and/or coastal marshes for nutrient uptake. 2. Establish wetland sinks at agricultural drains and/or vegetated buffers at margins of agricultural lands and other source areas for nutrient uptake.	Bob Hays (Facilitator: Contrac tor) Steve Painter (Facilitator: Contractor)
10:45 a.m.	Break-Out Sessions: Evaluate/Rank Each Identified Action/Measure for Nutrient Reduction in Terms of	Bob Hays Steve Painter
11:45 a.m.	Lunch on site	
12:30 p.m.	Break-Out Sessions: For Each Action/Measure Identify Demonstration Projects That Could be Implemented Over the Next 5-l 0 Years to Verify Nutrient Reduction	Bob Hays Steve Painter
1:45 p.m.	Break-Out Sessions: Provide Approximate Cost Estimates for Implementing Nutrient Reduction Demonstration Projects over the Next 5-10 Years	Bob Hays Steve Painter
2:30 p.m.	Coffee Break	
2:45 p.m.	Break-Out Sessions: Identify Strategies for Implementing Each Demonstration Project for Verifying Nutrient Reductions	Bob Hays Steve Painter
3:45 p.m.	Synthesis of Nutrient Reduction Measures and Demonstration Projects	Bob Stewart (USGS)
4:00 p.m.	Congressional Perspective on Solving the Gulf of Mexico Hypoxia Problem	U.S. Senator John Breaux

Appendix C

Strategies/measures for Mitigating Hypoxia in Gulf of Mexico Region

1. Develop an integrated data management, analysis, and modeling system for assessing nutrient loads and habitat degradation in the Mississippi River system on a spatial and temporal basis.
2. Evaluate hydraulic approaches and the effectiveness of river and stream diversions on reducing nutrient loads through biological and physical uptake mechanisms and/or transformations.
3. Monitor the effectiveness of U.S. Department of Agriculture (USDA) conservation programs and applied conservation practices on the reduction of nutrients in the Lower Mississippi River Valley.
4. Design a conceptual Framework that follows nutrients from their sources to the gulf.
5. Identify and determine the effectiveness of existing fertilizer abatement and/or habitat restoration programs in the Lower Mississippi River Valley.
6. Investigate river restoration and floodplain management as a means to reduce nutrient loads in the Gulf of Mexico.
7. Target nutrient reduction as a major goal for habitat restoration, preservation, and protection.
8. Educate stakeholders about existing research data pertaining to the hypoxia problem in the gulf.
9. Identify actions to deal with nutrient loads and contributions From the Upper Mississippi River Basin (north of Cairo).
10. Verify the effectiveness of Hydrogeomorphic Methods (HGM) as an approach to evaluate possible nutrient removal methods.
11. Reduce point-sources of nutrient loads and obtain data for inland systems specifically for nitrates.
12. Delineate and compare the relative contributions of various nutrient sources to water quality problems and hypoxic conditions in the Gulf of Mexico.
13. Don't solely use short-term research results for long-term management decisions; develop long-term research program to explore methods to reduce and monitor nutrient flow.

Appendix D

The Gulf of Mexico Hypoxia Problem

Bryon Griffith
Deputy Director
Gulf of Mexico Program Office

Overview of the Hypoxia Issue

The inner to mid-continental shelf from the Mississippi River westward to the upper Texas coast, is the site of the largest zone of hypoxic bottom waters in the western Atlantic Ocean. This area of hypoxia is defined as waters with dissolved oxygen concentrations of less than 2 parts per million (PPM). Two PPM dissolved oxygen is generally accepted as the limit for most aquatic life survival and reproduction. The size of the oxygen-depleted areas varies from year to year, can exceed 6,000 square miles in size, and may form as early as February and last as late as October. The most widespread and persistent conditions occur from mid-May to mid-September and are typically associated with the bottom waters but have been monitored and detected in higher water columns.

Presently available research has shown a relationship between Mississippi River flow, river borne nutrients, plankton productivity, and bottom water hypoxia. As the massive phytoplankton blooms decompose, they consume nearly all of the available oxygen in the water. Combined with stratification of fresh and salt water, this results in a zone of low dissolved oxygen (hypoxia) with very low fish and shellfish densities. The hypoxic conditions vary spatially and seasonally depending on the flow rates of the Mississippi River discharge, water circulation patterns, salt and fresh water stratification, wind mixing, tropical storms, and thermal fronts.

The nature of the hypoxia problem is complicated by the fact that a portion of the nutrient load from the Mississippi River is vital to maintaining the productivity of the gulf fisheries and the habitats upon which they depend. Approximately 40% of the U.S. fisheries landings, including a substantial part of the nation's most valuable fishery (shrimp), come from this highly productive area. In addition, the area also supports a large and valuable sport fishery. The concern is that the hypoxic area that may have always existed to some extent has been enlarging since the 1960's due largely to human activities in the watershed that have increased the nutrient loads beyond the sustainable capacity of the system. The impacts of expanding gulf hypoxia, either currently described or predicted, include:

- Altered coastal phytoplankton based food webs;
- Noxious algal blooms;
- Altered benthic ecosystems;
- Reduced economic productivity in both commercial and recreational fisheries; and,
- Both direct and indirect impacts on fisheries such as mortality and altered migration that may lead to declines in populations and landings.

The Gulf of Mexico Program has been studying the northern Gulf of Mexico oxygen depletion issues for years. The Program's Nutrient Enrichment Focus Team, formerly organized as the Nutrient Enrichment Issue Committee, has conducted studies of the nutrient concentrations in the Mississippi River. Preliminary conclusions indicate that a significant amount of the nutrients delivered to the gulf via the Mississippi River come from the upper Mississippi River watershed.

Status of Federal Activities

During the past year the Gulf of Mexico Program was appointed the responsibility for coordinating a Federal government-wide response to the issue of hypoxia in the Gulf of Mexico. The Federal agencies involved in the hypoxia issue are currently focusing their efforts on addressing five basic science and/or program coordination activities:

1. Increased understanding of the scientifically complex nature of hypoxia in the Gulf of Mexico;
2. Assessment of the major contributors to the hypoxia condition, believed to be excessive amounts of nutrients from the Mississippi and Atchafalaya river systems;
3. Coordination of existing environmental management programs already addressing nutrients throughout the Mississippi and Atchafalaya River and Gulf of Mexico watersheds;
4. Development of an integrated strategy or framework for addressing and alleviating hypoxia; and,
5. Coordination of hypoxia response activities with Federal, State and local organizations.

The focus on Gulf hypoxia at the Federal level has resulted in agreement by member agencies to make the hypoxia issue a priority and to form a Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. This task force has begun the effort of reviewing the basic science surrounding the issue by requesting the Committee on Environment and Natural Resources (CENR) to address six initial science and research questions concerning the hypoxia issue:

1. Describe seasonal, interannual, and long-term variation in hypoxia, and its relationship to nutrient loads from the Mississippi/Atchafalaya system. This report will document the relative roles of natural and human-induced factors in determining the size and duration of the hypoxic zone.
2. Evaluate the ecological and economic consequences of hypoxia, including impacts on gulf fisheries and the regional and national economy. This report will articulate both ecological and economic consequences and, to the extent appropriate, their interaction.
3. Identify the sources of nutrients within the Mississippi/Atchafalaya system. This effort has two distinct components. The first is to identify where, within the basin, the most significant nutrient additions to the surface water system occur. The second, more difficult component, is estimating the relative importance of specific human activities in contributing to these loads.
4. Estimate the effects of reducing the nutrient loads to surface waters within the basin and to the Gulf of Mexico. This report will include model analysis to aid in identifying load reduction targets needed to effect a significant change in hypoxia.
5. Identify and evaluate methods to reduce nutrient loads to surface water, ground water, and the Gulf of Mexico. This analysis will not be restricted to only reduction of sources. It will also include means to reduce loads by allowing the system to better accommodate those sources through, for example, modified hydraulic transport and internal cycling routes.
6. Evaluate the social and economic costs and benefits of the methods identified in topic five for reducing nutrient loads. This analysis will include an assessment of various incentive programs and will include any anticipated fiscal benefits generated for those attempting to reduce sources.

The Gulf of Mexico Program advocates that a basic "win-win" approach to addressing the increased area of hypoxia is to reduce the inputs of nutrients to surface water in the Mississippi and Atchafalaya River watersheds. The premise is that improved nutrient and land management practices at the local scale, and further prevention and reduction efforts by significant air and wastewater sources, will contribute to reductions. Properly designed and administered, these actions will benefit both the landowners and the water bodies they impact in the Mississippi River Watershed. Government support and priority for action should be guided by a comprehensive strategic assessment. Also, estimates of total nutrient input from different sources must be improved so that remedial and prevention measures can be targeted where they will have the greatest effect (i.e., risk assessment/risk management). A comprehensive Mississippi and Atchafalaya River watershed strategy developed with broad stakeholder involvement is needed to support innovative actions that can be undertaken cost-effectively and without significant economic or social disruption. In addition, research and monitoring are needed to complement current and subsequent management actions and to track progress. The Task Force is currently in the early stages of development.

National Assessment Process
for Hypoxia

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Mississippi River/Gulf of Mexico Watershed Taskforce

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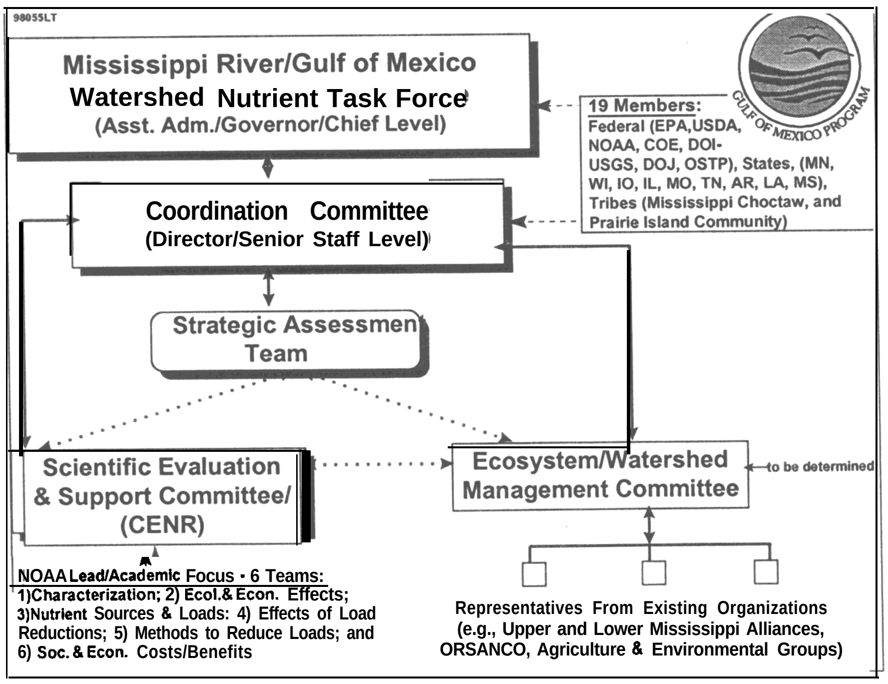
Mississippi River/Gulf of Mexico Watershed Nutrient Task Force

- Who are they?
- What do they do?



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Mississippi River/Gulf of Mexico Watershed
Nutrient Task Force

GULF OF MEXICO PROGRAM

MISSION:

The Task Force is established to understand the causes and effects of eutrophication in the Gulf of Mexico, to coordinate activities to reduce the size, severity and duration of this phenomenon, and to ameliorate its effects.

Activities include coordinating and supporting nutrient management activities from all sources, restoring habitats to trap and assimilate nutrients, and supporting other hypoxia related activities in the Mississippi River and Gulf of Mexico watersheds.

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Mississippi River/Gulf of Mexico Watershed
Nutrient Task Force

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ROLES & RESPONSIBILITIES:

The role of the Task Force is to provide executive level direction and support for coordinating the actions of participating organizations working on nutrient management within the Mississippi River/Gulf of Mexico Watershed.

The Task Force will designate members of a Coordination Committee, and solicit information from interested stakeholders.

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Mississippi River/Gulf of Mexico Watershed
Nutrient Task Force

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Coordination Committee

ROLES & RESPONSIBILITIES:

The Coordination Committee is comprised of senior managers from the Task Force member agencies.

The role of the Coordination Committee is to facilitate communications and coordination of all Teams and Committees, and make recommendations to the Task Force for their action.

The group is responsible for ensuring that all actions complement each other and that communication flows effectively to all Committees and Teams.

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Mississippi River/Gulf of Mexico Watershed
Nutrient Task Force

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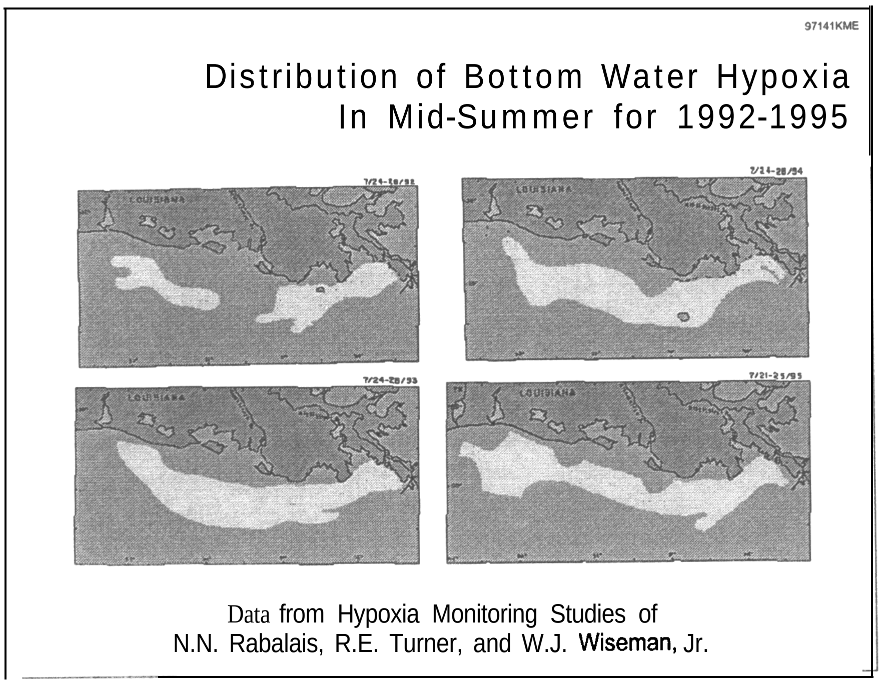
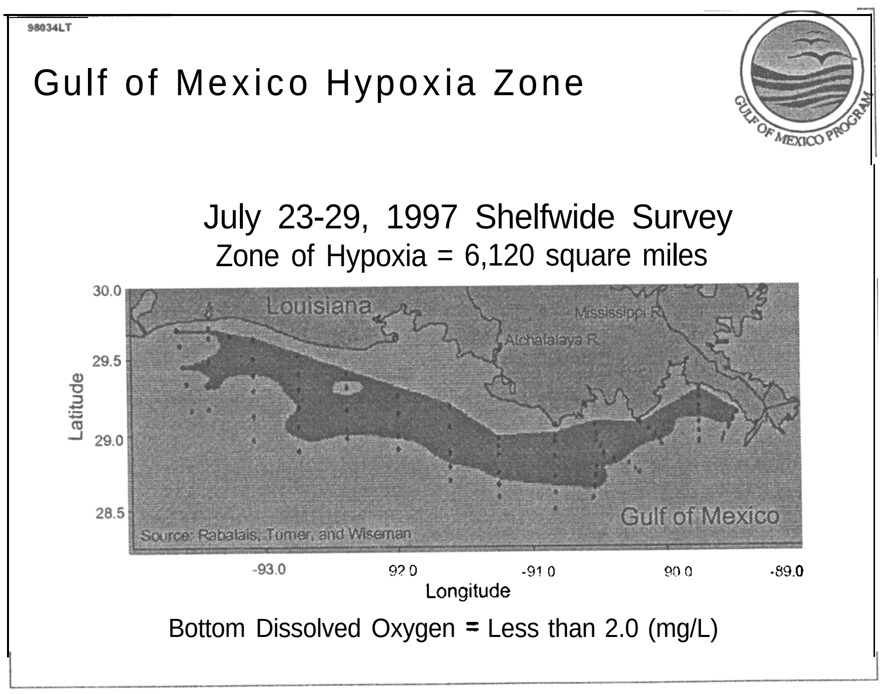
Scientific Evaluation and Support Committee

ROLES AND RESPONSIBILITIES:

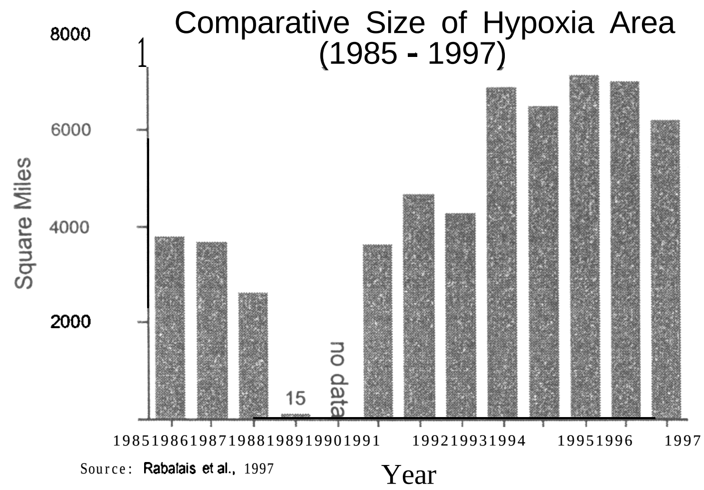
The Scientific Evaluation and Support Committee is conducting a scientific assessment of the causes and consequences of Gulf of Mexico hypoxia under the leadership of the Committee on Environment and Natural Resources (CENR) Subcommittee on Ecological Systems as part of the process of developing and implementing potential hypoxia policy actions.


97141KME
Distribution of Bottom Water Hypoxia
In Mid-Summer for 1992-1995
LOUISIANA
Data from Hypoxia Monitoring Studies of
N.N. Rabalais, R.E. Turner, and W.J. Wiseman, Jr.


98034LT
Gulf of Mexico Hypoxia Zone
GULF OF MEXICO PROGRAM
July 23-29, 1997 Shelfwide Survey
Zone of Hypoxia = 6,120 square miles
Louisiana
Mississippi R.
Atchafalaya R.
Gulf of Mexico
Source: Rabalais, Turner, and Wiseman
Latitude
30.0
29.5
29.0
28.5
-93.0
-92.0
-91.0
-90.0
-89.0
Longitude
Bottom Dissolved Oxygen = Less than 2.0 (mg/L)

98029LT

Gulf of Mexico Hypoxia Zone



Source: Rabalais et al., 1997

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National Assessment Process for Hypoxia

CENR Assessment:

Causes and Consequences of Gulf of Mexico Hypoxia

97184LT

Hypoxia Assessment

Assessment Plan

- **Produce a series of reports on critical topics**
- **Synthesize reports into integrated assessment**
- **Use both internal and external experts**
- **Peer-review reports and integrated assessment**
- **Policy review of integrated assessment through NTSC**

97185LT

Hypoxia Assessment

Hypoxia Reports

1. **Describe variations in hypoxia, and its relationship to nutrient loads from the MS system**
2. **Evaluate the ecological and economic consequences of hypoxia**
3. **Identify locations, causes, transport, and fate of nutrients in MS system**
4. **Estimate effects of reducing nutrient loads to surface waters within the basin and GOM**
5. **Identify and evaluate methods to reduce nutrient loads to surface water, ground water and the GOM**
6. **Evaluate the social and economic costs and benefits of the methods identified in topic #5 for reducing nutrient loads**

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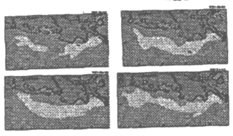
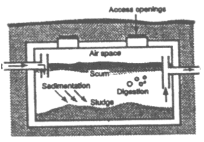
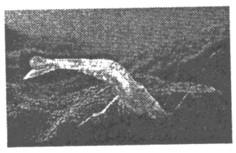
Questions to be **Answered** by CENR Process

1. **Hypoxia description**
2. **Ecological and economic consequences**

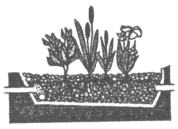


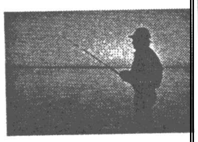


3. **Nutrient Sources**
4. **Effects of reducing nutrient inputs**



5. **Methods to reduce nutrient inputs**
6. **Social/economic cost-benefit analysis**





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Multi-Year Hypoxia Response Framework

1996 → 1998 1999 → 2003

- **Use Existing Programs and Priorities**
  - Nutrient Management
  - Monitoring, Modeling, and Assessment
  - Education and Outreach
  - Research
- **Plan for the Future** →
  - *A. Stewardship Actions*
    1. Frameworks
    2. Tools for Implementation
    3. Education and Outreach
  - *B. Science/Research Support*
    1. Land-based Processes
    2. Tributaries and Rivers
    3. Gulf of Mexico
    4. Special Considerations
- **Establish and Support Coordinating Structure** →
  - Mississippi River/Gulf of Mexico Watershed Nutrient Task Force

Milestones: Determine Baseline Characterizations — Establish Initial Nutrient Reductions and Performance Measures — Assess Cost-Effectiveness of Additional Nutrient Reduction vs Status Quo — Assess Need for Longer Term Response Plan

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Assessment Topics and Team Leads

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<u>Characterization of hvooxia: distribution. dvnamics, and causes.</u>
Dr. Nancy Rabalais, LUMCON.

<u>Ecoloqical and economic conseauences of hvooxia.</u>
Dr. Robert Diaz, VIMS; Dr. Andrew Solow, WHOI.

<u>Sources and loads of nutrients transported to the Gulf of Mexico.</u>
Dr. Donald Goolsby, USGS.

<u>Effects of reducina nutrient loads.</u>
Dr. Patrick Brezonik, Univ. of Minn.; Dr. Victor Bierman, Limno-Tech.

<u>Evaluation of methods to reduce nutrient loads.</u>
Dr. William Mitsch, Ohio State University.

<u>Evaluation of economic costs and benefits of reducina loads.</u>
Dr. Otto Doering, Purdue University.

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Hypoxia Assessment - Participating Organizations

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Academy of Natural Sciences
College of William and Mary, Virginia Institute of Marine Studies
Illinois State water Survey
Institute of Ecosystem Studies
Iowa State Universitv. Leopold Center for Sustainable Agriculture
Limno-Tech, Inc.
Louisiana Universities Marine Consortium
Louisiana State University, Louisiana Cooperative Extension Service
Louisiana State University, Coastal Ecology Institute
Louisiana State University, Coastal Fisheries Institute
Louisiana State University, Coastal Studies Institute
Purdue University, Agricultural Economics Department
U.S. Dept. of Agriculture. Economic Research Service
U.S. Dept. of Commerce, NOAA, National Marine Fisheries Service, Galveston Laboratory
U.S. Dept. of Commerce, NOAA, National Marine Fisheries Service, Panama City Laboratory
U.S. Dept. of Commerce, NOAA, Air Resources Laboratory
U.S. Geological Survey, Denver Federal Center
U.S. Geological Survey. Reston Area Office
U.S. Army Corps of Engineers, Waterways Experiment Station
North Carolina State University, Soil Science Department
Ohio State University
Texas Agricultural Experiment Station, Blackland Research Center
Texas A & M University
University of Texas at Austin, Marine Science Institute
University of Miami, Rosenstiel School of Marine and Atmospheric Sciences
University of Florida
University of Kansas
University of Minnesota. Water Resources Canter
University of Missouri. Agricultural Economics Department
Woods Hole Oceanographic Institution, Marine Policy Center

<u>In consultation with:</u>
American Farm Bureau
Florida State University
Louisiana Department of Wildlife and Fisheries
U.S. Dept. of Agriculture, Natural Resources Conservation Service
U S. Dept. of Agriculture, Agricultural Research Service
Others as needed

Appendix E

Sources and Transport of Nitrogen in the Mississippi River Basin

Donald A. Goolsby, William A. Battaglin
U.S. Geological Survey
Lakewood, CO
and
Richard P. Hooper
U.S. Geological Survey
Atlanta, GA

Introduction

The Mississippi and Atchafalaya Rivers are the primary riverine sources of fresh water and nutrients discharged to the Gulf of Mexico. The combined annual mean streamflow for the Mississippi and Atchafalaya Rivers (2 1,800 cubic meters per second) represents about 80 percent of the estimated freshwater discharge to the gulf (Dunn, 1996). These two rivers account for an estimated 90 percent of total nitrogen (N) load and 87 percent of the total phosphorus load discharged annually to the gulf (Dunn, 1996). Nitrate along with other nutrients has been implicated as a possible cause of oxygen depletion (hypoxia) in a large zone of the Gulf of Mexico along the Louisiana-Texas coast (Turner and Rabalais, 199 1; Justic, et al., 1993; Justic et al., 1994; Rabalais, et al., 1996). The seasonal reduction in dissolved oxygen (DO) occurs each year during late spring and summer following high inflows of fresh water and nutrients to the gulf. For example, following the 1993 flood, the hypoxia zone (DO less than 2 parts per million) covered nearly 17,000 square kilometers, twice the size of Chesapeake Bay. In 1994, 1995, and 1996 the zone of hypoxia was reported to be as large or larger (about 18,000 square kilometers) than during the summer of 1993 (Rabalais and Turner, press release, 1996). Estimates of the size of the zone of hypoxia prior to the 1993 flood (1985-92) averaged about 10,000 square kilometers.

Nitrogen Sources

The increased use of nitrogen and phosphorus fertilizers is being pointed to as a possible cause of water quality changes in the Mississippi River that lead to hypoxia in the Gulf of Mexico (Rabalais et al., 1996). Fertilizer use has increased significantly over the past 25 years (Goolsby and Battaglin, 1995)(figure 1) and has similar patterns to increasing nitrate concentrations in the Mississippi River. However, there are other sources of nitrogen in the basin including animal manure, legumes (soybeans and alfalfa), domestic effluents, atmospheric deposition and soil nitrogen. Estimates of some of these inputs of nitrogen to the Mississippi basin and its major tributary basins have been made by Battaglin and others (1997) and are given in table 1. Estimates of nitrogen fertilizer inputs are for 1987 and are given both as a total and by major type, based on data provided by the U.S. Environmental Protection Agency (1990) and summarized by Battaglin and Goolsby (1995). Estimates of manure nitrogen inputs are for 1987 and were computed by Alexander (USGS, written commun., 1992) from livestock population estimates in the 1987 Census of Agriculture (U.S. Department of Commerce, 1989) and estimates of the nutrient content of daily wastes produced by livestock provided by the National Resource Conservation Service. Estimates of nitrogen input from legumes are for 1987 and were calculated using information on soybean and alfalfa acreage from the 1987 Census of Agriculture and nitrogen replacement rates (N fixed minus N in harvested crop) of 35 kg/ha for soybeans and 65 kg/ha for alfalfa (Board on Agriculture, National Research Council, 1993). Estimates of nitrogen input in wet deposition are for 1987 and were calculated from estimates of annual mean nitrate deposition at 188 National Atmospheric Deposition Program stations across the United States (Alexander, R.L., USGS, written commun., 1995). Estimates of nitrogen input from human domestic waste are for 1990 and were calculated from population estimates (U.S. Department of Commerce, 1990) and an estimated per capita loading of nitrogen in untreated municipal waste of 8.65 kg per year. Estimates of municipal and industrial point loadings of nitrogen are typical for the time period 1977-81, and were reported originally as total Kjeldahl nitrogen (Gianessi and Peskin, 1984). Estimates of industrial point sources of nitrogen were included in the total inputs reported in table 1. Estimates of municipal points sources of nitrogen were considered to represent a subset of human domestic waste and were not included in the reported total inputs. The oxidation of soil organic nitrogen also contributes nitrate to surface water and groundwater. However the annual amount contributed by this source is difficult to estimate and is not included in table 1.

Table 1. Estimates of annual nitrogen inputs in metric tons to the Mississippi River basin and its major tributaries (unshaded, bracketed rows indicate a breakdown of the shaded row above into different components).

Sources of Nitrogen	Ohio Basin	Missouri Basin	Mississippi Basin above Missouri River	All of Mississippi Basin[1]
Commercial fertilizer				
all forms as N	1,058,200	1,684,900	1,898,800	5,873,800
as anhydrous ammonium	[336,700]	[871,800]	[901,000]	[2,518,700]
as urea	[156,800]	[251,900]	[271,400]	[970,700]
as nitrogen solutions	[256,000]	[305,100]	[361,100]	[1,142,300]
as miscellaneous forms of N	[256,800]	[181,200]	[329,000]	[974,000]
as ammonium nitrate	[51,900]	[74,900]	[36,200]	[268,100]
Livestock manure	547,600	1,173,300	914,100	3,451,300
Legumes (soybeans and alfalfa)	169,500	324,700	375,500	1,031,900
Atmospheric wet deposition of nitrate as N	130,000	130,200	107,700	512,300
Human domestic waste	222,900	83,300	188,600	627,800
Municipal point sources	[73,100]	[39,800]	[96,600]	[264,000]
Industrial point sources	52,100	2,840	12,600	105,800
Oxidized Soil N	?	?	?	?
Total, all sources	2,180,300	3,399,240	3,497,260	11,602,900

[1]Includes Atchafalaya River, a distributary of the Mississippi, and Red River.

Although most of the inputs of nitrogen to the Mississippi basin can be estimated and the outputs in surface water can be measured, the actual sources of the nitrate transported by the Mississippi River are unknown. How much is from fertilizer applied this year? from fertilizer applied last year and flushed from the soil zone? from manure? legumes? natural sources? Of an estimated 11.6 million metric tons of N added annually to the Mississippi and Atchafalaya basins, approximately 5 1 percent is from commercial fertilizer, 30 percent is from livestock manure, 9 percent is fixed by legumes, 5 percent is from human domestic waste, and 4 percent is deposited by rainfall. Municipal and industrial point discharges of N to rivers are estimated to contribute only 2 and 1 percent, respectively, to the total annual loading of N in the Mississippi basin. However, municipal and industrial point discharges of N are often directly to rivers, whereas the other potential N sources are applied or generated at the land surface. Municipal and industrial point discharges of N to rivers could be the source of *as* much as 25 percent of the total nitrogen discharged to the Gulf of Mexico.

Transport of Nitrogen

The transport of nitrogen (N) from the Mississippi River to the Gulf of Mexico has averaged about 1.5 million metric tons per year since 1980. This flux represents about 13 percent of the estimated annual nitrogen input from all sources except soil nitrogen. About 60 percent of the annual N flux is nitrate, and the remainder is mostly dissolved and particulate organic N. Both the concentration and flux of nitrate tend to be highest in the spring when streamflow is highest. This direct relationship between nitrate concentration and flow may result from leaching of nitrate from the soil and unsaturated zone during periods of high rainfall. Increased flows and elevated nitrate concentrations in agricultural tile drains also may contribute to this relationship.

The available data suggests accumulation of nitrate in the soil and unsaturated zone during dry years, such as the 1988-89 drought, and release of stored nitrate during wet years, such as the 1993 flood. The flux of dissolved nitrate tends to peak in the spring and early summer months when daily flux rates can exceed 5,000 metric tons per day (figure 2). The annual flux of nitrate from the Mississippi River to the gulf has more than doubled over the last 40 years (figure 3). Prior to 1972 annual loads were less than 300,000 metric tons. In the 1980s and 1990s annual loads of 800,000 to 1 million metric tons per year were not uncommon.

The principal source areas for nitrate discharged to the gulf are watersheds draining the combelt states, particularly Iowa, Illinois, Indiana, Ohio, and southern Minnesota. For example, the upper Mississippi basin, above the Missouri River, comprises about 15 percent of the drainage area of the Mississippi basin but contributes more than 50 percent of the nitrate discharged to the gulf. The average annual yields of nitrate in the combelt

Ohio and Indiana are typically were greater than 1,000 kg/km^2 per year for the 1980-96 time period. In contrast, outside of the combelt the annual nitrate yields for this same period ranged from less than 50 to about 300 kg/km^2 per year.

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OVERVIEW OF USGS-WRD MONITORING AND ASSESSMENT PROGRAMS IN THE MISSISSIPPI RIVER BASIN.

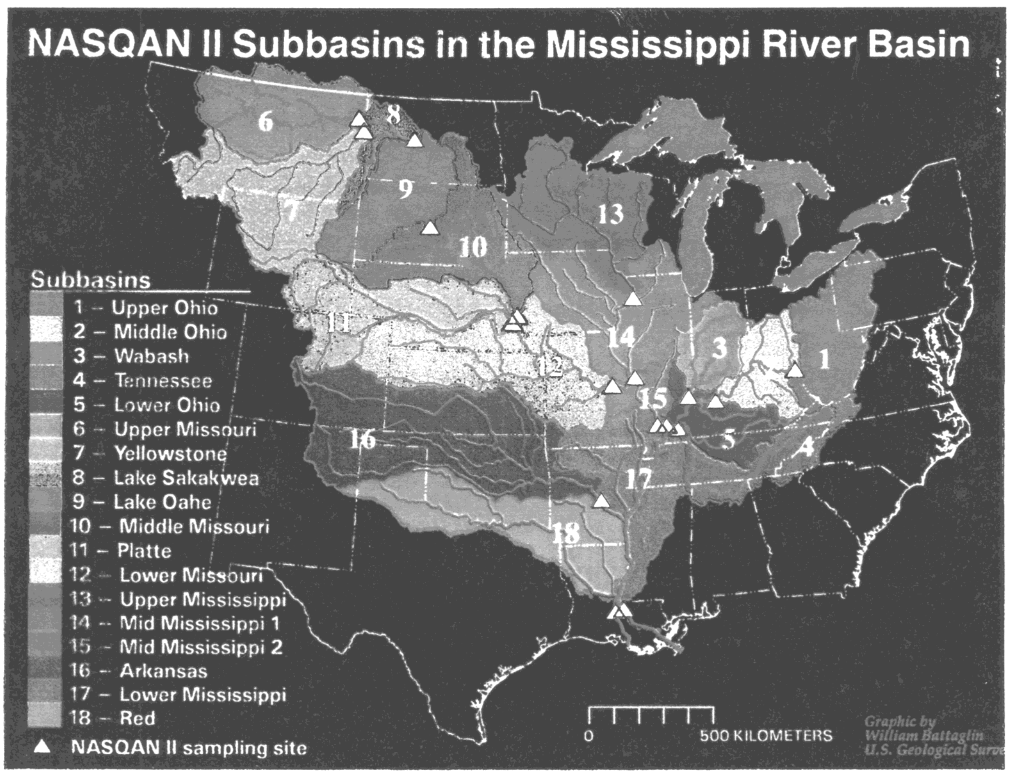
- NASQAN (LARGE SCALE)

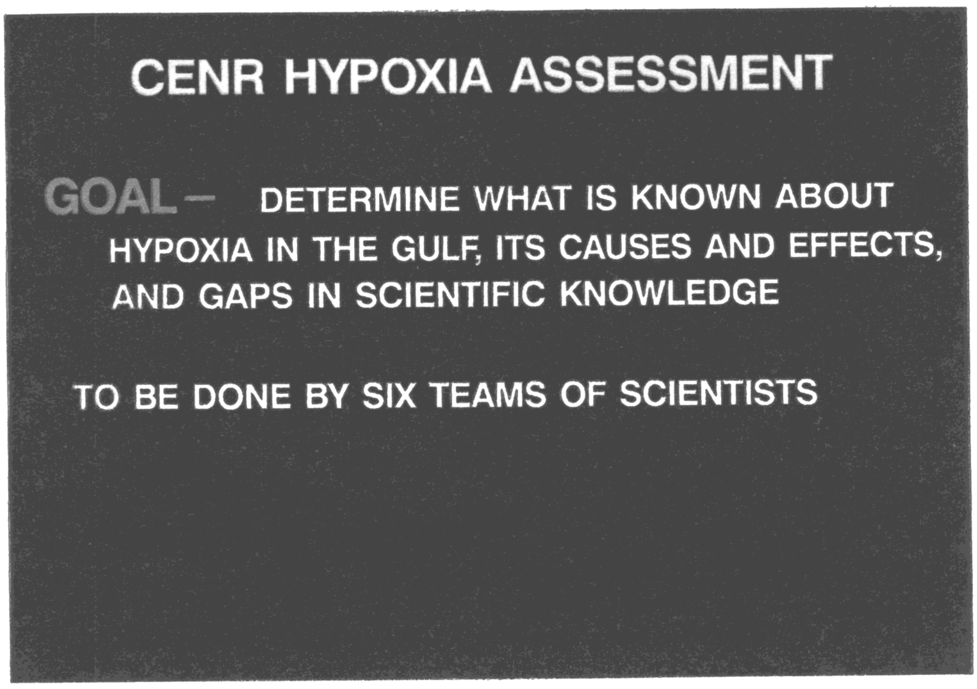
- NAWQA (INTERMEDIATE - SMALL SCALE)

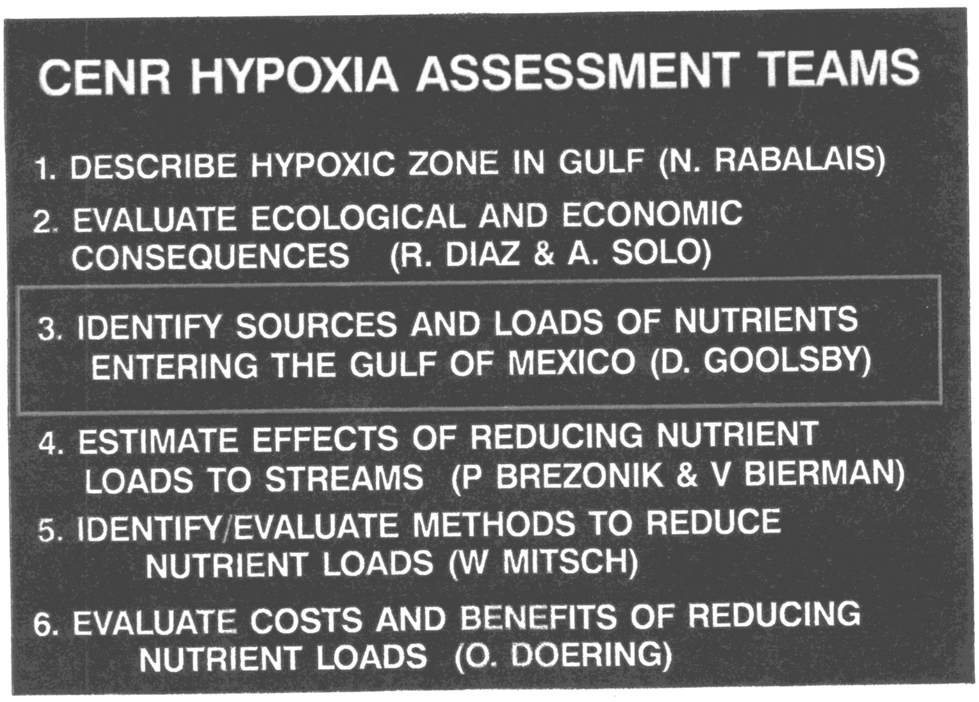
CURRENT WRD ACTIVITIES RELATED TO UNDERSTANDING CAUSES AND EFFECTS OF HYPOXIA IN THE GULF OF MEXICO (CENR ASSESSMENT).

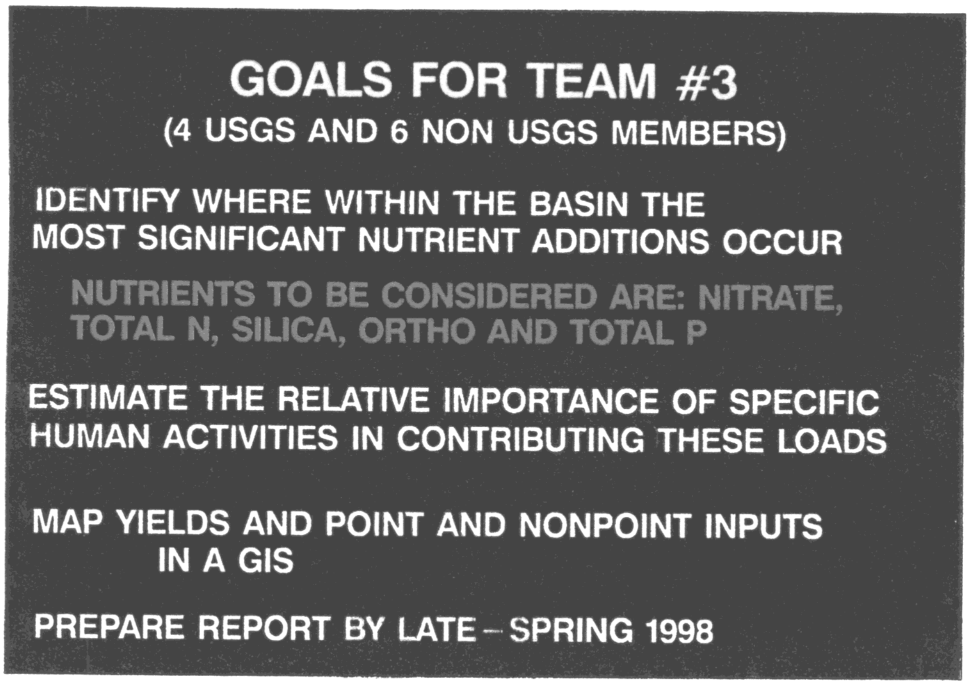
- SOURCES OF NUTRIENTS IN THE BASIN

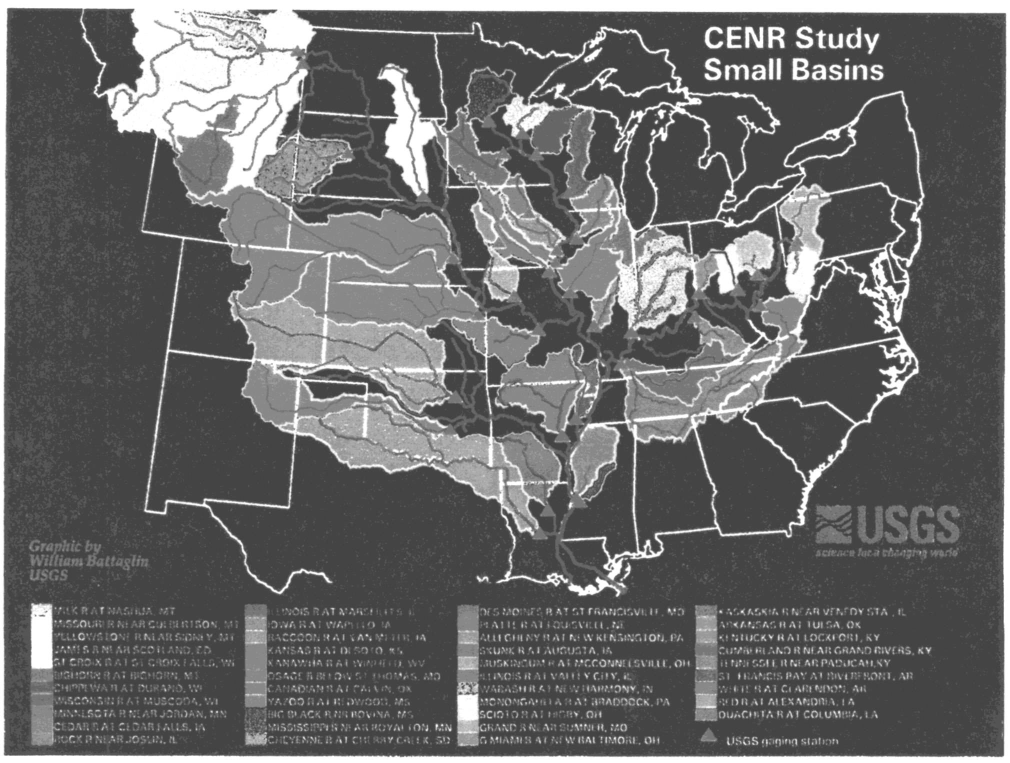
- NUTRIENT YIELDS AND FLUX FROM SUBBASINS

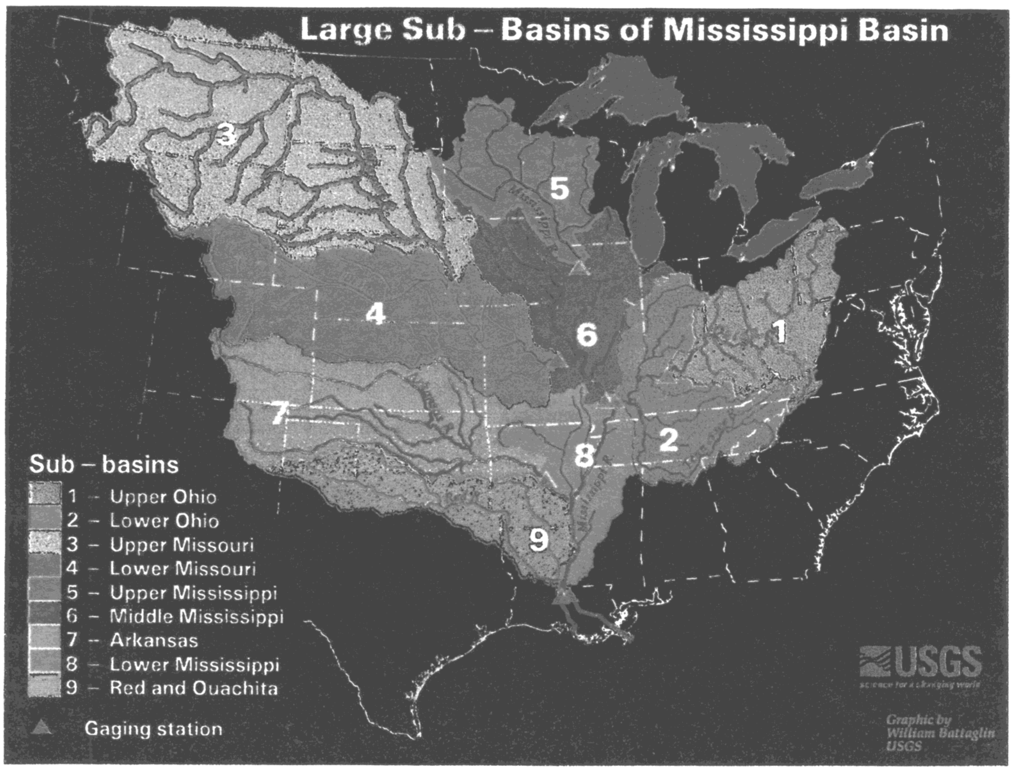


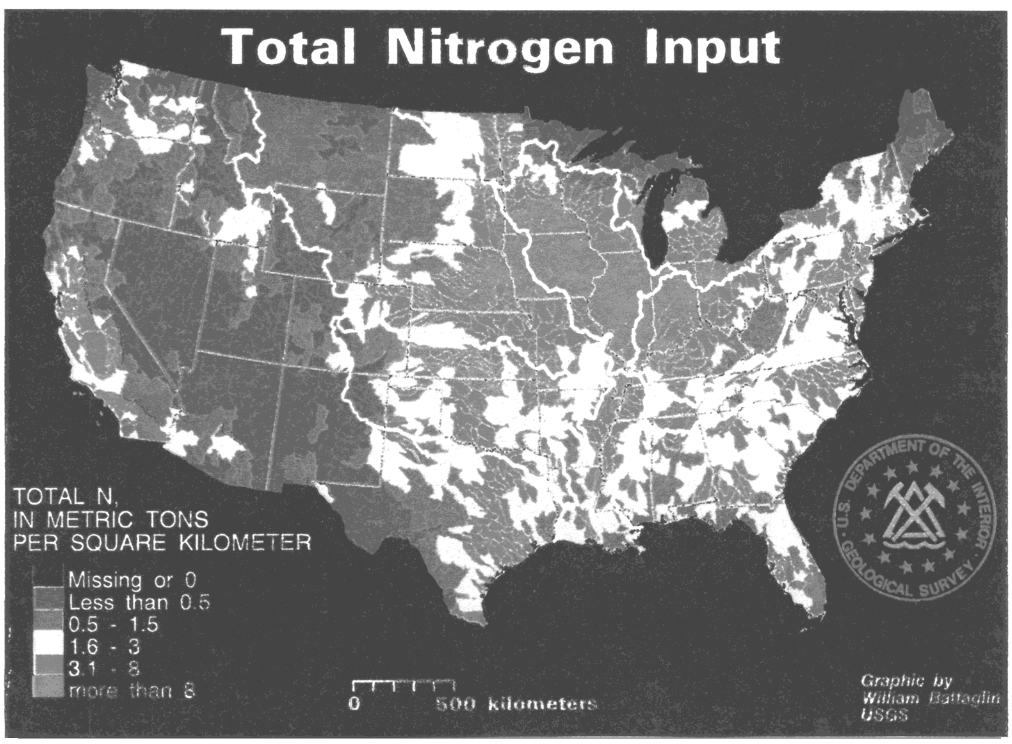

CENR HYPOXIA ASSESSMENT
GOAL – DETERMINE WHAT IS KNOWN ABOUT HYPOXIA IN THE GULF, ITS CAUSES AND EFFECTS, AND GAPS IN SCIENTIFIC KNOWLEDGE
TO BE DONE BY SIX TEAMS OF SCIENTISTS

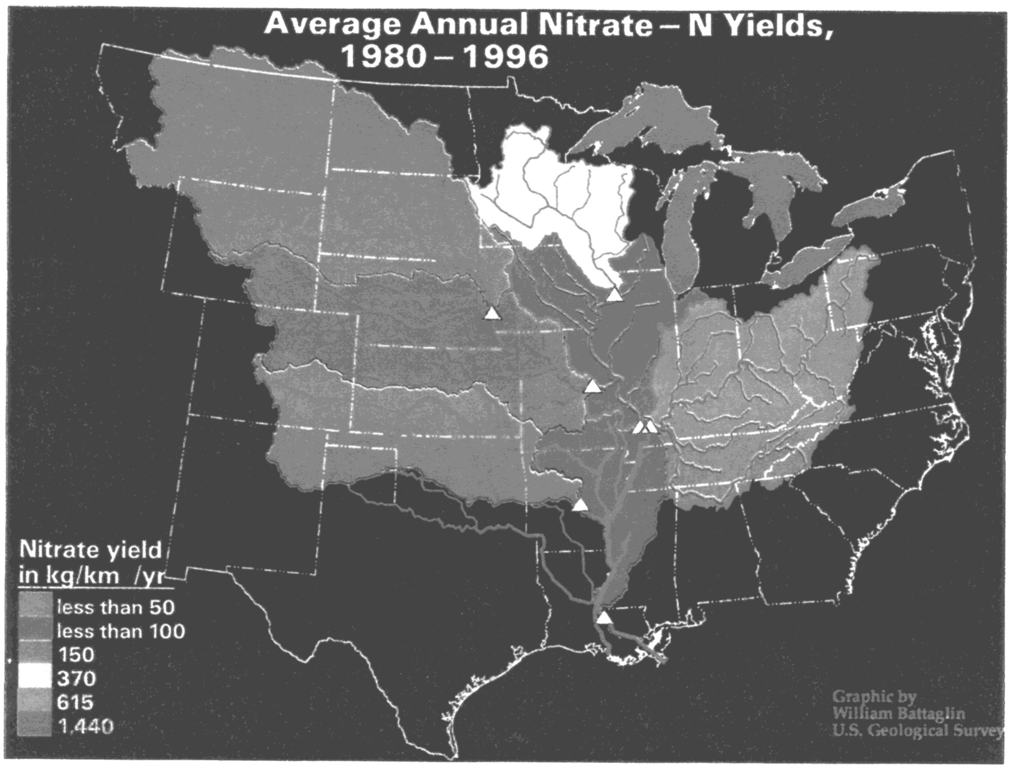

CENR HYPOXIA ASSESSMENT TEAMS
1. DESCRIBE HYPOXIC ZONE IN GULF (N. RABALAIS)
2. EVALUATE ECOLOGICAL AND ECONOMIC CONSEQUENCES (R. DIAZ & A. SOLO)
3. IDENTIFY SOURCES AND LOADS OF NUTRIENTS ENTERING THE GULF OF MEXICO (D. GOOLSBY)
4. ESTIMATE EFFECTS OF REDUCING NUTRIENT LOADS TO STREAMS (P BREZONIK & V BIERMAN)
5. IDENTIFY/EVALUATE METHODS TO REDUCE NUTRIENT LOADS (W MITSCH)
6. EVALUATE COSTS AND BENEFITS OF REDUCING NUTRIENT LOADS (O. DOERING)

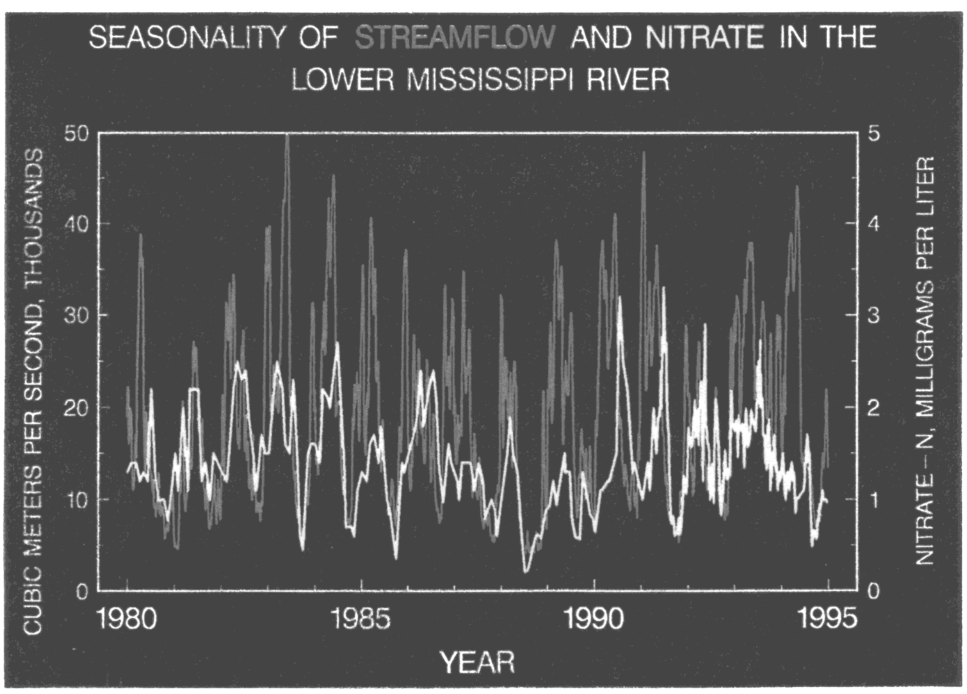

GOALS FOR TEAM #3
(4 USGS AND 6 NON USGS MEMBERS)
IDENTIFY WHERE WITHIN THE BASIN THE MOST SIGNIFICANT NUTRIENT ADDITIONS OCCUR
NUTRIENTS TO BE CONSIDERED ARE: NITRATE, TOTAL N, SILICA, ORTHO AND TOTAL P
ESTIMATE THE RELATIVE IMPORTANCE OF SPECIFIC HUMAN ACTIVITIES IN CONTRIBUTING THESE LOADS
MAP YIELDS AND POINT AND NONPOINT INPUTS IN A GIS
PREPARE REPORT BY LATE–SPRING 1998

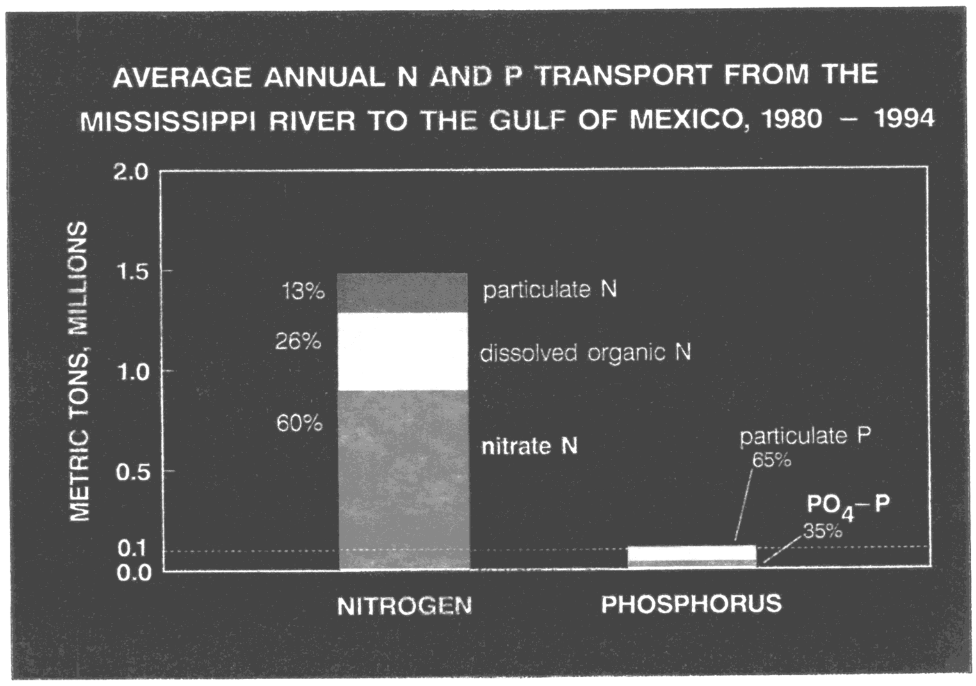

CENR Study
Small Basins
Graphic by
William Battaglin
USGS
USGS
science for a changing world
MISSOURI R NEAR CULBERTSON, MT
YELLOWSTONE R NEAR SIDNEY, MT
BIGHORN R AT BIGHORN, MT
CHIPPEWA R AT DURAND, WI
WISCONSIN R AT MUSCODA, WI
MINNESOTA R NEAR JORDAN, MN
CEDAR R AT CEDAR FALLS, IA
ROCK R NEAR JOSLIN, IL
RACCOON R AT VAN METER, IA
KANAWHA R AT WINFIELD, WV
OSAGE R BELOW ST THOMAS, MO
CANADIAN R AT CALVIN, OK
YAZOO R AT REDWOOD, MS
BIG BLACK R NR BOVINA, MS
MISSISSIPPI R NEAR ROYALTON, MN
CHEYENNE R AT CHERRY CREEK, SD
DES MOINES R AT ST FRANCISVILLE, MO
ALLEGHENY R AT NEW KENSINGTON, PA
SKUNK R AT AUGUSTA, IA
MUSKINGUM R AT MCCONNELSVILLE, OH
WABASH R AT NEW HARMONY, IN
MONONGAHELA R AT BRADDOCK, PA
GRAND R NEAR SUMNER, MO
G MIAMI R AT NEW BALTIMORE, OH
KASKASKIA R NEAR VENEDY STA., IL
ARKANSAS R AT TULSA, OK
KENTUCKY R AT LOCKPORT, KY
CUMBERLAND R NEAR GRAND RIVERS, KY
TENNESSEE R NEAR PADUCAH, KY
ST. FRANCIS BAY AT RIVERFRONT, AR
WHITE R AT CLARENDON, AR
RED R AT ALEXANDRIA, LA
OUACHITA R AT COLUMBIA, LA
USGS gaging station

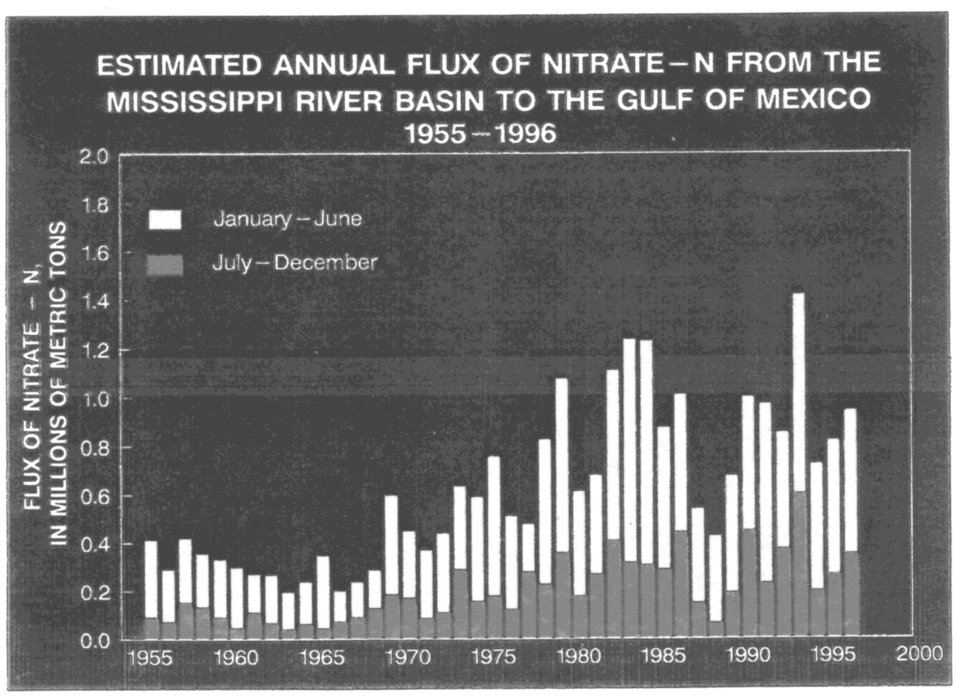

Large Sub – Basins of Mississippi Basin
Sub – basins
1 – Upper Ohio
2 – Lower Ohio
3 – Upper Missouri
4 – Lower Missouri
5 – Upper Mississippi
6 – Middle Mississippi
7 – Arkansas
8 – Lower Mississippi
9 – Red and Ouachita
Gaging station
1
2
3
4
5
6
7
8
9
USGS
Graphic by
William Battaglin
USGS

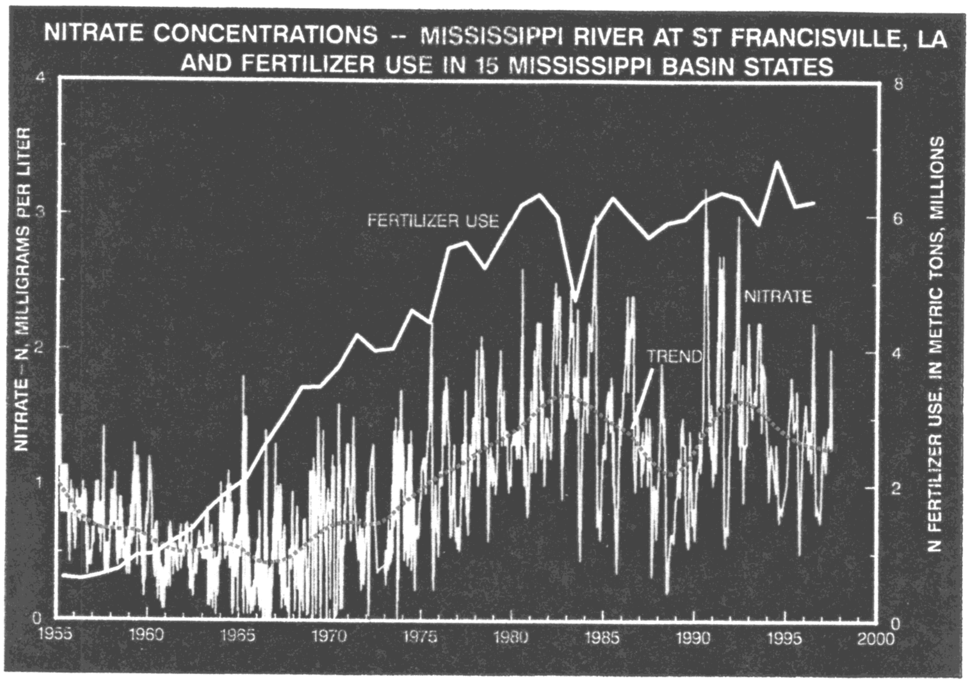

Total Nitrogen Input
TOTAL N,
IN METRIC TONS
PER SQUARE KILOMETER
Missing or 0
Less than 0.5
0.5 - 1.5
1.6 - 3
3.1 - 8
more than 8
0 500 kilometers
U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Graphic by
William Battaglin
USGS

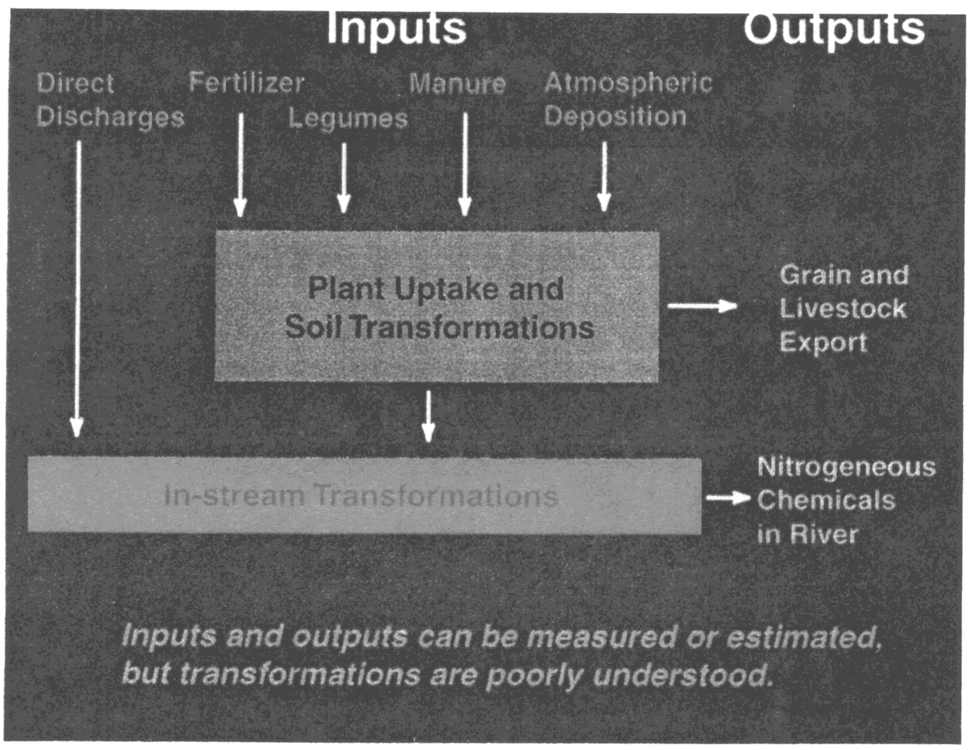

Average Annual Nitrate – N Yields,
1980 – 1996
Nitrate yield
in kg/km /yr
less than 50
less than 100
150
370
615
1,440
Graphic by
William Battaglin
U.S. Geological Survey


SEASONALITY OF STREAMFLOW AND NITRATE IN THE
LOWER MISSISSIPPI RIVER
CUBIC METERS PER SECOND, THOUSANDS
NITRATE – N, MILLIGRAMS PER LITER
0
10
20
30
40
50
1
2
3
4
5
1980
1985
1990
1995
YEAR


AVERAGE ANNUAL N AND P TRANSPORT FROM THE
MISSISSIPPI RIVER TO THE GULF OF MEXICO, 1980 – 1994
METRIC TONS, MILLIONS
2.0
1.5
1.0
0.5
0.1
0.0
13%
particulate N
26%
dissolved organic N
60%
nitrate N
particulate P
65%
PO4 – P
35%
NITROGEN
PHOSPHORUS


ESTIMATED ANNUAL FLUX OF NITRATE – N FROM THE
MISSISSIPPI RIVER BASIN TO THE GULF OF MEXICO
1955 – 1996
FLUX OF NITRATE – N,
IN MILLIONS OF METRIC TONS
January – June
July – December
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000


NITRATE CONCENTRATIONS -- MISSISSIPPI RIVER AT ST FRANCISVILLE, LA
AND FERTILIZER USE IN 15 MISSISSIPPI BASIN STATES
NITRATE - N, MILLIGRAMS PER LITER
N FERTILIZER USE, IN METRIC TONS, MILLIONS
FERTILIZER USE
NITRATE
TREND
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000


Inputs
Outputs
Direct Discharges
Fertilizer
Legumes
Manure
Atmospheric Deposition
Plant Uptake and Soil Transformations
Grain and Livestock Export
In-stream Transformations
Nitrogeneous Chemicals in River
Inputs and outputs can be measured or estimated, but transformations are poorly understood.

‘Appendix F

Presentation Outline and Notes

Hiram Boone
National Resources Conservation Service
(Gulf of Mexico Program)

USDA approach:

1. Watershed basin
2. Locally led
3. Voluntary approach
4. Find leaders within each watershed, and let them set the example and provide the leadership.

I will touch on several points that will deal with nitrogen flow into the gulf:

1. Partnering with Commodity Groups: National Pork Producers (NPP); Odors Management and Environmental Assessment Program. The program will take the top 12,000 producers representing 80% of pork produced in the United States mainly in I7 states (IA, NC, IL, MN, ID, NE, MO, OH, MI, PA, SD, AR, KS, WI, GA, KY, and OK). Iowa has 2,300 producers and Nebraska has 1,600. Each producer has over 1,000 hogs.

   Facilities will be assessed on the basis of their management, engineering, and production practices. Disposal of waste products and manure testing will also be carefully examined.

   Recommendations will be made for safe waste disposal over a 3-year period. This is a $20M program funded by NPP (looking for partners) and government agencies. National Pork Producers are leading the way-still having technical problems-identifying problems and solutions to put the right people in the right places.
2. American Farm Bureau—In the process of developing new program by 1999. Testing of surface water and tile drainage, 2 pilot states.

   Goals:

   1. Education
   2. Data base
   3. Serve as basis to plan for future developments
   4. Encourage research on interaction of nitrogen with water. If drain into wetland, then possibly monitor the wetland to determine the value. The information will be kept confidential as it relates to individual participants. Information can be provided on a watershed basis or area-wide planning unit. The program will be patterned after a very successful well water testing program.
3. Core conservation practices have four initiatives a) conservation tillage, b) nutrient management, c) pesticide management, and d) conservation buffer. We are continuing what we started with 1985 Farm Bill. Will continue to monitor erosion through conservation tillage, improve soil health, less tillage, more organic matter, improve organic mix in soil, help mineralize nitrogen pollutants in place.
4. NRCS is in the process of developing a new policy on nutrient management. It is still in the draft stage but should be finalized soon. Managing the amount, source, placement, form and timing of the application of nutrients, and soil amendments to ensure adequate soil fertility for plant production and to minimize the potential for environment degradation, particularly water quality impairment. Another way to say this: apply more in terms of plant needs, we develop plan with the individual landowner/operator.
5. Pesticide Management-Apply more by prescription according to need rather than on a schedule (for example an operator would not spray a field with herbicides every spring if weed infestation didn’t warrant it). Use a scouting program. Use pesticides that are adaptable to area; for example, in high rainfall areas don’t use a pesticide that is soluble and will runoff or get into groundwater. You would want it attached to the soil to prevent runoff.
6. USDA-75% of agricultural cropland intended to have an IPM by 2000. This will include scouting, risk analysis, prescripton for nutrients and pesticides. IPM is the pesticide part. Add nutrients to the mix and you have integrated crop management (ICM).
7. Buffers-Conservation Tillage intended to keep soil and water in place, decrease erosion, keep chemicals in place. The buffers will help trap nutrients. Thought of as a third tier. Good common sense conservation incorporates grass, riparian corridors, and/or wetlands.
8. Management System Evaluation Area (MSEA)-- Eight areas are being evaluated. Most are in

midwest but we have one in Mississippi. It is located in the delta region involving three oxbow land locked lakes. This project is unique because the other areas are located on streams.

A. The farmers are continuing conventional farm practices with no BMP's, and essentially no control.

B. Some conservation practices applied including BMP's and a few structures.

C. All practices applied including conservation tillage, BMP's, and structural and management practices. Hooded sprayers were used to spray only weeds and only when weeds were present. The GPS-Precision Farming System was used to determine fertilizer rates.

A and B are located in Sunflower County.

C is located in Leflore County.

The three lead research agencies are ARS, USGS, and Mississippi State University. This is a project to evaluate impacts of BMP's on water quality.

NRCS is an Action Agency. Take action through conservation districts and producers. Concentration on work with individuals. We do not have enough people to do bioassessment of natural habitat or water quality monitoring benefits. In the future, the National Wetlands Research Center (USGS/BRD) could identify how well we are doing as we put conservation practices on the ground.

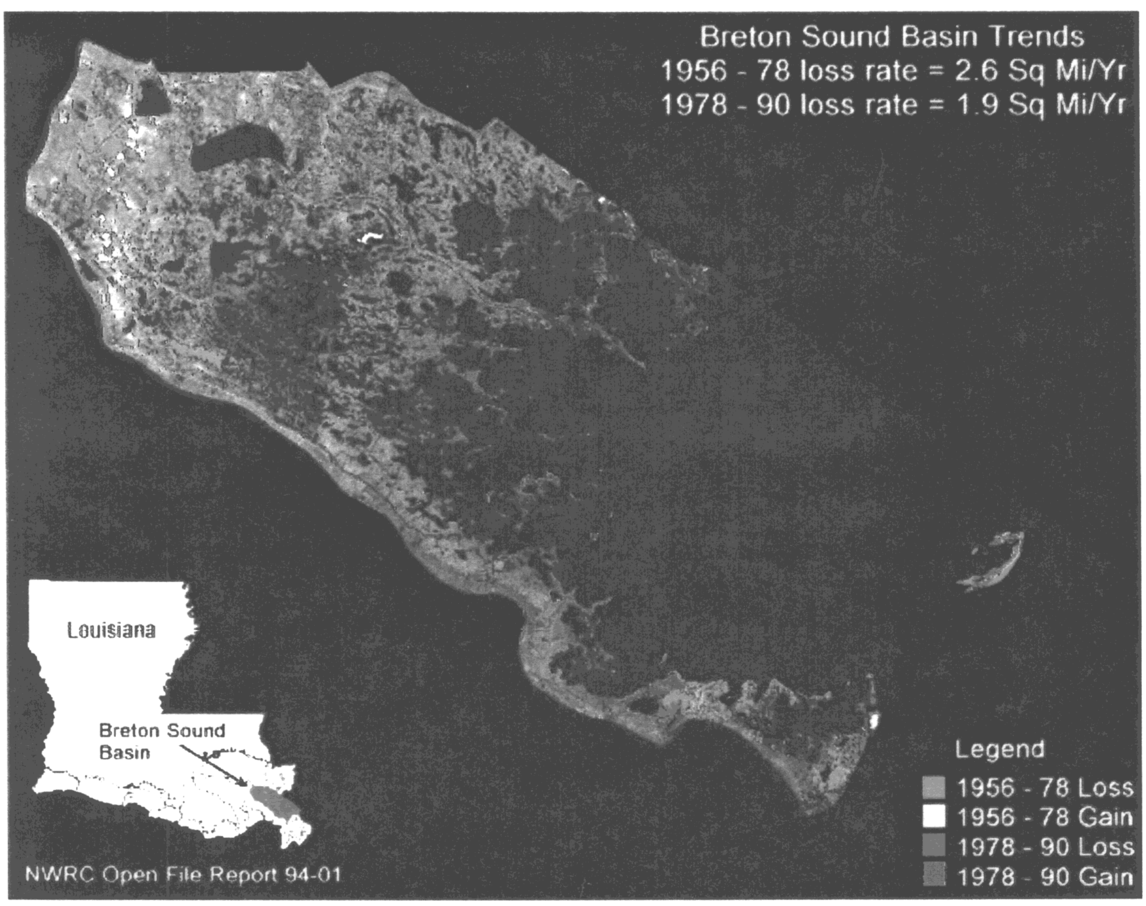
Appendix G
Freshwater Diversions, Nutrients and Hypoxia: Preliminary Observations from Caernarvon

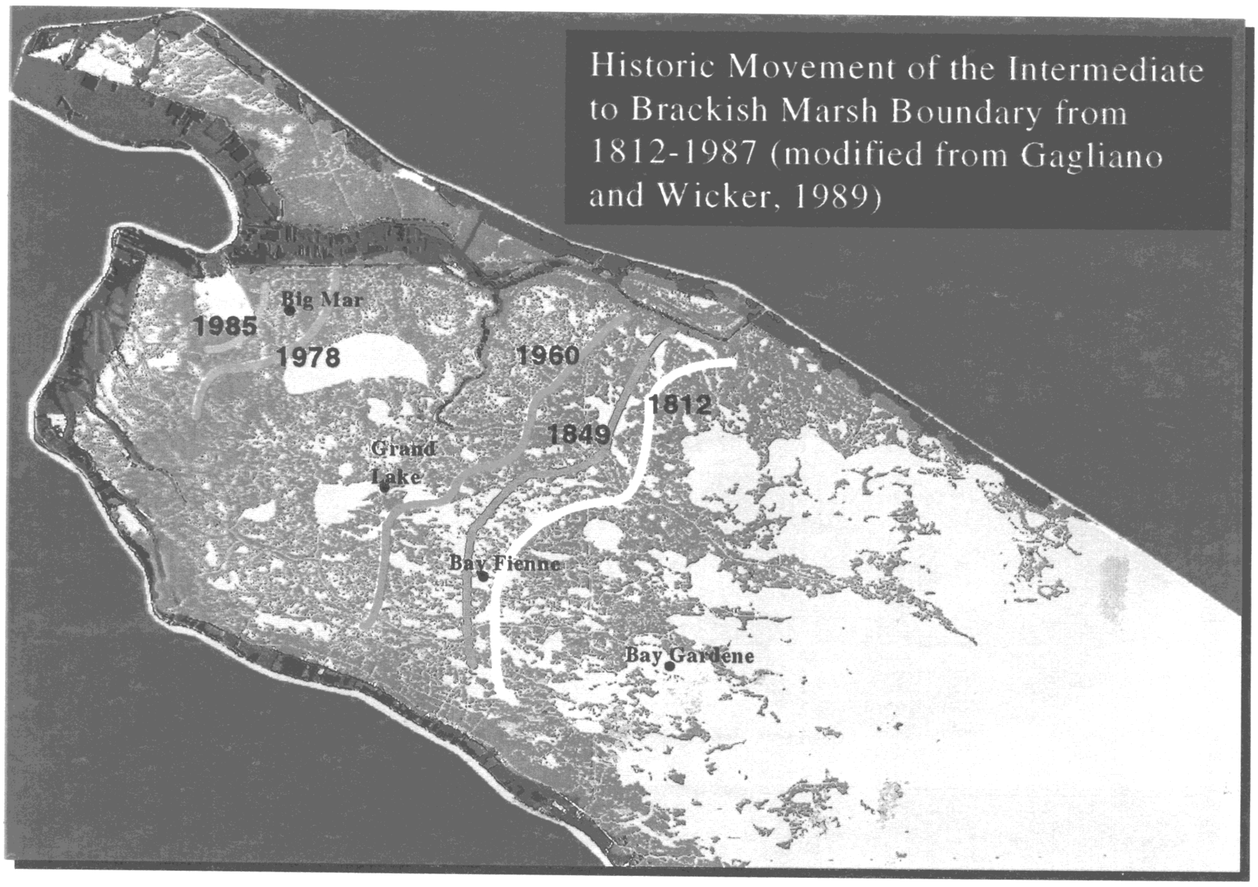
Charles Villarrubia
Louisiana Department of Natural Resources

Abstract

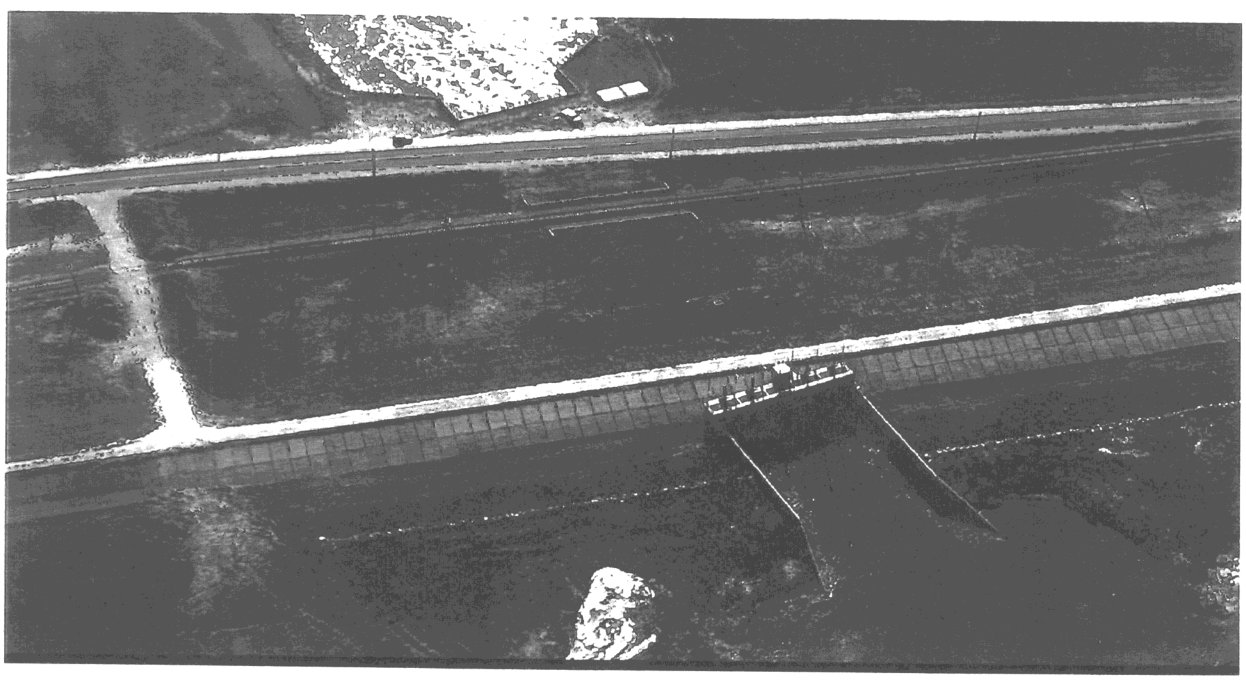
Louisiana has a serious wetland land loss problem; coastal land loss statewide is estimated at 25-35 square miles per year. While there are numerous causes of land loss, the elimination of freshwater, nutrient and sediment input from the Mississippi River has resulted in accretion deficits producing a more open estuary and changes in vegetative, wildlife, and fisheries distribution and productivity. The Caemarvon Freshwater Diversion was authorized by congress under the Water Resources Development Act in 1965 and implemented in 199 1 to restore a more historical salinity regime and to promote marsh development, wildlife and fisheries production in the Breton Estuary. The projects have been largely successful with fresh and brackish habitat increasing, increased marsh accretion and health, and benefits to the majority of fish and wildlife species monitored. Oysters, bass, and muskrat increased dramatically; however, brown shrimp decreased. Monitoring also revealed no significant water quality or eutrophying tendencies at the current level of operation. Adjustments to the operational plan are being made for optimal benefit and to address concerns by the public through the Caemarvon Inter-agency Advisory committee composed of State, Federal and local stakeholders. However, concerns exist regarding using the Mississippi River for coastal restoration purposes. While wetlands can retain or export nutrients, Louisiana coastal wetlands exhibit favorable characteristics which promote nutrient retention: low slope and flow velocity, long retention time, high productivity and long growing season. Recent studies have demonstrated significant reduction of nitrates and nitrites between the Mississippi River input station and all stations in the marsh at the current loading rates of Caemarvon diversion operation. Additionally, increased oyster production on the public seed ground may produce substantial nutrient and phytoplankton utilization prior to reaching the Gulf of Mexico. While river diversion through wetlands may not be a solution to hypoxia in the gulf, it is a step in the right direction along with other comprehensive land use management and non-point nutrient reduction strategies.

Freshwater Diversions, Nutrients and Hypoxia: Preliminary Observations from Caernarvon





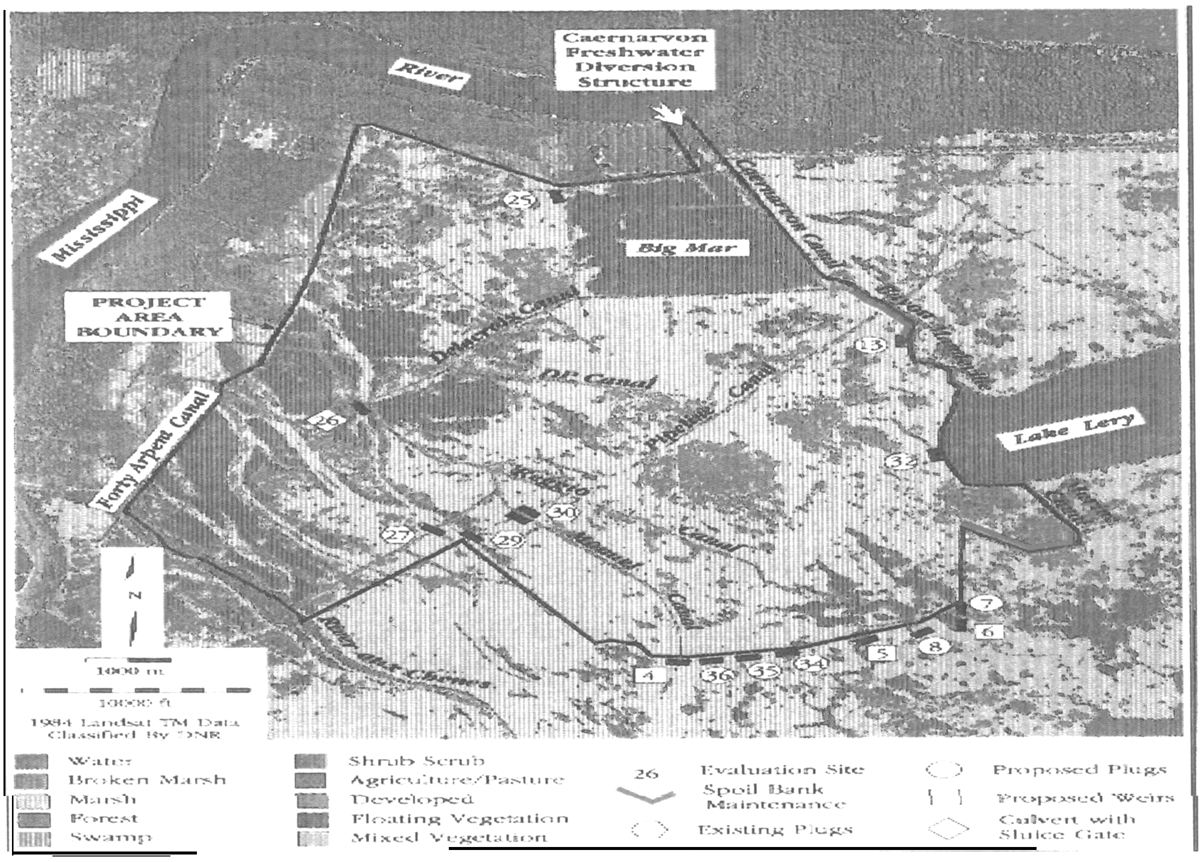
Caernarvon Freshwater Diversion

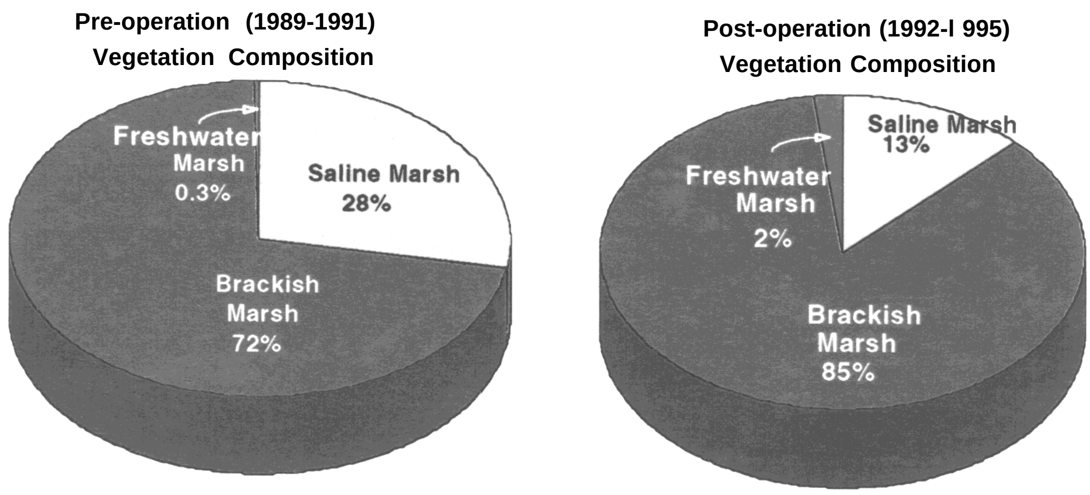


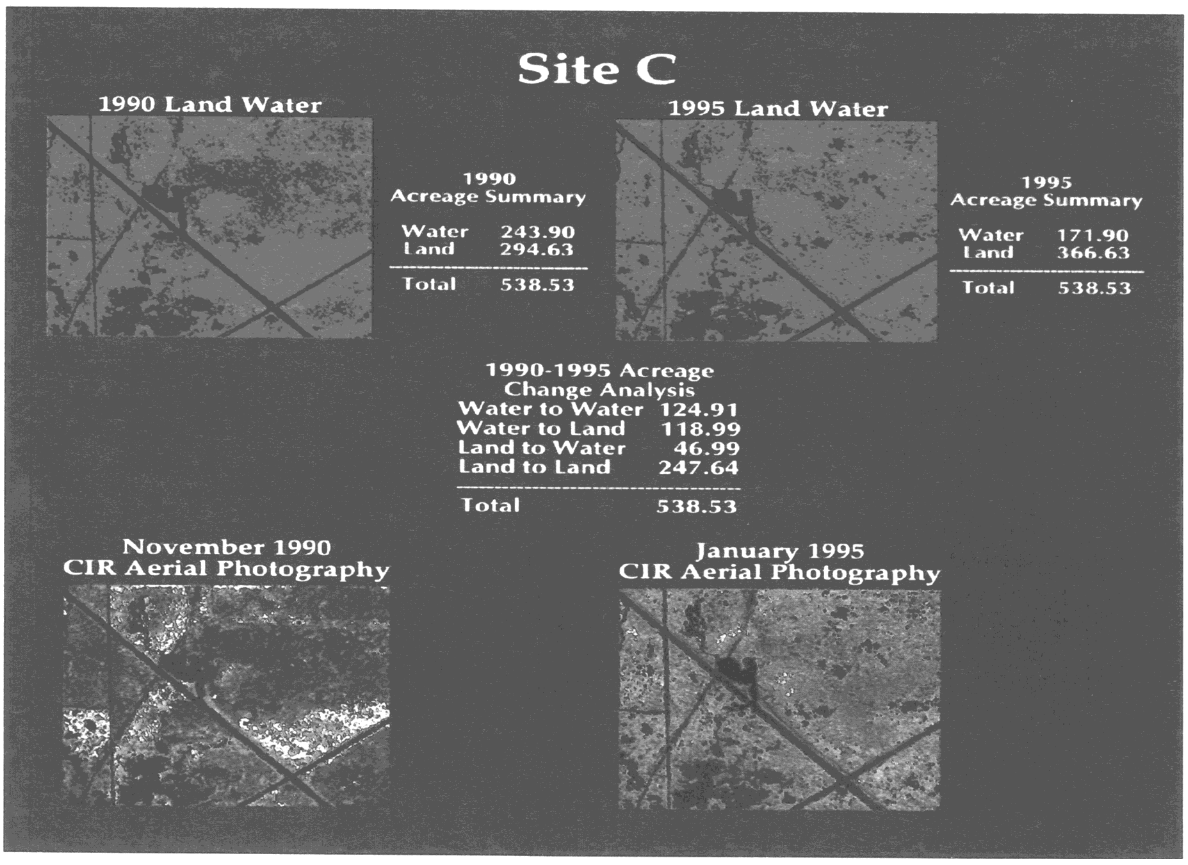
Caernarvon Goals

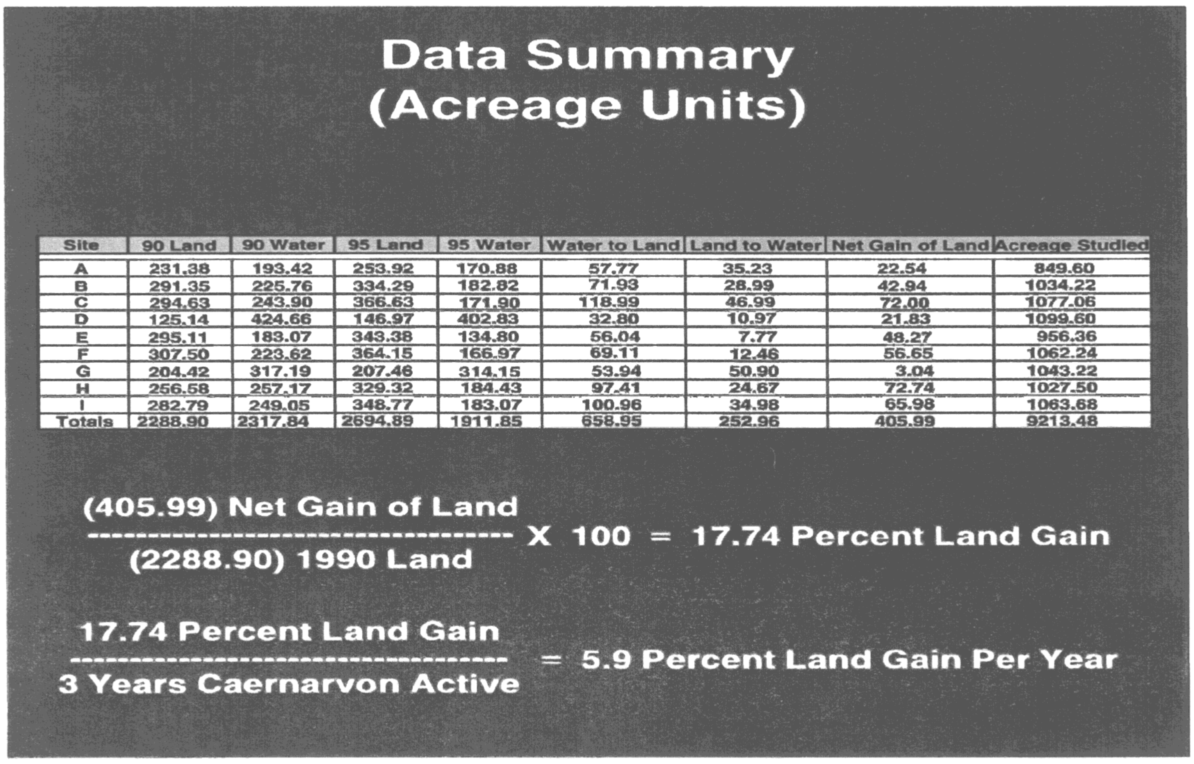
- Enhancement of emergent marsh vegetation growth
- Reduction of marsh loss
- Increase significant commercial and recreational fisheries productivity
- Increase significant commercial and recreational wildlife productivity

Caernarvon Interagency Advisory Committee 1993



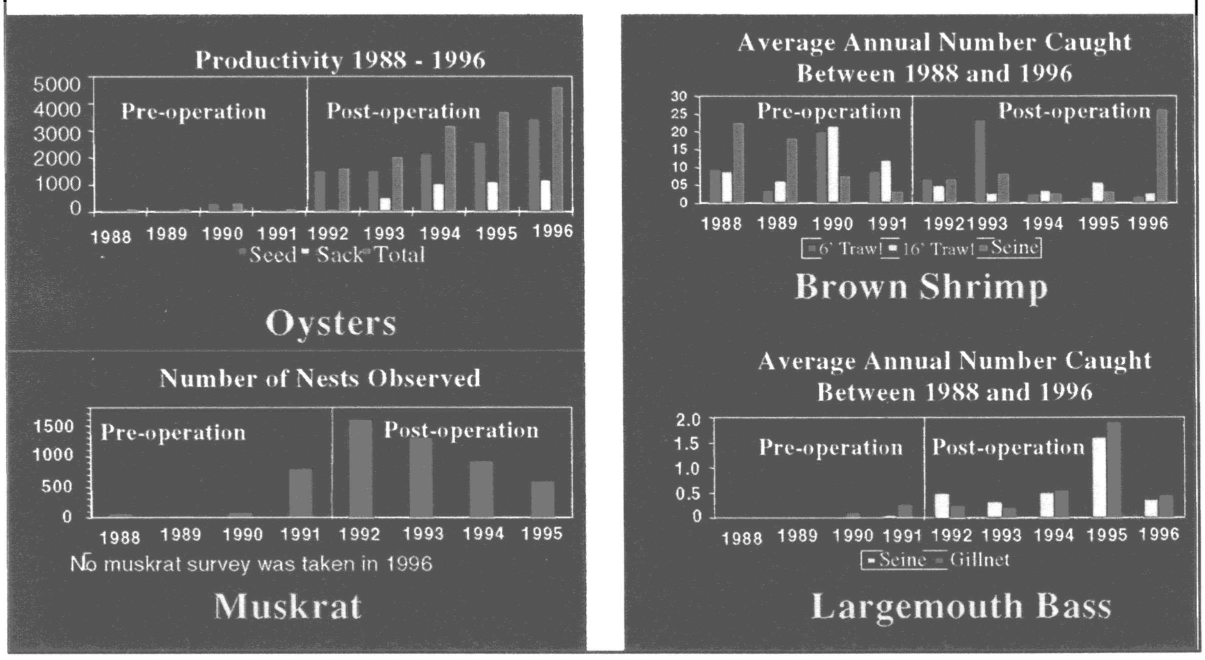

Pre-operation (1989-1991)
Vegetation Composition
Freshwater Marsh 0.3%
Saline Marsh 28%
Brackish Marsh 72%
Post-operation (1992-l 995)
Vegetation Composition
Saline Marsh 13%
Freshwater Marsh 2%
Brackish Marsh 85%

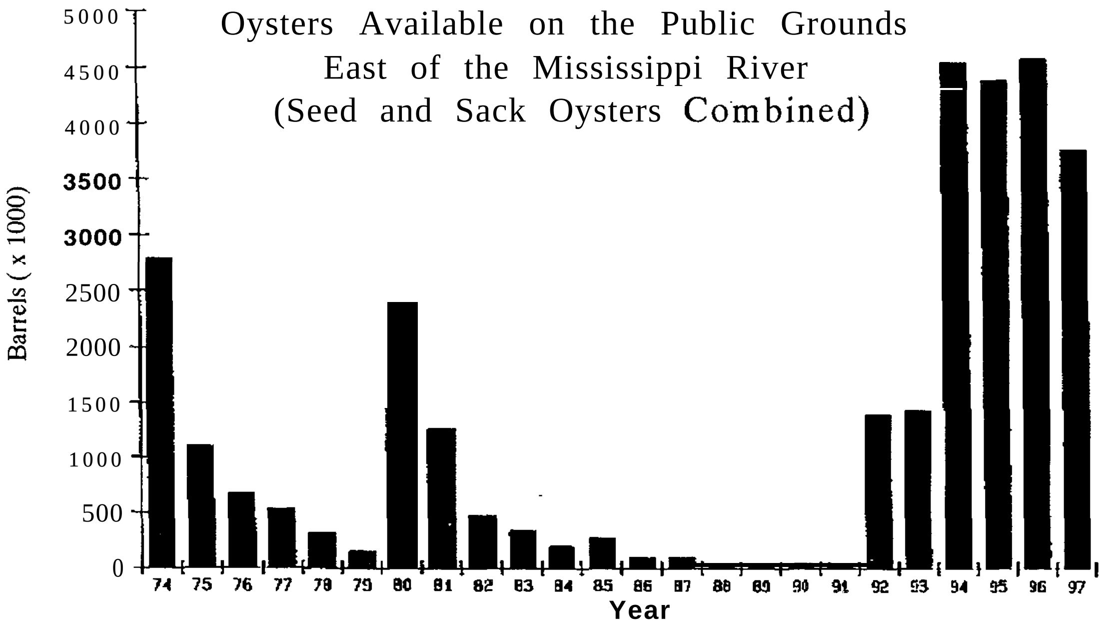

Site C
1990 Land Water
1995 Land Water
1990 Acreage Summary
Water 243.90
Land 294.63
Total 538.53
1995 Acreage Summary
Water 171.90
Land 366.63
Total 538.53
1990-1995 Acreage Change Analysis
Water to Water 124.91
Water to Land 118.99
Land to Water 46.99
Land to Land 247.64
Total 538.53
November 1990 CIR Aerial Photography
January 1995 CIR Aerial Photography



Site	90 Land	90 Water	95 Land	95 Water	Water to Land	Land to Water	Net Gain of Land	Acreage Studied
A	231.38	193.42	253.92	170.88	57.77	35.23	22.54	849.60
B	291.35	225.76	334.29	182.82	71.93	28.99	42.94	1034.22
C	294.63	243.90	366.63	171.90	118.99	46.99	72.00	1077.06
D	125.14	424.66	146.97	402.83	32.80	10.97	21.83	1099.60
E	295.11	183.07	343.38	134.80	56.04	7.77	48.27	956.36
F	307.50	223.62	364.15	166.97	69.11	12.46	56.65	1062.24
G	204.42	317.19	207.46	314.15	53.94	50.90	3.04	1043.22
H	256.58	257.17	329.32	184.43	97.41	24.67	72.74	1027.50
I	282.79	249.05	348.77	183.07	100.96	34.98	65.98	1063.68
Totals	2288.90	2317.84	2694.89	1911.85	658.95	252.96	405.99	9213.48

General Benefits to Wildlife and Fisheries



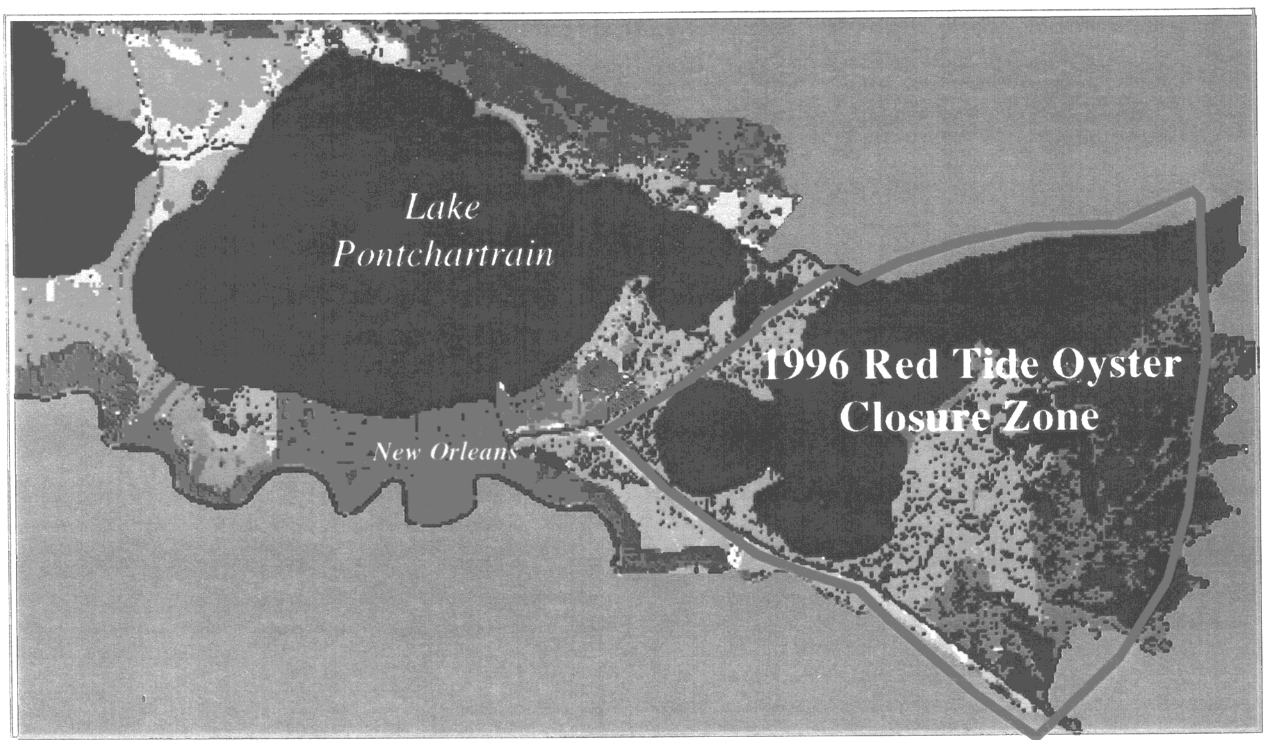


Studies Reveal No Link of Biological Contamination Attributed to Caernarvon

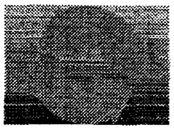
- Analysis by FDA indicates that distant sources of pollution, such as Caernarvon diversion, are not likely responsible for the Norwalk virus outbreak of December 1996; local sources of contamination likely contributed to the outbreak (Interstate Shellfish Sanitation Conference 1997)

Studies Reveal No Link of Biological Contamination Attributed to Caernarvon

- According to USACE 1995 monitoring report, no particular evidence of water quality degradation, fish kills or eutrophying tendencies are known. Although fecal coliform levels have increased in the upper basin, sources other than freshwater diversion, such as increased wildlife populations, may be responsible for this increase



Riverine Reintroduction Observations



- New Marsh Appearing
- Fresh and Intermediate Habitat Reappearing
- Increased Oyster Production on Historic Reefs
- Increased Wildlife Abundance
- Increase in Some Fisheries

The Concern

- If nutrients in Mississippi River water cause problems in the gulf, then do we want to divert river water through our marshes?

General Consensus

- Wetlands can act as sinks or sources for nutrients
- Nutrient retention is highly variable; results from studies do not generalize to other areas
- Hydrologic, biological, chemical and successional stage influence nutrient retention

Wetland Characteristics that Promote Nutrient Retention

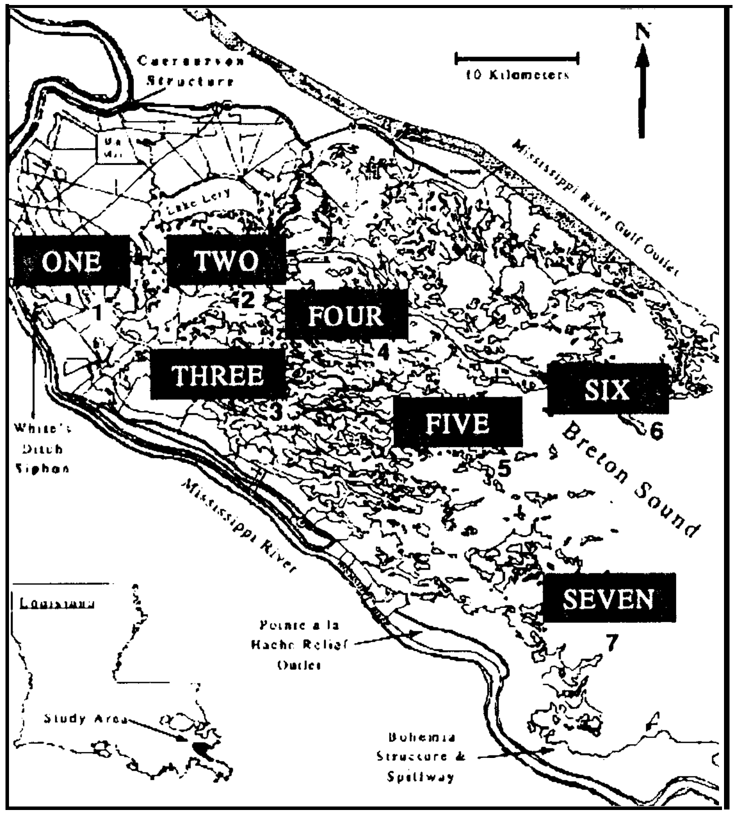
- Hydrology:
  - Low slope and low flow velocity
  - Long retention time
- Vegetation:
  - High productivity: biomass ratio of vegetation
  - Major nutrient input during growing season

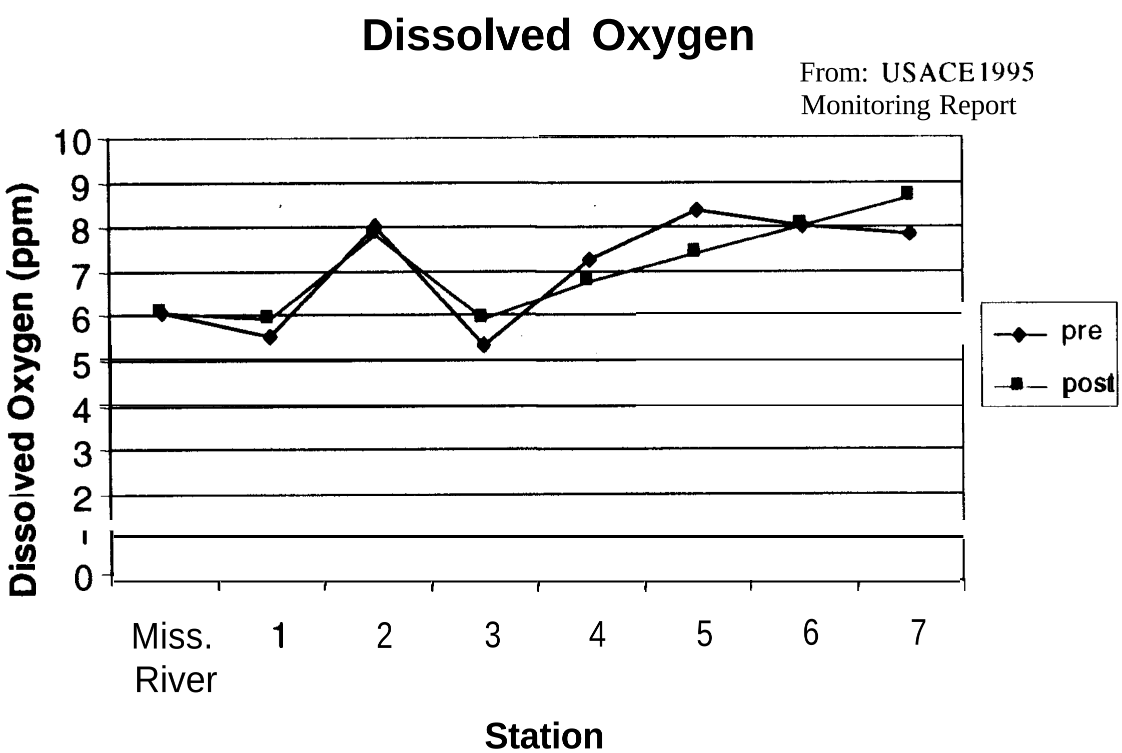
Wetland Characteristics that Promote Nutrient Retention

- Sediments:
  - High sorptive capacity of sediments
  - High sediment accretion rates
  - Anaerobic conditions in sediments
- Microbiota:
  - Diverse microbial community
  - Anaerobic biotransformations

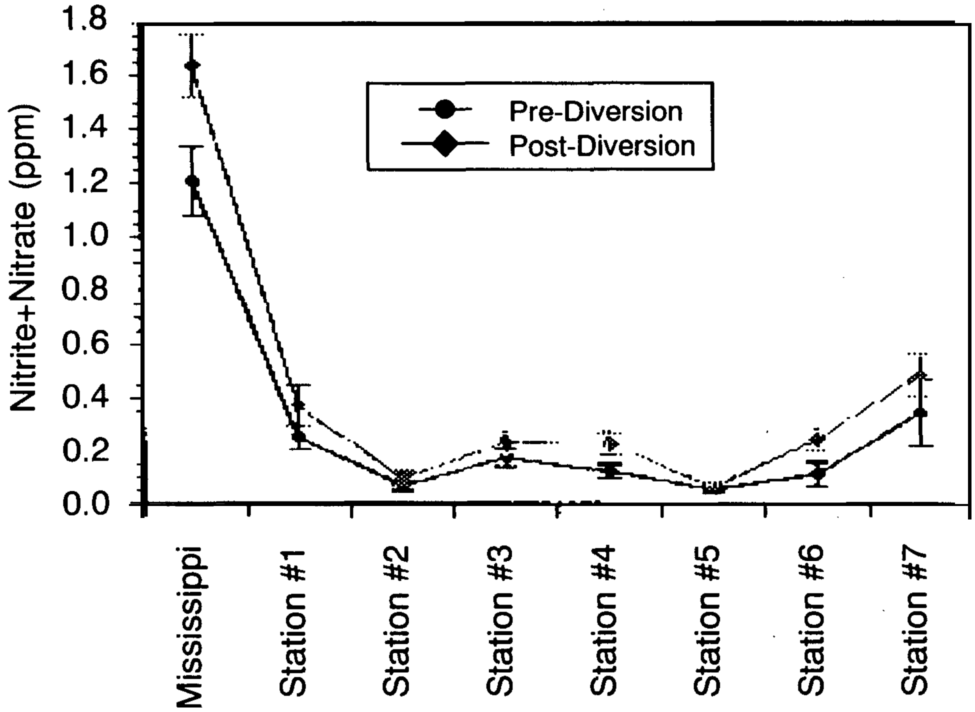
Nutrient Removal Mechanisms

- Direct plant uptake
- Chemical precipitation
- Uptake by algae and bacteria
- Soil absorption
- Denitrification
- Loss by insect and fish uptake
- Human harvesting of fish and wildlife


Caernarvon Structure
10 Kilometers
N
Lake Lery
Mississippi River Gulf Outlet
ONE
TWO
FOUR
THREE
SIX
FIVE
Breton Sound
White's Ditch Siphon
Mississippi River
SEVEN
Louisiana
Pointe a la Hache Relief Outlet
Study Area
Bohemia Structure & Spillway
1
2
3
4
5
6
7


Dissolved Oxygen
From: USACE 1995
Monitoring Report
Dissolved Oxygen (ppm)
10
9
8
7
6
5
4
3
2
1
0
pre
post
Miss. River
1
2
3
4
5
6
7
Station

From Lane, R., J. Day, B. Thibodaux. 1997 Waler Quality Analysis of a Freshwater Diversion at Caernarvon, LA



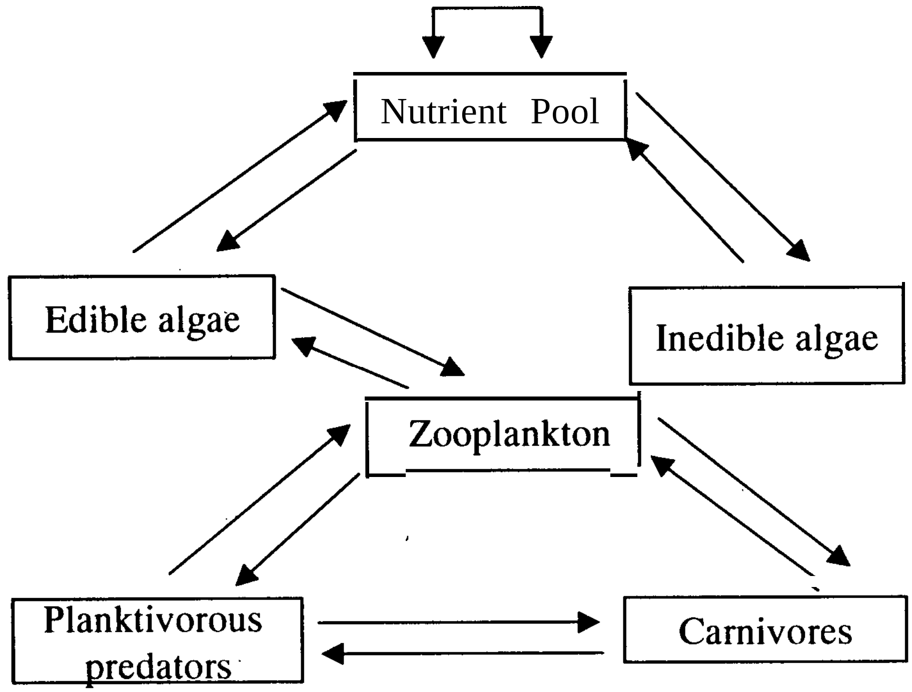
Pre- and post-diversion Nitrite+Nitrate data.

Loading Rate and Removal Between Caernarvon and Station 1

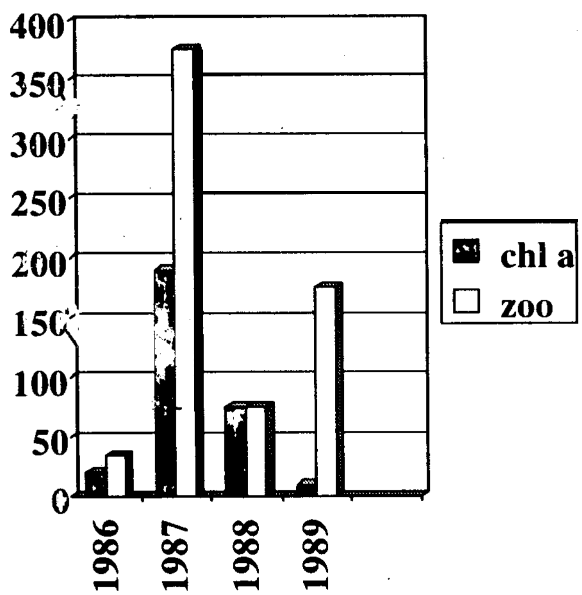
Year	TN Loading (g/m²/y r)	% Removal	TP Loading (g/m²/y r)	% Removal
1992	223	100	2.3	16
1993	30.4	90	3.5	35
1994	58.8	71	5.0	0

From Lane, R., J. Day, B. Thibodaux. 1997 Water Quality Analysis of a Freshwater Diversion at Caemarvon, LA

Eutrophication and Community Structure



Biomanipulation



- Phytoplankton biomass a function of zooplankton removed not nutrients
- Zooplankton positive function of nutrient loading
- Stability depends on maximum phosphorus loading and maximum zooplankton biomass

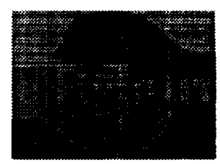
Briand and McCauley 1978

Oysters, Filtration, and Water Clarity

- Drastic decline in oysters in Chesapeake Bay may be major factor in shift in trophic structure and anoxic conditions
- Oysters stabilize DO and pH, cycle nutrients, transfer carbon to sediments
- Oysters filter 3.2-16.7 mg m-2 h-l chl a
- 1870 population remove 23-41% of 1982 phyto/ 1988 levels remove .4%

Gottlieb et al. 1996

Riverine Reintroduction Observations



- Shallow estuarine conditions favor denitrification and other nutrient uptake processes
- River diversions benefit and rebuild marsh vegetation, thereby increasing removal potential
- Healthy oysters populations are beneficial to nutrient removal, cycling, and water clarity
- Although river diversions through wetlands may not solve the hypoxia problem alone, Caernarvon is a step in the right direction
- Comprehensive land use management and non-point reductions are needed