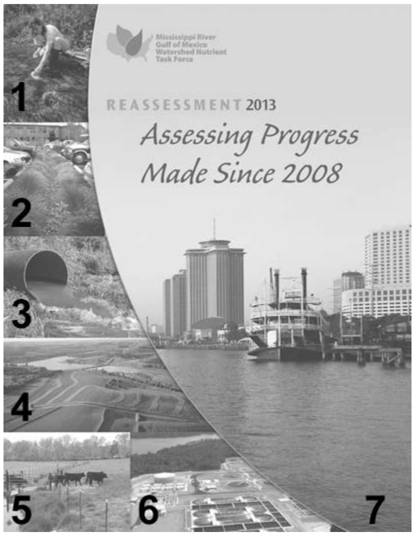
Mississippi River Gulf of Mexico Watershed Nutrient Task Force

REASSESSMENT 2013

Assessing Progress Made Since 2008



Mississippi River Gulf of Mexico Watershed Nutrient Task Force

REASSESSMENT 2013

Assessing Progress Made Since 2008

Cover:

1. Stream monitoring can provide vital information about nutrients in surface waters. (USDA NRCS)
2. Parking lot bioswales can intercept stormwater and allow it to filter through soil, which removes pollutants, including nutrients.
3. Discharge pipes are one type of point source of nutrients. (Missouri USDA NRCS)
4. Terraces, buffers, and conservation tillage are among the practices being used by Shelby County, Iowa farmers in a water quality improvement project to benefit a nearby lake. (USDA NRCS)
5. Stream crossings and exclusion fencing can limit cattle access to water bodies, and ultimately reduce nutrients in surface waters. (Alabama USDA NRCS)
6. Wastewater treatment plants can be upgraded to remove greater amounts of nutrients from wastewater. (USACE)
7. New Orleans skyline along the banks of the Mississippi River. (© istockphoto)

Back Cover: A trawler on the ocean at sunset. (© istockphoto)

Contents

List of Task Force Members as of 2013

State Agencies

Arkansas Natural Resources Commission

Illinois Department of Agriculture

Indiana State Department of Agriculture

Iowa Department of Agriculture and Land Stewardship

Kentucky Department for Environmental Protection

Louisiana Governor's Office of Coastal Activities

Minnesota Pollution Control Agency

Mississippi Department of Environmental Quality

Missouri Department of Natural Resources

Ohio Environmental Protection Agency

Tennessee Department of Agriculture

Wisconsin Department of Natural Resources

Regional Groups

Lower Mississippi River Sub-basin Committee

Ohio River Valley Water Sanitation Commission

Federal Agencies

U.S. Army Corps of Engineers

U.S. Department of Agriculture:
Natural Resources and Environment

U.S. Department of Agriculture:
Research, Education, and Economics

U.S. Department of Commerce:
National Oceanic and Atmospheric Administration

U.S. Department of the Interior:
U.S. Geological Survey

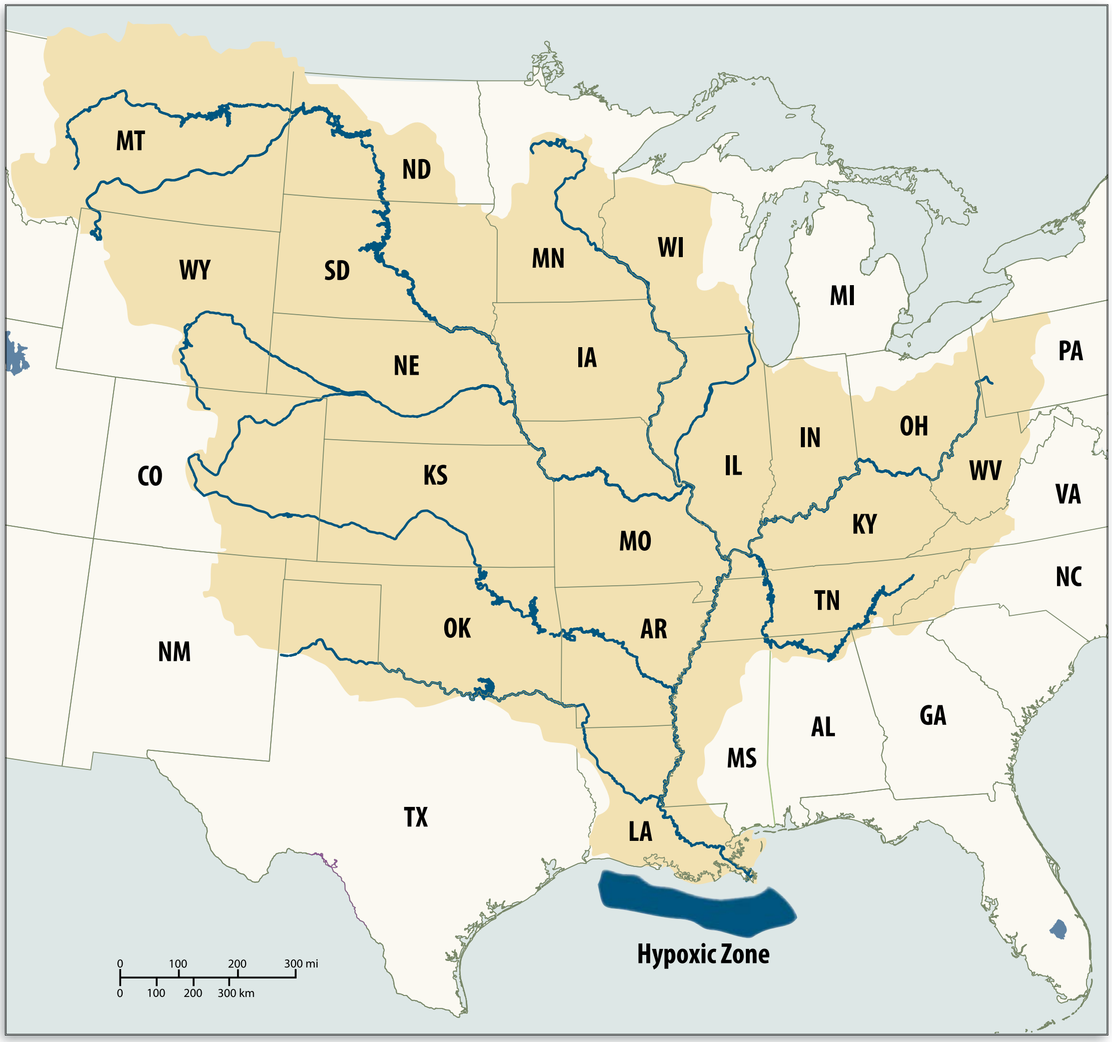
U.S. Environmental Protection Agency

Tribes

National Tribal Water Council

Preface

The Hypoxia Task Force (Task Force), consisting of five federal agencies and 12 states bordering the Mississippi and Ohio rivers, has been working to implement the 2008 Gulf Hypoxia Action Plan. Since 2008, the states and federal agencies have targeted funding to agricultural producers to implement critical parts of the Action Plan, improved partnerships among Task Force members and other organizations with similar goals, and continued to develop new management approaches to reduce nutrient runoff in the Mississippi/Atchafalaya River Basin (MARB) and eventually to the Gulf of Mexico. Although achieving measurable water quality improvements takes time, and more frequent extreme weather events pose challenges, the progress we are making in developing state and federal nutrient reduction strategies, improving access to monitoring data, sponsoring science forums, and coordinating with other Gulf Coast efforts is providing an excellent foundation as we look to the next five years of accelerating our progress.



The MARB and hypoxic zone in the Gulf of Mexico.

Executive Summary

Background

Every summer, a large hypoxic zone forms in the Gulf of Mexico. This hypoxic zone, where dissolved oxygen is too low for many aquatic species to survive, is fueled by nutrient (nitrogen and phosphorus) runoff from the Mississippi/Atchafalaya River Basin (MARB) and is also affected by stratification (layering) of waters in the Gulf. Nutrient-laden freshwater from the MARB is warmer and less dense than the deep ocean water, and contributes to the formation of an upper, less saline, surface layer. This stratification of the water column restricts mixing of oxygen-rich surface water with oxygen-poor deep water. Furthermore, the excessive nutrient loads trigger an overgrowth of algae that rapidly consumes oxygen when decomposed. This decomposition in bottom waters, coupled with water column stratification, results in hypoxia. The nitrogen and phosphorus loads originate predominantly from sources relatively far upstream from the Gulf. Sources of nitrogen include agriculture—both row crop agriculture and animal feeding operations—atmospheric deposition, urban runoff, and various point sources. Sources of phosphorus also include agriculture, urban runoff, point sources, stream channels, and natural soil deposits.

Low dissolved oxygen in the Gulf is a serious environmental concern that can impact valuable fisheries and disrupt sensitive ecosystems. Mobile animals (e.g., adult fish) can typically survive hypoxic events by moving to areas of higher oxygen, but this may push them into less optimal habitats, often along the edge of the hypoxic zone. Exposure to hypoxia can cause severe health effects, such as reduced growth and reproduction. Less mobile animals (e.g., clams, worms) that typically constitute critical food sources for fish populations cannot move to higher oxygen waters and are often killed during hypoxic events.

The Task Force[1] is working to reduce nutrient loads in the MARB and mitigate Gulf hypoxia. It provides a forum for state water, natural resources, and agricultural agencies and federal agencies to partner on local, state, and regional nutrient reduction efforts, encouraging a holistic approach that takes into account upstream sources and downstream impacts. To learn more about the Task Force and each of its member organizations, visit http://water.epa.gov/type/watersheds/named/msbasin/members.cfm.

Learn more about nutrient pollution, hypoxia, and the Task Force at www2.epa.gov/nutrientpollution and http://water.epa.gov/type/watersheds/named/msbasin/index.cfm.

The Task Force 2008 Action Plan

The Task Force developed the **2008 Gulf Hypoxia Action Plan**[2] (http://water.epa.gov/type/watersheds/named/msbasin/actionplan.cfm) as a product of a four-year reassessment of the 2001 Action Plan and the science and steps needed to reduce the size of the hypoxic zone and improve water quality in the Basin. The 2008 Action Plan reflects emerging science, including a report by U.S. Environmental Protection Agency's (USEPA's) Science Advisory Board (USEPA 2008). It describes a basin-wide strategy that reiterates the 2001 Action Plan's goals of reducing, mitigating, and controlling hypoxia in the northern Gulf of Mexico and protecting water quality in the MARB. Eleven key action items in the 2008 Action Plan outline critical needs to complete and implement

---

[1] Also referred to as the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force.

[2] The full title is *Gulf Hypoxia Action Plan 2008*, referred to throughout this document as the 2008 Action Plan.

nitrogen and phosphorus reduction strategies, promote effective conservation practices to manage rural runoff, use existing regulatory controls to reduce point source discharges of nitrogen and phosphorus, track progress, reduce existing scientific uncertainties, and promote effective communication to increase awareness of Gulf hypoxia.

What's Been Done Since 2008: The Focus of this 2013 Reassessment

Action Item 11 of the 2008 Action Plan called for a reassessment in five years:

"In five years (2013) reassess nitrogen and phosphorus load reductions, the response of the hypoxic zone, changes in water quality throughout the Mississippi/Atchafalaya River Basin, and the economic and social effects, including changes in land use and management, of the reductions in terms of the goals of this Action Plan. Evaluate how current policies and programs affect the management decisions made by industrial and agricultural producers, evaluate lessons learned, and determine appropriate actions to continue to implement or, if necessary, revise this strategy."

In response to Action Item 11, the Task Force has developed the 2013 reassessment to provide a snapshot of progress to date in implementing the other 10 action items in the 2008 Action Plan.

Our understanding of the science connecting nitrogen and phosphorus pollution in the MARB with the northern Gulf of Mexico hypoxic zone has advanced considerably since the previous reassessment. These advancements have strengthened the broad consensus in the scientific community that nitrogen and phosphorus loads from the MARB flow down the Mississippi River to the Gulf of Mexico where, in combination with stratification (layering) of the water column, those loads contribute in a significant way to an area of oxygen-depleted water.

Research on the Gulf ecosystem since the last reassessment (2005–2007) has led to a more comprehensive understanding of factors regulating hypoxia, but the overwhelming majority of these studies have reinforced the central tenet of the 2008 Action Plan that "reducing nutrient loadings from the various sources in the Basin addresses the most critical and controllable cause of hypoxia." Reducing nutrient inputs into the MARB and Gulf will continue to be the Task Force's overall approach towards reducing the size of the Gulf hypoxic zone and protecting in-basin waters. The advancement of new tools and analyses has also better refined our approaches to controlling nutrient loads.

In the 2008 Action Plan, the Task Force revised and reaffirmed the Coastal Goal, agreeing to "strive to reduce or make significant progress towards reducing" the five-year running average size of the zone to less than 5,000 square kilometers by 2015, "subject to the availability of additional resources." One of the conclusions from the 2007 Reassessment is that reducing the size of the hypoxic zone to 5,000 square kilometers "remains a reasonable goal in an adaptive management context; however, it may not be possible to achieve this goal by 2015." The nutrient reduction strategies in development by the states are expected to include additional state-level goals and measures of success. Tracking state implementation of the strategies will help the Task Force determine progress towards reducing overall nutrient loads getting to the Gulf. The Task Force has also formed a new workgroup in spring 2013 to discuss not only the time frame for achievement of the Coastal Goal, but also explore the benefits of supplementing the Coastal Goal with other incremental measures that track ongoing nutrient reduction activities and nutrient load reductions.

Trends in Size of Hypoxic Zone

The size of the zone varies considerably year to year, depending on natural and anthropogenic factors (Figure 1). Potential effects of climate change—including severe weather events, prolonged drought, and early spring runoff—compound this variability within the reassessment timeline. For 2013, the hypoxic zone measured 15,126 square kilometers, which was smaller than forecasted due to mixing events and winds forcing the low oxygen water towards the east. In 2012 the zone measured 7,580 square kilometers. Although still larger than the size of the goal, this is significantly smaller than the previous year's size (17,520 square kilometers). Significant flooding contributed to a larger zone in 2011, while the smaller zone in 2012 can be attributed, at least in part, to summer drought conditions in the MARB that resulted in greatly reduced nutrient outputs into the Gulf of Mexico. On the basis of the current five-year running average size of the zone, and as anticipated in the 2007 Reassessment, the Coastal Goal is unlikely to be achieved in 2015. While incremental improvements and significant investments have been made, complex influences of factors like climate change and drought continue to provide significant challenges to measuring success.

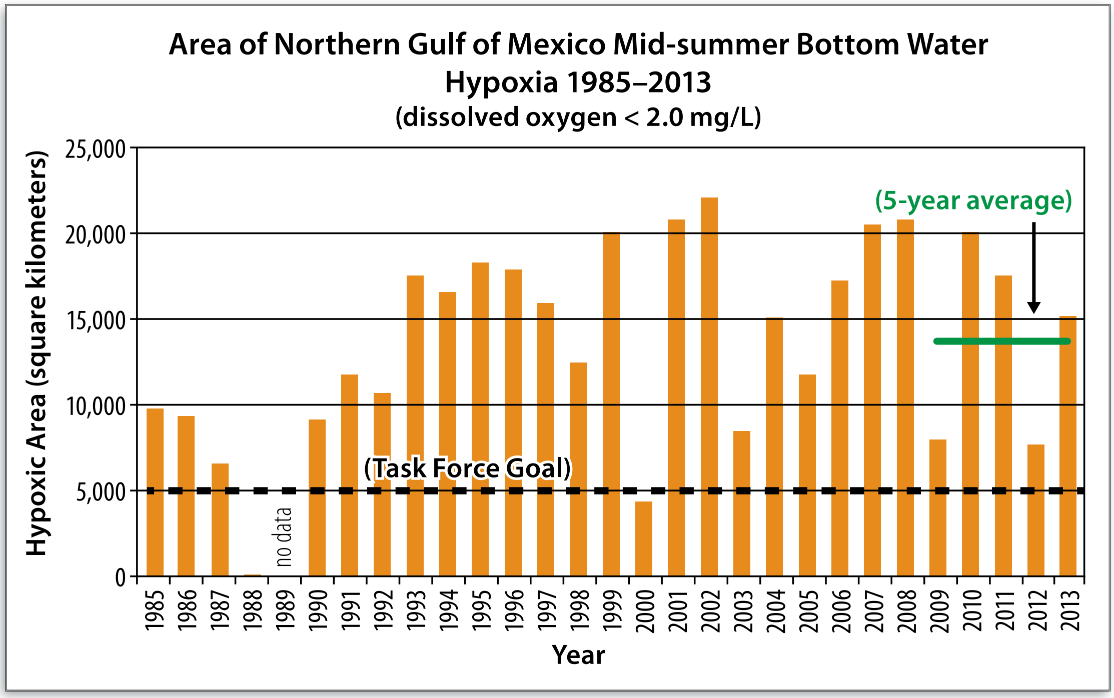


Figure 1. Size of the Gulf of Mexico hypoxic zone from 1985 to 2013.

In-basin Nutrient Load Trends

According to U.S. Geological Survey (USGS) data, annual nutrient loads also vary considerably year-to-year (Figures 2 and 3). Between 1980 and 2011, annual nutrient loads ranged from lows of 810,000 metric tons of total nitrogen (TN) and 73,100 metric tons of total phosphorus (TP) to highs of 2,209,000 metric tons of TN and 213,000 metric tons of TP. The five-year average for TN delivered to the Gulf generally decreased from 1997 to 2007, but it has steadily increased since 2007. The five-year average for TP delivered to the Gulf has generally increased since 1997. Between 1980 and 2008, flow-normalized nitrate concentration and flux at the Mississippi River outlet have increased by about 10 percent. Nitrate concentrations have increased at low and moderate streamflows but decreased at high streamflows. Notably, nitrate concentrations decreased at high streamflows in the spring, when nitrate fluxes were highest. Many factors including population growth, climate change, atmospheric deposition, and changes in farm management practices can influence variability in nutrient loading.

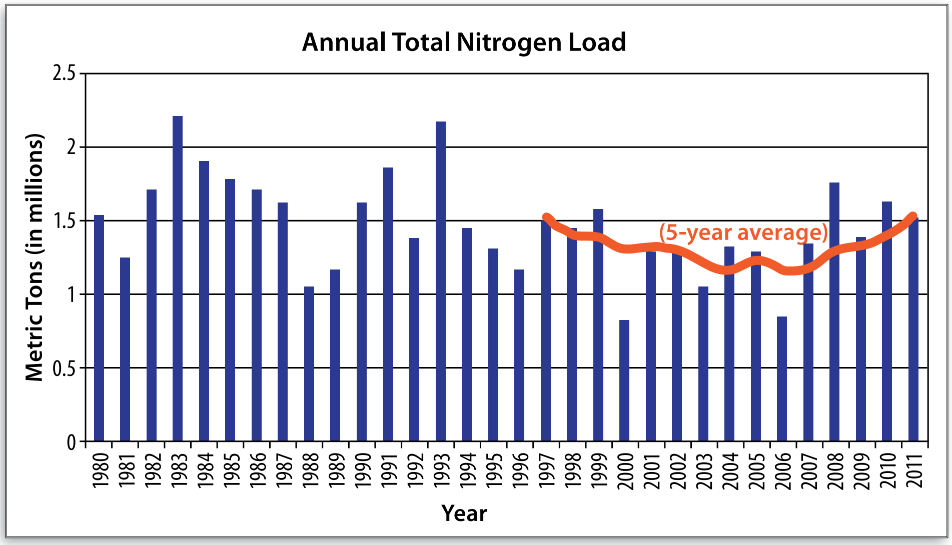


Figure 2. Annual TN loads to the Gulf of Mexico.

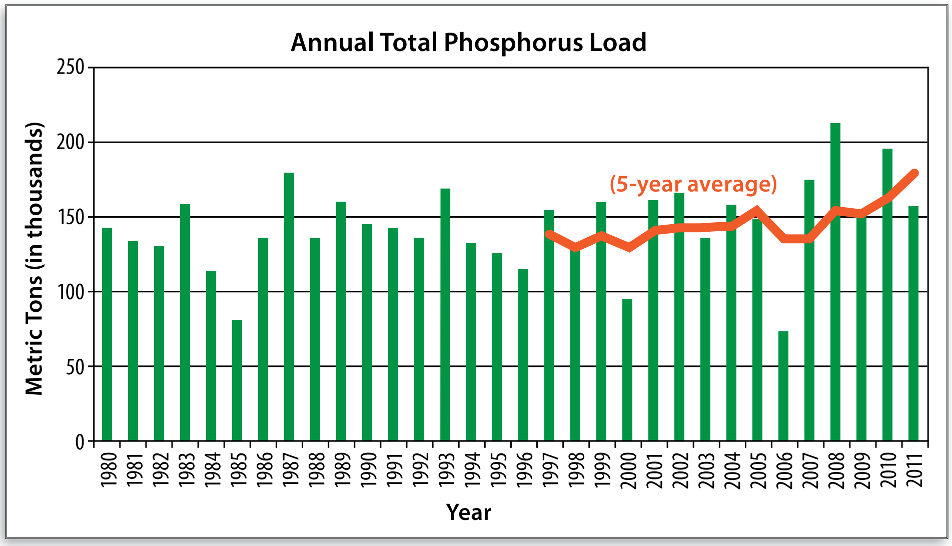


Figure 3. Annual TP loads to the Gulf of Mexico.

Action Items Status Summary

Action Items 1, 2, and 3 of the 2008 Action Plan focus on developing state nutrient reduction strategies (Action Item 1) and federal nutrient reduction strategies (Action Item 2), and looking for opportunities to use existing federal and state programs to enhance protection of the Gulf and local water quality (Action Item 3). The Task Force continues to focus on drafting, finalizing, supporting, and implementing state nutrient reduction strategies as its highest priority. State strategies allow for flexibility yet provide similarly organized, detailed plans for making progress tailored to each state. Five Task Force states have already finalized or released drafts of their nutrient reduction strategies, while all of the remaining seven states expect to have at least draft strategies completed by late 2013 or early 2014.

The Task Force **Federal Strategy** (http://water.epa.gov/type/watersheds/named/msbasin/nutrient_strategies.cfm) provides a blueprint for how federal agencies are currently focusing and planning future activities that provide targeted and well-coordinated support to states. In addition, the Task Force federal agencies have developed a detailed **appendix** (http://water.epa.gov/type/watersheds/named/msbasin/upload/REPORT-Federal-Strategy-090612-_APPENDIX_updated.pdf) to the Task Force Federal Strategy as a reference to help states select, from a broad array of federal programs, those that could best support each phase of developing or implementing their nutrient reduction strategies. The federal agencies have also used the Task Force as a platform to develop new cooperative programs and enhance existing collaborations, increasing opportunities to effectively leverage limited resources to improve in-state water quality and reduce nutrient loadings to the Gulf. Although demand for federal assistance to Task Force states exceeds available resources, federal agencies are devoting significant funds and leveraging these efforts where possible.

While developing these nutrient reduction strategies, the Task Force identified a myriad of other state and federal programs whose primary purpose is not specifically to mitigate hypoxia, but can also be used to address nutrient pollution. Examples of existing federal programs that support states in reducing nutrients include the Clean Water Act section 319 funding program for nonpoint sources and the Environmental Quality Incentives Program administered by the Natural Resources Conservation Service.

Action Item 4 of the 2008 Action Plan focuses on developing, promoting, and evaluating nutrient conservation practices in the MARB. U.S. Department of Agriculture (USDA), which has taken the lead on this action item, has made progress through a variety of actions, such as creating the **Mississippi River Basin Healthy Watersheds Initiative (MRBI)** (www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/farmbill/initiatives/?cid=stelprdb1048200), the National Water Quality Initiative in concert with USEPA and state water quality agencies, and the Gulf of Mexico Initiative to promote conservation systems that avoid, control, and trap nutrients. The MRBI will have targeted over $341 million in technical and financial assistance across 123 projects and 640 small watersheds by the close of fiscal year 2013. In year four of implementation, the demand for MRBI's targeted assistance remains very strong, outstripping the supply of available financial assistance by a margin of over two to one.

Other USDA actions include quantifying the effectiveness of conservation practices, using models to predict impacts of those practices, and delivering technical support to farmers and ranchers in the MARB though a variety of mechanisms, such as learning centers. USEPA has taken the lead on further analyzing nutrient contributions from industrial and municipal point sources and non-agricultural sources (e.g., industries, atmospheric deposition).

Action Items 5, 6, and 7 of the 2008 Action Plan focus on identifying and quantifying the effects of the hypoxic zone on the economic, human, and natural resources in the MARB (Action Item 5); coordinating, consolidating, and improving access to data collected (Action Item 6); and tracking interim progress on actions that reduce nitrogen and phosphorus by producing an annual report on reduction activities and results (Action Item 7). Examples of activities conducted by the Task Force (or its individual member agencies and partners) that address these action items include the following:

- Reviewed various impacts of excessive nutrients in the MARB (e.g., costs associated with nutrient pollution in Grand Lake St. Marys) and impacts of the hypoxic zone in the Gulf of Mexico (e.g., socioeconomic impacts to the shrimp fishery in the Gulf of Mexico). Much work remains to better identify and quantify the effects and benefits of nutrient reduction.
- Developed tools to track and measure progress on meeting the 2008 Action Plan, such as USEPA's Discharge Monitoring Report Pollutant Loading Tool and the Nitrogen and Phosphorus Data Access Tool.
- Released a Water Quality Portal in 2012 that provides consolidated, publicly available water quality data from USGS' National Water Information Systems and USEPA's Storage and Retrieval Data.

Action Items 8 and 9 of the 2008 Action Plan focus on decreasing scientific uncertainty on source, fate, and transport of nitrogen and phosphorus (Action Item 8) and the effects of nutrients on hypoxia (Action Item 9). Action 10 promotes effective communication to increase awareness of the issue and actions being taken. Examples of activities conducted by the Task Force (or its member agencies and partners) that address these action items include the following:

- Convened the MARB Monitoring Collaborative (composed of representatives from each Task Force state and federal agency) to identify monitoring objectives and necessary funding to establish a long-term, multiscale MARB water quality monitoring network using existing sites and resources.
- Conducted basin-wide assessments and used models to greatly increase the understanding of nutrient delivery and transport within the MARB. These models can then be used to evaluate management strategies.
- Convened workshops to coordinate hypoxic zone monitoring and modeling research, provide a forum for discussing the state-of-knowledge and information gaps, and provide updates on Task Force and other efforts.
- Promoted communication of various nutrient reduction activities through updating the Task Force website with relevant information, conducting in-person meetings to share progress and come up with solutions, and using webinars or online virtual workshops to hold numerous sessions on various hypoxia- and nutrient-related topics. In addition, the Task Force is reaching out to organizations who have similar objectives and to identify opportunities to leverage resources for addressing nutrient pollution in the MARB and, ultimately, the Gulf of Mexico.

Numerous other activities have been taken to make progress on each of the action items in the 2008 Action Plan. Read the entire reassessment to learn more (www.epa.gov/msbasin).

Conclusion

As a result of our reassessment, the Task Force believes that the current 2008 Action Plan continues to provide a strong framework for and path toward reducing nitrogen and phosphorus in the MARB and reducing the size of the Gulf hypoxic zone. Its most important recommendations remain valid, and the Task Force members remain committed to its implementation.

The most efficient and effective approach to move forward is for the Task Force to accelerate implementation of the actions contained in the 2008 Action Plan, while refining specific approaches as better science, new tools, and policy innovations become available. One of the refinements is likely to include identifying additional metrics—whether at the basin-wide or state level—to measure interim progress in the Task Force's activities, such as implementation of agriculture best management practices or reductions in nutrient loads at a variety of scales, from small streams to the outlet to the Gulf of Mexico.

The completion and implementation of the state nutrient strategies for all states in early 2014 will be a significant step forward in reducing nutrient loads to the Gulf.

Abbreviations and Acronyms

4Rs	Right source, Right time, Right place, Right rate
ANM	adaptive nutrient management
APEX	Agricultural Policy/Environmental eXtender
ARDE	Atchafalaya River Delta Estuary
ARS	Agricultural Research Service
AUV	autonomous underwater vehicle
BMPs	best management practices
CAFO	concentrated animal feeding operation
CAS	Conservation Activity Standard
CEAP	Conservation Effects Assessment Project
CIG	Conservation Innovation Grant
CPS	Conservation Practice Standard
CREP	Conservation Reserve Enhancement Program
Delta F.A.R.M.	Delta Farmers Advocating Resource Management
DMR	Discharge Monitoring Report
DNRA	dissimilatory nitrate reduction to ammonium
EQIP	Environmental Quality Incentives Program
FY	fiscal year
GOMA	Gulf of Mexico Alliance
GoMI	Gulf of Mexico Initiative
HIF	hypoxia inducible-factor
HUC	hydrologic unit code
HUMUS	Hydrologic Unit Model for the United States
LDEQ	Louisiana Department of Environmental Quality
LOADEST	Load Estimator
LUMCON	Louisiana Universities Marine Consortium
MARB	Mississippi/Atchafalaya River Basin

MDEQ	Mississippi Department of Environmental Quality
MPCA	Minnesota Pollution Control Agency
MRBI	Mississippi River Basin Healthy Watersheds Initiative
NIFA	National Institute of Food and Agriculture
NOAA	National Oceanic and Atmospheric Administration
NPDAT	Nitrogen and Phosphorus Pollution Data Access Tool
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NTT	Nutrient Tracking Tool
NWIS	National Water Information Systems
NWQI	National Water Quality Initiative
OAR	Office of Air and Radiation
Ohio EPA	Ohio Environmental Protection Agency
POTW	publicly owned treatment works
SAB	Science Advisory Board
SEAMAP	Southeast Area Monitoring and Assessment Program
SPARROW	SPAtially Referenced Regressions On Watershed attributes
STORET	Storage and Retrieval Data Warehouse
SWAT	Soil and Water Assessment Tool
TAMU	Texas A&M University
TMDL	total maximum daily load
TN	total nitrogen
TP	total phosphorus
TSP	technical service provider
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WQIag	Water Quality Index for Runoff Water from Agricultural Fields

Action Item 1

State-level Nutrient Reduction Strategies

"Complete and implement comprehensive nitrogen and phosphorus reduction strategies for states within the Mississippi/Atchafalaya River Basin encompassing watershed with significant contributions of nitrogen and phosphorus to the surface waters of the Mississippi/Atchafalaya River Basin, and ultimately to the Gulf of Mexico."

State-level nutrient reduction strategies are a major focus of the Hypoxia Task Force (Task Force). The importance of developing and implementing nutrient reduction strategies to reduce nitrogen and phosphorus pollution in the Mississippi/Atchafalaya River Basin (MARB), and the size of the hypoxic zone, was originally stressed in the first **2001 Action Plan**[1] (http://water.epa.gov/type/watersheds/named/msbasin/upload/2001_04_04_msbasin_actionplan2001.pdf). The 2001 version tasked states, tribes, and federal agencies in the MARB to develop nutrient reduction strategies by fall 2002, using "available data and tools, local partnerships, and coordination through sub-basin committees." The goal of putting strategies in place by fall 2002 was not achieved, and a revised **2008 Action Plan**[2] (http://water.epa.gov/type/watersheds/named/msbasin/actionplan.cfm) was published to incorporate updated science, and to reiterate the goals and commitment of the Task Force in protecting the MARB and Gulf of Mexico.

The Task Force changed its approach between the 2001 and 2008 Action Plans with regard to strategy development. The 2008 Action Plan identifies as its first action item the completion and implementation of "comprehensive nitrogen and phosphorus reduction strategies for states within the MARB encompassing watersheds with significant contributions of nitrogen and phosphorus to the surface waters of the MARB, and ultimately to the Gulf of Mexico" by 2013. By promoting state-level strategies, the Task Force recognizes that no one approach to nutrient reduction can account for the considerable heterogeneity of soils, hydrology, and land use practices as well as administrative and legislative differences across the MARB. Having each state develop and implement its own strategy provides flexibility for tailoring the strategy's approaches and components. State-level strategies will also be the *roadmaps* for decreasing nutrient pollution. They allow for a more detailed basis for developing and implementing load reductions and provide a vehicle for coordinating with federal agencies and other MARB states. States are also most qualified to identify the stakeholders who can influence and support needed changes in practices and programs, targeting activities using their on-the-ground expertise and relationships with the local constituents.

MDEQ

State members of the Hypoxia Task Force meet to discuss state nutrient reduction strategies.

---

[1] The full title is *Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico*, referred to throughout this document as the 2001 Action Plan.

[2] The full title is *Gulf Hypoxia Action Plan 2008*, referred to throughout this document as the 2008 Action Plan.

To aid development of state-level strategies, in 2010, the Task Force established the State Nutrient Reduction Strategy Development Work Group (Work Group)—composed of state and federal members. The Work Group identified essential components of state-level nutrient reduction strategies, resource needs, potential federal resources for strategy development, and other information. As many states identified the lack of funding and other resource support as a major impediment to developing their nutrient reduction strategies, the Work Group also requested funding support for state-level strategy development, development of federal strategies to support implementation of state-level strategies, and continued communication and logistical support for Task Force states. Potential sources of federal funding for the states include programs, grants, or both from U.S. Environmental Protection Agency (USEPA), U.S. Department of Agriculture (USDA), U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA). Additional USEPA funding was also made available to states for strategy development through a USEPA Gulf of Mexico Program Office request for proposals, and two federally sponsored workshops for strategy development were held in 2010 and 2011. A key consideration for these workshops was for each Task Force state to include representatives from its environmental, agricultural, and conservation agencies, as well as stakeholder organizations. This consideration is also consistent with two recommendations under the first action item in the 2008 Action Plan—(1) involve and communicate with all state-level agencies and (2) engage key state stakeholders in the very beginning of the strategy development process.

Furthermore, the Work Group noted that, while states generally prefer flexibility in determining their own nutrient reduction strategy approach and components, an *aligned approach* among MARB states is critical to increasing the likelihood of success in achieving the 2008 Action Plan goal. There was a broad, general consensus among workgroup members on the essential components to be included in a comprehensive state-level nutrient reduction strategy. These components also closely resemble the recommended nutrient framework outlined in the next section.

USEPA Issues Recommended Nutrient Framework

In a memorandum dated March 16, 2011, USEPA Acting Assistant Administrator for Water, Nancy Stoner, set out USEPA's approach for partnering with states and collaborating with stakeholders to make further progress in reducing nutrient loadings to waters nationwide, including the MARB. Titled *Working in Partnership with States to Address Phosphorus and Nitrogen Pollution through Use of a Framework for State Nutrient Reductions*, the memo provides these Recommended Elements of a State Nutrient Framework:

1. Prioritize watersheds on a statewide basis for nitrogen and phosphorus loading reductions
2. Set watershed load reduction goals using best available information
3. Ensure effectiveness of point source permits
4. Control runoff from agricultural areas
5. Control point source pollution from municipal and industrial sources, stormwater runoff, and septic systems

During rain events, stormwater runoff can carry nutrients into local water bodies.

6. Implement accountability and verification measures
7. Submit annual reports on implementation activities, biannual reports on load reductions and environmental impacts in targeted watersheds
8. Develop a work plan and schedule for numeric nutrient criteria development

These eight elements are similar to and consistent with the scope and content of the Task Force states' nutrient reduction strategies. Like the Task Force State Nutrient Reduction Strategy Development Work Group report, the memo recognizes that a one-size-fits-all approach is neither desirable nor needed. At the same time, it identifies certain minimum building blocks for effective programs to manage nutrients (particularly watershed prioritization and load reduction goals), along with effective use of available programs and tools to reduce loadings from point and nonpoint sources. USDA and state departments of agriculture are identified as vital partners in efforts to address nonpoint runoff of nitrogen and phosphorus.

Status on State Strategies *(As of September 2013)*

All Task Force states expect to have at least draft strategies completed by late 2013 or early 2014. Below are state-by-state summaries, based on information gathered from the states, on their progress related to nutrient strategies.

Arkansas

State and federal agencies continue coordinated implementation of nutrient reduction efforts in Arkansas. Voluntary participation in nonpoint source pollution and conservation programs, decreases in point source discharge loadings in surplus nutrient areas, and increases in monitoring represent key elements of Arkansas' nutrient reduction strategy framework. Water resource agencies are discussing how to incorporate and describe these elements fully in the state nutrient reduction strategy document.

Illinois

Illinois' development of a statewide nutrient reduction strategy began with the initiation of a science assessment by the University of Illinois. The science assessment uses available data to update previous nitrogen and phosphorus loading determinations by watershed, identify critical watersheds, assess baseline conditions related to implementation of nutrient reduction practices (point and nonpoint sources), and identify the most effective actions to achieve needed nutrient reductions. This process will be done in consultation with experts in agriculture and wastewater management. In parallel with the science assessment will be development of the policy and strategy, using USEPA's nutrient strategy framework as a guide. The policy and strategy development will actively engage stakeholders who have been working on various aspects of addressing nutrients since 2001, including representatives from wastewater agencies, agricultural groups, government, environmental groups, and academia or technical assistance providers.

Illinois is also continuing its cooperative efforts with the agricultural community regarding the adoption of best management practices (BMPs) intended to reduce nutrient losses from farm fields. For example, the residual nitrogen testing program initiated by agriculture-industry groups last year in response to the 2012 drought will be expanded to include additional watersheds this fall where water quality concerns have been identified. That effort, coupled with the promotion of cover crops, split nitrogen applications, and other BMPs, continues to demonstrate the commitment of its many partners in the private sector to address these concerns. Illinois anticipates completion of its strategy by March 2014.

Indiana

Indiana's draft strategy was released for public comment in July 2013. Its objectives include: acknowledgment of the obstacles facing the improvement of Indiana's impaired waters; prioritization of eight-digit hydrologic unit code (HUC-8) and preliminary HUC-12 watersheds; the inventory and utilization of resources to achieve their highest impact on nutrient reduction; involvement and engaging of stakeholders in the state's efforts to reduce nutrient loads; and in addition to regulatory control of point sources, encouragement of voluntary, incentive-based conservation through the many state and federal water quality related programs. The strategy also encourages outreach and education to conservation partnerships and the public alike regarding stewardship of Indiana's waters. Many of these objectives will be aided by the completion of a science assessment, which will create a comprehensive picture of the state's waters as a whole through a meta-analysis of the state's water quality data and subsequently provide insight as to the direction of Indiana's strategy in the future.

Iowa

A final updated version of the Iowa Nutrient Reduction Strategy was released on May 29, 2013, following updates made in response to public comments received. The public comment period generated a tremendous response with over 1,700 written comments received, and each comment was thoroughly reviewed. Elements of its strategy are consistent with those recommended by USEPA. Its development involved an intensive, two-year collaboration between Iowa's Department of Agriculture and Land Stewardship, Department of Natural Resources, and Iowa State University. In those two years, a large team of experts conducted a scientific assessment to evaluate and quantify the effectiveness of current conservation practices for reducing nutrients. This assessment involved establishing baseline nutrient conditions in Iowa and estimating load reductions of various scenarios and their associated implementation costs. From implementing nutrient reduction practices in both point and nonpoint sources, Iowa aims to reduce its discharge of total nitrogen (TN) and total phosphorus (TP) by 45 percent each.

The updated strategy and a summary of the comments and areas of the strategy that have been changed from the draft report can be found at www.nutrientstrategy.iastate.edu. With a final version of Iowa's strategy in place, the focus now is on beginning implementation.

Kentucky

Kentucky plans to have an early draft of its strategy to stakeholders by the end of October 2013, allowing time for review and revision before the draft is completed in December 2013. The state anticipates that the final document will be complete in spring 2014. An integral part of the strategy will be the continued use of the Kentucky Agricultural Water Quality Act to assure that agricultural operations of 10 acres or greater are implementing BMPs in the control of phosphorus and nitrogen. Under the act, cost-share technical and financial assistance funds have been set aside, routine informational meetings are held, operational inspections performed, and if needed, enforcement actions are taken. As part of the strategy, Kentucky in 2012 entered into an interstate agreement with Ohio and Indiana for an Ohio River Basin Water Quality Trading Project, where funding will be provided to farmers for completion of conservation projects. The trading project is in a pilot stage and focused on a limited number of watersheds, but plans are to expand the program statewide. Probabilistic monitoring of nutrient levels across the state and completion and implementation of nutrient total maximum daily loads (TMDLs) for all impaired waters also figure prominently in the strategy.

Louisiana

In Louisiana, the Coastal Protection & Restoration Authority and the Departments of Agriculture and Forestry, Environmental Quality (LDEQ), and Natural Resources are developing a Nutrient Management Strategy that focuses on improving water quality in state waters and the Gulf of Mexico. Louisiana is evaluating nutrient management activities, implementing BMPs to address nutrient concerns, and considering nutrient trapping and removal through wetland assimilation and river diversion projects. This interagency team recently completed a series of stakeholder engagement meetings with leaders from industries, municipalities, agriculture and forestry groups, nongovernmental organizations, and academic institutions to solicit input. Watershed-level assessments are being done to evaluate water quality trends over the past several decades and to correlate BMP implementation with water quality improvements.

Through participation in the Task Force and Gulf of Mexico Alliance (GOMA) and in review of guidance presented by the Task Force, GOMA, and USEPA, the Louisiana interagency team has identified 10 key strategic components for the Louisiana Statewide Nutrient Management Strategy: (1) stakeholder engagement; (2) decision support tools; (3) regulations, policies, and programs; (4) management practices and restoration activities; (5) status and trends; (6) watershed characterization, source identification, and prioritization; (7) incentives, funding, and economic impact analyses; (8) targets and goals; (9) monitoring; and (10) reporting.

Minnesota

Minnesota's strategy development process involves a collaborative and interagency team of state, regional, federal, and academic partners. A science assessment of water conditions, nutrient loads, sources, trends, and reduction options has already been completed, and the statewide nutrient reduction strategy is scheduled for completion by the end of 2013. Stakeholder engagement will also occur following the release of Minnesota's first draft strategy in fall 2013, including a formal commenting period along with availability for discussions at various stakeholder meetings normally held in December. The final strategy will identify a path forward in reducing nutrient impacts and loads to waters in and downstream of Minnesota, including the Gulf of Mexico. It will integrate environmental goals with actions needed to achieve progress toward meeting these goals. Where achieving overall nutrient reduction goals are cost prohibitive in the short term, Minnesota will consider drafting interim goals and associated adaptive management strategies that will assess progress and move toward achievable milestones. For more information visit **Minnesota's nutrient reduction strategy website** (www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/nutrient-reduction/nutrient-reduction-strategy.html).

Mississippi

Mississippi's Department of Environmental Quality (MDEQ) and its partners have been implementing their comprehensive nutrient reduction strategies throughout the state using available resources. Mississippi's Strategies to Reduce Nutrients and Associated Pollutants resulted from a highly collaborative and stakeholder supported process that aimed to develop and implement a comprehensive approach for nonpoint and point sources of pollution. The strategy development process began in 2009 with a focus in the Delta, which is the state's primary row crop agricultural region. MDEQ and the agricultural stakeholder organization Delta F.A.R.M. (Farmers Advocating Resource Management) jointly led the development of the strategy for this region. Staff members spanning 30 governmental agencies, stakeholder organizations, academic institutions, and farmers all participated in the strategy development process. A similar level of stakeholder engagement also occurred while formulating strategies for the coastal and upland regions, which were then folded into the Delta strategy to establish the state's nutrient reduction strategy. The comprehensive, state-level strategies and the Delta, coastal, and upland strategies are available on the MDEQ website at: www.deq.state.ms.us/MDEQ.nsf/page/WMB_Basin_Management_Approach?OpenDocument.

Missouri

Missouri held its first committee meeting in October 2011, and more than 100 stakeholders participated in committee and workgroup meetings. In addition, a USEPA Gulf of Mexico Program Office grant was awarded to Missouri and used to hire two temporary full-time employees to assist with developing the Missouri Nutrient Reduction Strategy. To date, Missouri has developed a vision statement, guiding principles, watershed nutrient loading potential spreadsheet, and numerous strategies. Missouri has also held regular meetings with stakeholders to build stakeholder support and address many of their concerns prior to the public comment period.

Ohio

In July 2013, Ohio Environmental Protection Agency (Ohio EPA) formally submitted its nutrient reduction strategy to USEPA Region 5 for review. Ohio EPA collaborated with the Ohio Departments of Natural Resources and Agriculture to develop the strategy, which also incorporates input from two advisory groups on agricultural and point sources of nutrients, as well as recommendations solicited through stakeholder and public workgroups. The strategy identifies the activities to improve effectiveness of point source permitting and targeted implementation of nonpoint nutrient abatement practices. Ohio EPA and other state agencies will continue to pursue further stakeholder engagement and public input to refine and implement the strategic approaches and practices laid out in their nutrient reduction strategy.

Tennessee

Tennessee has a draft nutrient reduction framework that will be in a final form by December 31, 2013. However, consistent with its Clean Water Act section 104(b)(3) grant, Tennessee plans on holding stakeholder meetings in 2014 and 2015. The meetings will be with farmers (for the nonpoint sources component) and with National Pollutant Discharge Elimination System (NPDES) permit holders (for the point sources component). Given that the purpose of these meetings will be to solicit feedback from the point and nonpoint communities, the framework will likely change. The point and nonpoint source portions of the framework in draft form are essentially complete. Tennessee has planned meetings with agricultural stakeholders in order to determine the most cost-effective management practices to address nutrient management. The state believes that the most effective means to address agricultural nutrient management is through a farmer-led approach. Tennessee has conducted one producer meeting, and there are more planned in 2014 and 2015. These meetings will hopefully bring together a core group of agricultural leaders to take ownership of this issue and lead by example.

Wisconsin

Wisconsin released a draft strategy for public comments in September 2013 with substantial input from federal, state, and local agencies and stakeholders. This multiagency workgroup has prioritized a group of HUC-10 watersheds for phosphorus and nitrogen reduction to surface waters and nitrates to groundwater. The strategy also provides information on progress in enhancing nutrient load and trend monitoring at the HUC-8 level and creating a structure for tracking at the HUC-12 level, using county-level nonpoint source best management tracking systems and point source discharge monitoring reports (DMRs). It also documents how past implementation efforts have reduced by about 23 percent the amount of phosphorus from Wisconsin watersheds to the Mississippi River. The strategy is generally organized around the eight elements recommended by USEPA and is intended to be a "living" document that changes to reflect new developments and advances in Wisconsin's nutrient reduction efforts.

Action Item 2

Comprehensive Federal Strategy

"Complete and implement comprehensive nitrogen and phosphorus reduction strategies for appropriate basin-wide programs and projects. Target first those programs and projects with significant federal lead or co-implementation responsibilities."

The Task Force **Federal Strategy** (http://water.epa.gov/type/watersheds/named/msbasin/nutrient_strategies.cfm) emphasizes an approach that integrates federal efforts to work collaboratively in identifying opportunities to align programs across agencies to support the development and implementation of the state nutrient strategies. It provides a blueprint for how federal agencies are currently focusing and planning new future activities that provide targeted and well-coordinated support to states. The strategy also enhances the dialogue between federal agencies and states, identifies actions that can leverage federal resources, and addresses the Task Force's overall goals for implementing the 2008 Action Plan. The strategy is organized around the key areas identified in past Task Force meetings as priorities:

- Monitoring programs to measure water quality improvement over the long term
- Decision support tools
- In-basin and Gulf modeling to target high-priority areas and predict water quality impacts
- Regulatory program activities that target nitrogen and phosphorus loads
- Financial and technical assistance
- Outreach and education initiatives that expand awareness and broaden partnerships

In addition, the Task Force federal agencies have developed a detailed **appendix** (http://water.epa.gov/type/watersheds/named/msbasin/upload/REPORT-Federal-Strategy-090612-_APPENDIX_updated.pdf) to the Task Force Federal Strategy that compiles the past four years of federal support for nutrient reduction as examples of possible future support to state efforts. This appendix also serves as a reference to help states select, from a broad array of federal programs, those that could best support each phase of developing or implementing their nutrient reduction strategies. Both the appendix and Federal Strategy highlight many federal programs that promote innovative approaches to nutrient reduction, including certainty agreements for agricultural producers and efforts to establish nutrient trading markets. The federal agencies have also used the Task Force as a platform to develop new cooperative programs and enhance existing collaborations, increasing opportunities to effectively leverage limited resources to improve in-state water quality and reduce nutrient loadings to the Gulf.

Although demand for federal assistance to Task Force states exceeds available resources, through leveraging, federal agencies are devoting significant funds to these efforts where possible. For example, in fiscal year (FY) 2011, USEPA provided $1 million in competitive grant funding for states to develop and implement nutrient reduction strategies through a comprehensive partnership. USDA's Mississippi River Basin Healthy Watersheds Initiative (MRBI) will invest over $341 million in technical and financial assistance across 123 projects by the end of FY 2013. As of April 2013, demand for Environmental Quality Incentives Program (EQIP) financial assistance in FY 2013 under MRBI was more than double the available funding at $123 million across almost 3,500 applications. Through 2013, USDA's Natural Resources Conservation Service (NRCS) will also provide up to $50 million through the Gulf of Mexico Initiative (GoMI), which among other things, assists agricultural producers in applying management systems that avoid, control, and trap nutrient runoff. Section 5022 of the 2007 Water Resources Development Act provides a basis for the U.S. Army Corps of Engineers' (USACE's) assistance with aquatic ecosystem restoration and other nutrient reduction projects. Through a variety of federal and cooperative programs with numerous local, state, and federal agencies, the USGS operates over 3,000 stream gages and conducts nutrient and wetland monitoring and modeling assessments throughout the MARB, totaling about $62 million in 2010. NOAA's infusion of more than $10 million for research and monitoring since 2009 has improved understanding of the causes and effects of Gulf hypoxia, including advancement of scenario forecast models to inform nutrient management. These research advances help support the Task Force adaptive management approach in refining nutrient reduction targets and assess measures of success.

Action Item 3

Opportunities Under Existing Programs to Enhance Protection of the Gulf and Local Water Quality

"While developing comprehensive state and federal nitrogen and phosphorus reduction strategies and continuing current reduction efforts, examine and, where possible, implement opportunities to enhance protection of the Gulf and local water quality through existing federal and state water quality, water management, and conservation programs."

The state-level and federal strategies capture major nutrient reduction programs that target either or both point and nonpoint sources of nutrients. States and federal agencies are also actively engaged in activities whose primary purpose is not to mitigate hypoxia, but that nevertheless offer the additional benefits of addressing nutrient pollution and enhancing water quality, which is consistent with Action Item 3.

For example, the Clean Water State Revolving Fund under the Clean Water Act offers states a variety of assistance options to fund water quality protection projects, including those that address excess nutrients. Another Clean Water Act program under section 319 applies specifically to nonpoint sources of pollution, including urban and agricultural runoff. It provides states, territories, and tribes with grant funding that supports a wide variety of activities, such as technical and financial assistance, education, and monitoring to assess the success of specific nutrient reduction implementation projects. Clean Water Act section 303(d) requires states, territories, and authorized tribes to identify waters impaired by one or more pollutant, including nitrogen and phosphorus, and develop a TMDL for these waters. A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still safely meet water quality standards. In addition, source water protection programs under the Safe Drinking Water Act aim to prevent or reduce contamination of drinking water sources from contaminants, including nitrates, protect public health, and lower treatment costs.

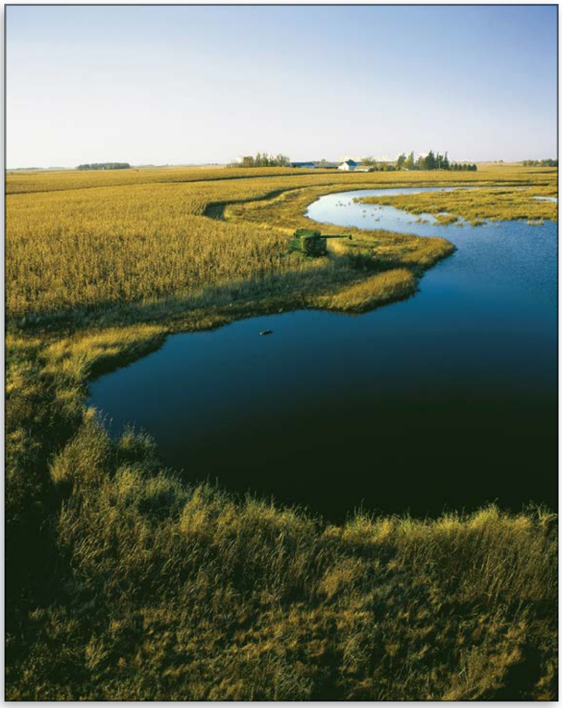
Under EQIP, NRCS provides financial and technical assistance to agricultural producers to help plan and implement conservation practices that address natural resource concerns, including keeping nutrients on the land and out of the water. Conservation Innovation Grants (CIGs) are also funded through EQIP and can play a role in reducing nitrogen and phosphorus runoff from agricultural production. These grants are intended to stimulate development and adoption of innovative conservation approaches, while leveraging federal investment in environmental enhancement and protection.

The USACE's Continuing Authorities Program under the Water Resources Development Act has three authorities that allow the USACE to perform water-related projects with costs shared among the federal and nonfederal sponsor(s). Project objectives include review of existing water resources projects to determine opportunities for environmentally beneficial structural modification; protecting, restoring, and creating aquatic habitats in connection with dredging of authorized federal navigation projects; and building projects to restore aquatic ecosystems. Another USACE effort is the massive coastal protection and restoration project in Louisiana, with assistance from many other stakeholder groups. Freshwater diversions are being used to introduce nutrient-laden water into marshes to restore degraded habitat and create new marsh.

The **USGS' Cooperative Water Program** (http://water.usgs.gov/coop/) can also be leveraged to increase support and action for mitigating Gulf hypoxia. It brings together local, state, and tribal water needs and decision making with USGS capabilities, involving partnerships between USGS and more than 1,500 state, tribal, and local agencies. Some of these partnerships focus on real-time monitoring of nitrate in Iowa, Illinois, and other Task Force states; long-term ambient water quality monitoring in Missouri; and water quality improvements and agricultural BMPs in Wisconsin and Mississippi. In addition, the **USACE/USGS Long-Term Resource Monitoring Program** (www.umesc.usgs.gov/ltrmp.html), under the direction of the USACE Environmental Management Program and in collaboration with USGS, partners with other federal and state agencies in Illinois, Iowa, Minnesota, Missouri, and Wisconsin to provide critical information about the status and trends of key environmental resources to support decision makers with information and understanding needed to maintain the Upper Mississippi River System as a viable, multiple-use, large river ecosystem.

The **National Wetlands Research Center** (www.nwrc.usgs.gov/), also under the leadership of USGS, engages in robust alliances to develop and disseminate scientific information needed for understanding the ecology and values of wetlands, and for managing or restoring wetlands and coastal habitats. This program potentially yields significant benefits toward nutrient reduction and hypoxia mitigation through its protection of wetlands.

Aside from the federal agencies, states are also addressing nutrient reductions through a broad variety of approaches. Some of the approaches include NPDES permitting, TMDLs, state-enacted legislation, partnering with other states and federal agencies, and education and outreach programs, in particular, as part of efforts to accomplish nutrient reductions on agricultural lands. The following section highlights the diversity of state efforts implemented through existing programs, using information provided by the states.



USDA NRCS

A restored wetland sits within a corn field in Kossuth County, Iowa.

Point Sources and NPDES Permits

Several states are actively engaged in incorporating phosphorus limits into their NPDES permits for wastewater dischargers.

- Minnesota is aiming to establish a watershed permit for TP (www.pca.state.mn.us/index.php/view-document.html?gid=18770) for the Minnesota River (and associated allowable trading between point sources).
- Illinois is inserting nutrient limits into NPDES permits pursuant to a 2011 agreement with USEPA.
- Ohio's efforts are aimed at reducing phosphorus loads delivered to surface waters in the western Lake Erie Basin: NPDES permit phosphorus limits and accelerated implementation of selected combined sewer overflow elimination steps.
- Wisconsin municipal and industrial wastewater dischargers have reduced their phosphorus load discharges by 67 percent since the mid-1990s in response to state-enacted technology-based limits. Recently enacted water quality-based limits in Wisconsin will further reduce the phosphorus load.

TMDLs and Section 319

- In Louisiana, more than 750 TMDLs have been completed for more than 200 impaired water bodies. LDEQ, partnering with USDA and Louisiana Department of Agriculture and Forestry, has prioritized 40 water bodies to restore or partially restore by October 2016. Approximately half of these water bodies have nutrient impairments, and several were targeted through USDA's MRBI, GoMI, and National Watershed Quality Initiative for implementing nutrient BMPs to reduce nitrogen and phosphorus loads entering the state's waters. USEPA provided Louisiana additional section 319 funds to leverage with these federal USDA funds to monitor in-stream water quality improvements that should result from implementing nutrient reduction BMPs.
- Other Task Force states are also involved in developing nutrient TMDLs and promoting agricultural BMPs in watersheds with nitrogen and phosphorus TMDLs already in place.

State-enacted Legislation

- Through a state law in Arkansas, nutrient surplus watersheds have been identified and designated. In those watersheds, the state law requires all producers to obtain an approved nutrient reduction management plan, nutrient applicators to become certified, and application rates to be based on a phosphorus index.
- In Kentucky, the Agricultural Water Quality Act requires all agricultural operations of 10 acres or greater to implement BMPs in the control of phosphorus and nitrogen. Under the act, cost-share technical and financial assistance funds have been set aside, routine informational meetings are held, operational inspections performed, and if needed, enforcement actions are taken.

- In 2008, Minnesota voters approved the Clean Water, Land, and Legacy Amendment, which among other things, establishes a dedicated funding source for clean water. This sustainable and long-term funding source—the **Clean Water Fund** (www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/clean-water-fund/index.html) —will fund the protection, enhancement, and restoration of water quality in lakes, rivers, streams, and groundwater.

Clean Water Fund

On November 4, 2008, Minnesota voters approved the Clean Water, Land and Legacy Amendment to the constitution to protect drinking water sources; to protect, enhance, and restore wetlands, prairies, forests, and fish, game, and wildlife habitat; to preserve arts and cultural heritage; to support parks and trails; and to protect, enhance, and restore lakes, rivers, streams, and groundwater.

The amendment increases the sales and use tax rate by three-eighths of one percent on taxable sales, starting July 1, 2009, continuing through 2034. Of those funds, approximately 33% will be dedicated to a Clean Water Fund to protect, enhance, and restore water quality in lakes, rivers, streams, and groundwater, with at least 5% of the fund targeted to protect drinking water sources.

2012 Clean Water Fund Performance Report

Minnesota agencies released their first collaborative report in February 2012 to help Minnesotans clarify connections between Clean Water Funds invested, actions taken and outcomes achieved in FY2010-2011. Eighteen measures in the report provide a snapshot of how Clean Water Fund dollars are being spent and what progress has been made.
Read more.

Clean Water Fund website.

Fertilizer Use and Detergent Restrictions

- Illinois implements bans on both phosphorus-containing dishwashing detergent and application of phosphorus fertilizer to residential lawns by commercial lawn care companies.
- The Minnesota Phosphorus Lawn Fertilizer Law was enacted in 2002 and amended in 2004. It prohibits use of phosphorus lawn fertilizer unless new turf is being established or a soil or tissue test shows the need for phosphorus fertilization. Trained golf course staff and sod farms are exempt from these restrictions. The law also requires fertilizer of any type to be cleaned up immediately if spread or spilled on a paved surface, such as a street or driveway.
- Wisconsin has enacted statewide phosphate bans for lawn fertilizer and dishwasher detergents. Previously, bans were enacted for dish detergent.

Agricultural Programs

- In Illinois, the state's fertilizer law was recently revised to create a Nutrient Research and Education Council and a dedicated funding stream for nutrient research and education. Furthermore, the Keep it for the Crops 2025 program aims to improve nutrient efficiency and reduce nutrient losses through research and extensive education about the importance of good stewardship practices in communities and in agriculture to improve water quality.
- In Indiana, programs that are serving to reduce nutrient loads in the state include the Conservation Reserve Enhancement Program (CREP), the Lake and River Enhancement Program, the Healthy Rivers Initiative, the Indiana On-Farm Network, the Conservation Cropping Systems Initiative, and Indiana Department of Environmental Management's Watershed Management Plans.
- The Missouri Soil and Water Conservation Cost-Share Program annually provides more than $24 million in cost-share and incentive payments to Missouri producers for implementing more than 6,000 conservation practices and treating more than 200,000 acres of agricultural land. The Soil and Water

Conservation Program has successfully led stakeholder efforts to develop project proposals and provide nonfederal matching funds for NRCS funding opportunities such as the MRBI and Cooperative Conservation Partnership Initiative, for which Missouri is expected to receive up to $45.6 million and $7.9 million, respectively, in additional federal cost-share funds from 2010 to 2016. The Concentrated Animal Feeding Operation (CAFO) permit program has permitted all CAFOs in Missouri and requires each CAFO to develop and implement a Nutrient Management Plan.

- In Ohio, an extensive education effort is underway through 4Rs (Right source, Right time, Right place, Right rate) nutrient outreach programs, which are designed to promote the principles of nutrient stewardship to Ohio's agricultural producers. Training on the 4Rs is being conducted statewide through local Soil and Water Conservation Districts, Ohio State University Extension, and other agricultural organizations. Ninety-one programs reaching 5,567 participants have been held as of March 2013. Furthermore, $3 million in state funds are assisting with pilot projects (i.e., controlled drainage structures and variable rate technology nutrient application) aimed at agricultural nutrient issues.
- Through a number of federal, state, and local programs in Wisconsin, state-required performance standards and prohibitions are being implemented, including a phosphorus index for croplands, pastures, and other lands. Implementation approaches include cross compliance for working lands tax credits; state, federal, and local financial and technical assistance; and local ordinances.

Action Item 4

Management Practices for Conserving Nonpoint and Point Sources of Nutrients

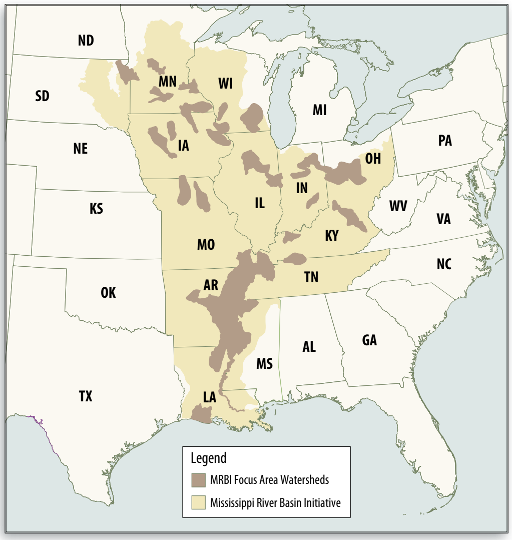
"Develop and promote more efficient and cost-effective conservation practices and management practices for conserving nutrients within the Mississippi/Atchafalaya River Basin watershed and evaluate their effectiveness at all scales beginning with local watersheds and aggregating them up to the scale of the Mississippi/Atchafalaya River Basin."

Action Item 4 tasks the Task Force with developing efficient and cost-effective nutrient reduction practices, and evaluating their effectiveness from the local watersheds and aggregating up to the scale of the MARB. Identifying effective management practices and technologies that target both agricultural and non-agricultural sources of nutrients is central to the success of nutrient reduction strategies. The USDA has taken the lead in developing, evaluating, and supporting implementation of conservation systems to aid agricultural producers and landowners in keeping nutrients on the field and reducing nutrient inputs to the MARB. These efforts include work with a broad spectrum of partners to find innovative methods to support conservation through environmental markets and agricultural certainty efforts. This section highlights the progress under the stated goals from Action Item 4, and reference links have been included for further follow-up.

1. Continue to develop field and farm scale management practices that conserve nutrients for the wide range of agricultural production systems within the MARB.

Mississippi River Basin Healthy Watersheds Initiative

In 2010, NRCS initiated the MRBI, a landscape initiative that targets financial and technical assistance for conservation in high-priority, small watersheds within 13 states, including the 12 Task Force states. MRBI emphasizes a cost-effective conservation systems approach, with a focus on suites of practices that optimize use of nutrients, control nutrient runoff, and trap or filter nutrients before they run into surface water or leach into groundwater. NRCS conservationists and partners work with farmers to develop these conservation systems for their individual operations.



USDA NRCS

FY 2012 MRBI Focus Areas.

On a national scale, MRBI supports additional conservation activities, focused on water quality concerns to a set of states and watersheds in the Mississippi Drainage Basin. At the state level, NRCS State Conservationists assist state and local partners who propose projects at the HUC-12 level. Within approved projects, farmers are eligible for additional federal funds for conservation, leveraged by state and local in-kind services to magnify efforts. An average of 9.5 partners supports each of the 123 MRBI projects. Through these mechanisms, MRBI accelerates conservation efforts by overlaying targeted conservation assistance on top of what is generally available through Farm Bill conservation programs. By the close of FY 2013, NRCS is projected to have over $341 million invested in conservation systems on nearly 887,000 acres.

The effectiveness of MRBI's small watershed targeting and conservation systems approach was modeled under the NRCS Conservation Effects Assessment Project (CEAP) in April 2013. For conservation systems under contract with farmers through MRBI between FYs 2010 and 2012, when fully applied it is projected that the per acre benefits of these systems will be 1.7 times greater for sediment reduction, 1.4 times greater for phosphorus reduction, and 1.3 times greater for nitrogen reduction compared to a non-targeted approach. More information is at www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/farmbill/initiatives/?&cid=stelprdb1048200.

National Water Quality Initiative (NWQI)

In FY 2012, NRCS created the NWQI in concert with USEPA and state water quality agencies. NWQI initially targeted 154 small (HUC-12) watersheds in all 50 states and Puerto Rico to improve water quality, particularly in water bodies that are on the Clean Water Act section 303(d) list of impaired waters. Through NWQI, NRCS helps producers implement systems of conservation practices to reduce nutrient and sediment losses from their farms. These systems include practices to optimize nutrient inputs and to control and trap nutrient and manure runoff.

Nationally, NWQI dedicated almost $34 million in funding in FY 2012 to producers who voluntarily implemented conservation systems. In FY 2013, NRCS will again dedicate nearly $35 million in EQIP funding to qualified producers in 165 watersheds. These priority watersheds were selected with input from USEPA and state water quality agencies, and state programs will use USEPA section 319 or other funds to conduct water quality monitoring in these selected priority watersheds. Many of the small watersheds funded in FYs 2012 and 2013 are in the MARB. Through NWQI, NRCS is also piloting the use of its new Water Quality Index for Runoff Water from Agricultural Fields (WQIag) in at least one watershed per state. The Index will enable producers to evaluate the effects of alternative conservation systems. More information about NWQI is at www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/financial/eqip/?cid=stelprdb1047761.

USDA NRCS

Overall area of the GoMI, as well as focus areas within the initiative and priority watersheds.

Gulf of Mexico Initiative

The GoMI is a landscape conservation initiative that NRCS offers to accelerate conservation system implementation in priority watersheds in the Gulf of Mexico states. Through GoMI, NRCS and partners work with agricultural producers to improve ecosystem health, water quality, relieve overuse of water resources, and prevent saltwater from entering the habitats of many threatened and endangered species. The GoMI project area includes selected watersheds in the five Gulf states: Alabama, Florida, Louisiana, Mississippi, and Texas. In FY 2012, its initial year, over $8 million was obligated in voluntary contracts to provide agricultural producers with assistance in accelerating implementation of conservation systems. More information about GoMI is at www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/home/?&cid=stelprdb1046039.

State Water Quality Certainty Programs

“Certainty,” “Assurance,” and “Certification” programs provide states with a tool to accelerate the voluntary adoption of systems of conservation practices that improve and protect water quality, reducing the pressure for additional state water quality regulations. These programs also recognize the environmental stewardship of farmers and ranchers and help lay the groundwork for establishment of markets for ecosystem services. Agricultural producers participate in Certainty programs by voluntarily implementing systems of conservation practices to reduce soil erosion and sediment/nutrient runoff. In turn, these producers receive assurance from the state that they have put into place all appropriate and practicable measures for addressing water quality concerns, for a defined period of time. Some states with Certainty programs have given participating producers assurance that their farms are in compliance with current and future state regulations for the length of the Certainty agreement.

Several states within the MARB have either successfully adopted or are developing Certainty programs. Others are exploring the benefits of adopting such a program. USDA fully supports these efforts and is committed to assisting states as they develop their programs. USDA will also provide producers with technical and financial assistance to support state Certainty programs.

Environmental Markets

The quantification of ecosystem services and development of ecosystem markets present opportunities for reducing the costs of regulatory compliance and increasing private sector funding for voluntary conservation on private lands, all in service of improving natural resource and environmental conditions. Given its cadre of technical experts and science-based conservation practice standards (CPSs), USDA is uniquely positioned to play a leading role in supporting the development and operation of ecosystem markets. Ecosystem market practitioners view NRCS as a trusted resource for tools and information that can lend credibility to market transactions.

During the period of this reassessment, USDA has made a number of significant steps to advance environmental markets:

- USDA’s Office of Environmental Markets partnered with the Willamette Partnership to develop a document titled *In It Together: A How-To Reference for Building Point-Nonpoint Water Quality Trading Programs*. This document, released in July 2012, is intended for use by states and third parties interested in developing credible and transparent water quality trading programs. http://willamettepartnership.org/in-it-together/
- Ecosystem market transactions, particularly those involving agricultural credit generators, require tools that can credibly and transparently quantify ecosystem benefits. NRCS has developed two primary quantification tools—Nutrient Tracking Tool (NTT) for quantifying

nutrient load reductions, and COMET-Farm for greenhouse gas estimation. These tools allow agricultural producers to estimate the ecosystem benefits from proposed land management changes. NRCS has also developed a Water Quality Index for Agriculture, an easy-to-use tool that can quickly give a user a qualitative indication of the benefits of land management changes.

- NRCS has funded ecosystem markets projects through CIG since 2004. An opportunity for water quality trading projects was offered in 2012. For these efforts, NRCS has established awardee networks, which are forums for the grantees to convene regularly and share information and lessons learned. CIG has previously funded the development of a number of ecosystem markets projects, including projects led by the Willamette Partnership and the Electric Power Research Institute, both of which have established industry leading water quality trading programs.

From FY 2009 through FY 2012, NRCS has invested more than $3.8 billion in the regions of the Task Force states that are within the MARB through these targeted initiatives and other conservation programs (Table 1).

Table 1. NRCS investments in Task Force states from FY 2009 to FY 2012

Program	2009	2010	2011	2012	Total
Conservation Technical Assistance (CTA)	$163,463,163	$170,288,870	$169,381,847	$151,518,609	$654,652,489
Farmland Protection Program (FRPP)	$13,842,812	$10,966,260	$16,528,779	$20,590,143	$61,927,994
Wildlife Habitat Incentives Program (WHIP)	$13,408,098	$22,017,569	$12,422,474	$13,829,360	$61,677,502
Environmental Quality Incentives Program (EQIP)	$240,988,094	$279,239,683	$303,997,478	$367,939,054	$1,192,164,310
Wetlands Reserve Program (WRP)	$147,287,357	$203,186,503	$228,785,962	$255,910,523	$835,170,345
Conservation Security Program (CSP)	$114,787,843	$92,865,866	$83,273,380	$81,134,906	$372,061,996
Grasslands Reserve Program (GRP)	$730,925	$1,086,301	$1,600,238	$1,028,324	$4,445,788
Conservation Stewardship Program (CSpT)	$3,616,175	$134,488,502	$196,746,426	$263,245,727	$598,096,830
Agri Water Enhancement Program (AWEP)	$4,385,680	$5,901,159	$8,036,105	$7,372,859	$25,695,803
Healthy Forests Reserve Program (HFRP)	$1,321,405	$2,440,651	$3,317,797	$2,863,197	$9,943,050
Total	**$703,831,554**	**$922,481,365**	**$1,024,090,486**	**$1,165,432,702**	**$3,815,836,107**

Note: Major programs do not include reimbursable funds.

2. Quantify the effectiveness of conservation practices within local watersheds that are representative of the wide range of soils, climates, and farming systems within the MARB.

- Since 2003, USDA has worked cooperatively through CEAP to better understand watershed dynamics and conservation system effectiveness in the MARB. CEAP is a multiagency effort to measure the environmental effects of conservation practices and programs and to develop the science base for managing the agricultural landscape for environmental quality. Project findings are guiding USDA conservation policy and program development and helping conservationists, farmers, and ranchers make more informed conservation decisions. As part of the CEAP watershed assessments, USDA's National Institute of Food and Agriculture (NIFA) and NRCS jointly funded 13 projects to evaluate the effects of cropland and pastureland conservation practices on spatial and temporal trends in water quality at the watershed scale. Six of the 13 projects demonstrated water quality changes, and the results identified a number of important lessons:

- Conservation planning must be done at the watershed scale.
- It is important to understand critical pollutants and their sources.
- Knowledge of land use, management, and conservation practices is essential.
- It is important to select appropriate models and understand their limits.
- It is beneficial to identify farmers' attitudes toward conservation practices and work with them by offering economic incentives, technical assistance, and continued assistance after adoption.

More information is available at:

- www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/ceap/?cid=nrcs143_014135
- www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap/pub/
- www.ars.usda.gov/Research/docs.htm?docid=18645

Scientists from the Agricultural Research Service (ARS) at Temple, Texas, El Reno, Oklahoma, and Tifton, Georgia, developed new algorithms for the river basin-scale model Soil and Water Assessment Tool (SWAT) to simulate real-time irrigation management, fate and transport of hormones and antibiotics, and the reduction in glacier volumes. As part of CEAP National Cropland Assessment, the team validated SWAT at more than 40 USGS stream gauges across the country to assure realistic simulation of streamflow, sediment, nutrient, and atrazine loads. The team also completed final SWAT validation and scenario analyses for the Missouri River Basin, the Arkansas-Red River Basin, and the Texas Gulf Basin. Scenario runs from this model identified the optimum placement of conservation practices in the MARB to minimize the flux of nitrogen and phosphorus into the Gulf of Mexico, thus limiting the extent of the hypoxic zone (Moriasi et al. 2011; Zhang et al. 2011).


USDA NRCS

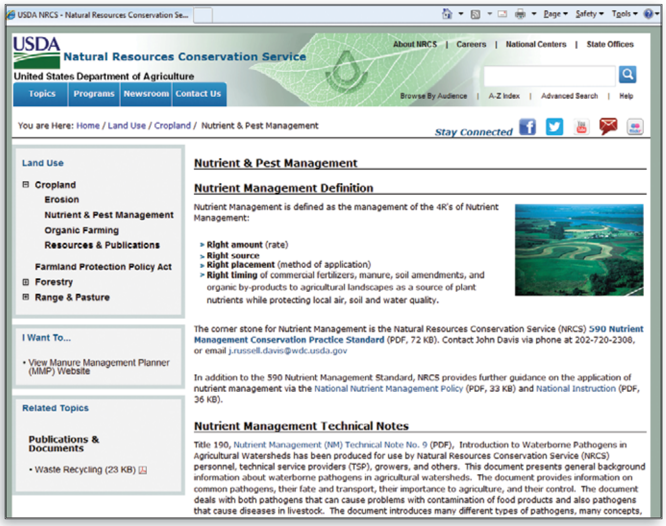
Contour farming, terraces, and rye grass field strips.

- ARS scientists are also actively researching the effectiveness of conservation practices in reducing nutrients and sediment, including cover crops and landscape water storage. In Ames, Iowa, researchers used the Root Zone Water Quality Model to predict the impact of a cereal rye cover crop on nitrate losses from drained fields across five upper Midwest states. Across the region, winter cover crops planted at main crop maturity in a corn–soybean rotation reduced nitrogen loss in tile flow by an average of more than 40 percent. If planted in the area of the five states draining to the Mississippi River, the potential reduction in nitrate-nitrogen losses from drained fields would be 166 million kilograms (kg) per year, or about 20 percent of the total nitrate-nitrogen load in the river. The cost of nitrate-nitrogen removed by cover crops ranges from $2.08 to $4.13 per kg, which is competitive with other management practices that reduce nitrate losses to surface waters (Qi et al. 2011).

- ARS researchers at St. Paul, Minnesota, showed that combining increased landscape water storage with supplemental irrigation reduces flooding and associated nutrient losses in the U.S. Corn Belt. It could also stabilize yields and permit the adoption of alternative cropping practices. Storing water during periods of excess makes the water available for supplemental irrigation. Restoration of wetlands and construction of ponds could provide the storage, with the added benefits of creating wildlife habitat, reducing downstream losses of sediment and nutrients, and providing additional crop biomass for forages or renewable fuels (Baker et al. 2012).
- USDA cooperated with partners to develop, refine, or implement the use of the following computer-assisted tools to facilitate conservation planning:
  - **2012 NTT.** NTT provides agricultural producers and land managers the ability to compare nitrogen, phosphorus, potential sediment loss, and crop yield under their current management practices with those of an alternative conservation management regime (http://nn.tarleton.edu/NTTWebARS).
  - **WQIag.** This Web-based software application assigns a value between 1 and 10 according to factors affecting runoff water quality. A value of 10 represents the highest runoff water quality, and a value of 1 represents the poorest runoff water quality. NRCS is piloting the application of WQIag in at least one NWQI watershed per state (ftp.wcc.nrcs.usda.gov/wntsc/WQI/RunoffWaterQualityIndex.pdf).
  - **DRAINMOD Program.** First developed by North Carolina State University in 1977 and used on a national platform in 1982 by NRCS, the suite of DRAINMOD products simulate whole system models for crop production on drained lands. Evaluations of the model have been field tested in Midwest settings where artificial drainage is common (Skaggs et al. 2012).
- NRCS has provided assistance for nearly 50 edge-of-field water quality monitoring contracts since 2008 with private landowners in eight MARB states for evaluating the effectiveness of conservation practices implemented on the land. These standards are discussed in the next section.
- The USGS is working with multiple agencies throughout the MARB to assess the effectiveness of conservation actions in urban and agricultural land use settings. Examples include:
  - **Grove Development in Bloomington, Illinois** (http://il.water.usgs.gov/data/kcb/index.html)
  - **Watershed restoration studies in Mississippi** (http://ms.water.usgs.gov/projects/319/)
  - **Nonpoint evaluation studies in Wisconsin** (http://wi.water.usgs.gov/non-point/index.html)

3. Review, update, or develop NRCS national and state CPSs for the practices most effective in conserving nutrients.

- In December 2011, NRCS released a revised CPS for Nutrient Management (CPS 590). NRCS created CPS 590 to manage nutrients for plant production, minimize agricultural nonpoint pollution, protect air quality, and maintain or improve soil conditions. It is an important tool for NRCS staff and others to help agricultural producers apply nutrients using the 4R principles—the right amount, right source, right placement, and right timing. The revisions to CPS 590 include expanding the use of technology to streamline the nutrient management process and using site-specific data to inform adaptive nutrient management (ANM) planning. More information is at www.nrcs.usda.gov/wps/portal/nrcs/main/national/landuse/crops/npm/.



Nutrient & Pest Management

Nutrient Management Definition

Nutrient Management is defined as the management of the 4R's of Nutrient Management:

- **Right amount** (rate)
- **Right source**
- **Right placement** (method of application)
- **Right timing** of commercial fertilizers, manure, soil amendments, and organic by-products to agricultural landscapes as a source of plant nutrients while protecting local air, soil and water quality.

The corner stone for Nutrient Management is the Natural Resources Conservation Service (NRCS) **590 Nutrient Management Conservation Practice Standard** (PDF, 72 KB). Contact John Davis via phone at 202-720-2308, or email j.russell.davis@wdc.usda.gov

In addition to the 590 Nutrient Management Standard, NRCS provides further guidance on the application of nutrient management via the National Nutrient Management Policy (PDF, 33 KB) and National Instruction (PDF, 36 KB).

Nutrient Management Technical Notes

Title 190, Nutrient Management (NM) Technical Note No. 9 (PDF), Introduction to Waterborne Pathogens in Agricultural Watersheds has been produced for use by Natural Resources Conservation Service (NRCS) personnel, technical service providers (TSP), growers, and others. This document presents general background information about waterborne pathogens in agricultural watersheds. The document provides information on common pathogens, their fate and transport, their importance to agriculture, and their control. The document deals with both pathogens that can cause problems with contamination of food products and also pathogens that cause diseases in livestock. The document introduces many different types of pathogens, many concepts,

USDA NRCS website for CPS for Nutrient Management (CPS 590).

For the FY 2011 CPS 590 revisions, NRCS collaborated with universities, nongovernment organizations, and others in an effort to develop a science-based consensus on the modifications. Recommendations from committees outside NRCS regarding the revisions included those from SERA-17 and an ANM team. SERA-17 is an organization of research scientists, policy makers, extension personnel, and educators whose mission is to develop and promote innovative solutions to minimize phosphorus losses from agriculture. The ANM team includes experts from other agencies, organizations, and universities, with a mission of promoting and accelerating the adoption of ANM principles as a systematic process for on-farm refinement of nutrient management.

- In FY 2010, USDA created Interim Standard and Specification 799 Monitoring and Evaluation. The new standard enabled NRCS to provide financial assistance through EQIP to farmers and ranchers to evaluate the effectiveness of conservation systems on private land. In FY 2013, USDA revised the 799 CPS into two new Edge of Field Water Quality Monitoring Conservation Activity Standards (CAS 201 for Data Collection and CAS 202 for System Installation). Each activity serves to upgrade the original Interim Standard 799 with fortified scientific procedures and standardized data collection. The objectives of edge-of-field monitoring are to assess the efficacy of selected priority conservation systems, to calibrate models used to predict edge-of-field nutrient and sediment reductions, and to inform adaptive management decisions.
- Of the $7 million available in EQIP nationwide to support the targeted implementation of these new water quality monitoring standards, over $2 million is targeted for use in MRBI's small watersheds. An additional $2 million is targeted for use in NWQI. Using these NRCS technical standards and a rigorous evaluation of applications, only the most promising sites—those that are scientifically sound and include strong partner support—will be selected for funding to implement edge-of-field water quality monitoring to assess the efficacy of selected priority conservation practices, to calibrate models used to verify edge of field nutrient and sediment load reductions, and to employ adaptive management to improve conservation efforts.
- Closed depressions (i.e., potholes) are pervasive in the young glacial till landscapes of the upper Midwest. Water from surface drainage collects at the lowest spot in the pothole, keeping the area too wet for farming, even when using standard subsurface tile drains in the field. Most farmed potholes are drained using subsurface tiles, but some also have supplemental drainage from a tile riser (a pipe with holes drilled in its sides) that extends vertically above the soil surface. ARS scientists in West Lafayette, Indiana, found that the extent of potholes in a watershed is directly related to concentrations or loads of nutrients lost from

that watershed. Research shows that an alternate practice, called a blind inlet, provides greater filtration of surface water from potholes. Compared to a tile riser, when drained with a blind inlet, watershed-scale phosphorus losses decreased by about 78 percent, and nitrogen losses decreased by more than 50 percent. Decreased nutrient losses in runoff waters improve water quality, but they also save farmers money, increasing their bottom line. In 2012 ARS scientists in West Lafayette worked with the NRCS to develop a CPS. The NRCS in Indiana now offers blind inlets as a cost-sharable practice through EQIP.

- USDA developed interim CPSs for Denitrifying Bioreactors and Vegetated Subsurface Drain Outlets (saturated buffers). Both of these practices are designed to improve water quality by reducing nitrates entering surface waters from subsurface drainage; both are being implemented and evaluated for effectiveness and practicality at the farm level. At least 35 denitrifying bioreactors have been installed across the Upper MARB. Vegetated subsurface drain outlets are being evaluated in four states in FY 2013.


Jeff Cook, USDA ARS

Denitrifying bioreactors, like this one in Iowa, may operate for a decade without maintenance.

4. Assist State Extension, USDA personnel, and agricultural consultants in delivering nutrient-conserving practices to farmers and ranchers in the MARB.

- NRCS is focusing technical and financial resources to assist states in the application of voluntary conservation efforts to reduce nitrates leaving farmland through drainage. A team of more than 20 NRCS technical specialists initially focused on addressing the intensively drained farmlands in the Upper MARB—Indiana, Illinois, Iowa, Missouri, Minnesota, and Ohio. The focus area has since been expanded to include portions of Wisconsin and three additional states in the Great Lakes Basin and the Red River Valley. This team is working in close collaboration with partners to develop and implement an Agricultural Water Management Action Plan, which provides outreach and financial and technical assistance to producers that voluntarily apply nutrient and water management practices. The outreach emphasizes providing information and training to producers, technical service providers (TSPs), contractors, and agencies.

  As part of the Agricultural Water Management Action Plan, NRCS is examining how drainage water management is being applied, identifying barriers to adoption, and documenting lessons learned by those who have implemented drainage water management. With this information, the team will make recommendations on how to increase the adoption of drainage water management throughout the focus area. The goals of this effort are to: (1) encourage producers to manage water in existing tile and surface drainage systems for environmental benefits; (2) evaluate recommendations for feasibility and priority; (3) engage with partners in the action plan implementation; and (4) stimulate innovation in addressing nutrient management in subsurface drainage systems. The action plan is at www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1046081.pdf.

USDA NRCS

Tile outlet into drainage ditch in central Iowa.

- A network of NRCS TSPs is available to provide for-hire conservation planning and design expertise to farmers, ranchers, businesses, organizations, and agencies. TSPs are required to complete an NRCS certification process, including training and verification of proficiency. NRCS recently streamlined the training and certification for TSPs by combining two required training courses into one course and exam. The new course is TSP Orientation and Conservation Planning and is available online through **AgLearn** (www.aglearn.usda.gov). TSPs should contact their NRCS state or regional coordinator for upcoming training events. Once TSPs become certified through NRCS, their service/contact information is posted to TechReg, the NRCS online registry for TSPs. Producers can search and identify available TSPs through an online registry at http://techreg.usda.gov/CustLocateTSP.aspx.

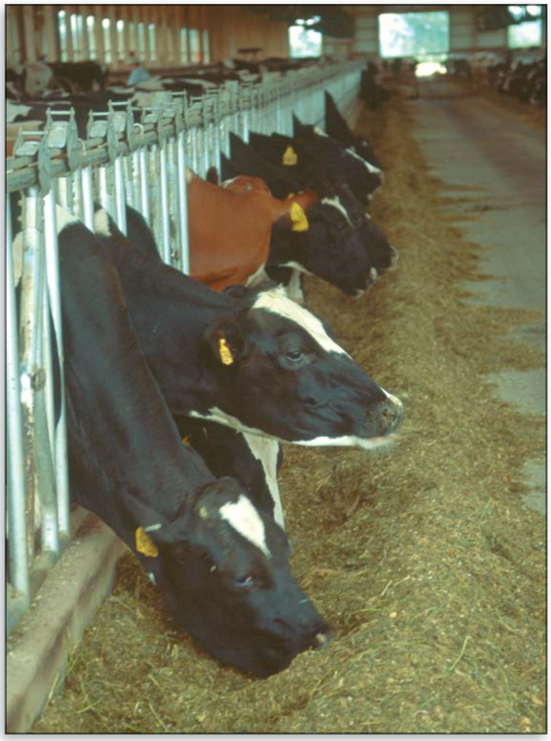
  Strengthening the TSP effort has accelerated NRCS conservation assistance to producers. Producer use of TSPs has increased by nearly 100 percent since 2008. Currently, over 2,095 TSPs provide conservation planning and other related technical assistance to landowners. More information on the TSP is at www.airquality.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/technical/tsp.
- NRCS is developing a campaign to promote soil health through conservation systems. A series of seven webinars was conducted beginning in June 2011 to cover research related to improving soil health through cropping systems. Technical experts from NRCS and university faculty from across the nation delivered soil health information to NRCS state specialists, field staff, and partners who work with farmers in developing conservation plans. The main objective of the training series was to provide in-depth training on the effects of nutrient management and healthy soils on water quality.
- Training and workshops have also been conducted at a state level to discuss the role of healthy soils in nutrient management to improve water quality. This effort is being supported by NRCS Technical Centers, which have incorporated soil health training workshops into their business plans; those training workshops have been conducted throughout the country. The format of the trainings has been formalized into a standard course for NRCS employees and offered through the National Employee Development Center. In FY 2012 alone, more than

5,000 people received soil health training in the United States, including approximately 2,900 in the MARB (www.nrcs.usda.gov/wps/portal/nrcs/main/national/soils/health/).

- NIFA supports multi-state teams of universities in relevant hypoxia research topics such as nitrogen management, manure management, cover crops, tile water drainage management, animal nutrition to reduce excess nutrient excretion, and precision farming for fertilizer accuracy. NIFA also supports multi-state extension projects such as the **Livestock and Poultry Environmental Learning Center** (www.extension.org/animal_manure_management) that offers monthly webinars and archived fact sheets and information on manure nutrient management. Most state extension programs offer workshops, field days, nutrient management training, crop fertilizer recommendations, and sometimes soil testing to improve nutrient management accuracy. Additional NIFA research and extension projects are also featured on www.usawaterquality.org.

5. Further analyze nutrient pollution contributions from point sources and non-agricultural sectors, including a full analysis of costs; target cost-effective actions to reduce nutrient loads from point sources as warranted.

USEPA has taken the lead in analyzing the nutrient loads from point sources, including CAFOs, municipalities, and industries, as well as non-agricultural nonpoint sectors, such as atmospheric deposition. Recent estimates are that nationwide, approximately 17,300 CAFOs operate and that 7,600 of those (44 percent) have NPDES permits. In the Task Force states, an estimated 6,861 CAFOs exist, with 3,134 of those (46 percent) having NPDES permits. Since 2008, USEPA has been working to ensure full implementation of the NPDES permitting requirements for CAFOs and to identify state technical standards for nutrient management and improve public access to these standards. Upcoming work will focus on collecting and sharing data on CAFOs and on forging new relationships with key stakeholders to ensure that activities at CAFOs do not adversely affect water quality.


USDA NRCS

Feed management is practiced on a large CAFO at a large dairy farm in Lafayette County, WI.

For point sources, including publicly owned treatment works (POTWs) and industrial facilities, USEPA has developed a Web-based DMR Pollutant Loading Tool to help users determine who is discharging what pollutant, where, and how much. According to data submitted through the DMR and modeled data for similar facilities, users can retrieve counts of the number of point sources in their state, or watershed, and for Task Force states, the trends in nutrient discharges for their state or watershed. More information about the features of this loading tool is in Action Item 7.

USEPA's Office of Air and Radiation (OAR) has developed regulations and programs that are reducing emissions of NOx from stationary and mobile sources by reducing concentrations of NOx, fine-particle pollution, ozone in the ambient air, and the oxide forms of atmospheric nitrogen deposition. These regulations are national in terms of their geographic applicability and provide significant reductions in NOx emissions and deposition. As atmospheric deposition contributes approximately 16 percent of nitrogen loads to the Gulf (Alexander et al. 2008), these programs have important implications for Gulf hypoxia and the goals of the Task Force. Initial projections through 2020 are that controls on sources through several programs like the Clean Air Interstate Rule will achieve about a 4 percent reduction in nitrogen deposition to the Gulf. As USEPA OAR continues to improve and implement existing programs or develop new programs, the reduction in atmospheric deposition can also be expected to increase.

Action Item 5

Basin-wide and Coastal Impacts of Hypoxia and Excess Nutrients

"Identify and, where possible, quantify the effects of the hypoxic zone on the economic, human and natural resources in the Mississippi/Atchafalaya River Basin and Northern Gulf of Mexico, including the benefits of actions to reduce nitrogen and phosphorus and the costs of alternative management strategies."

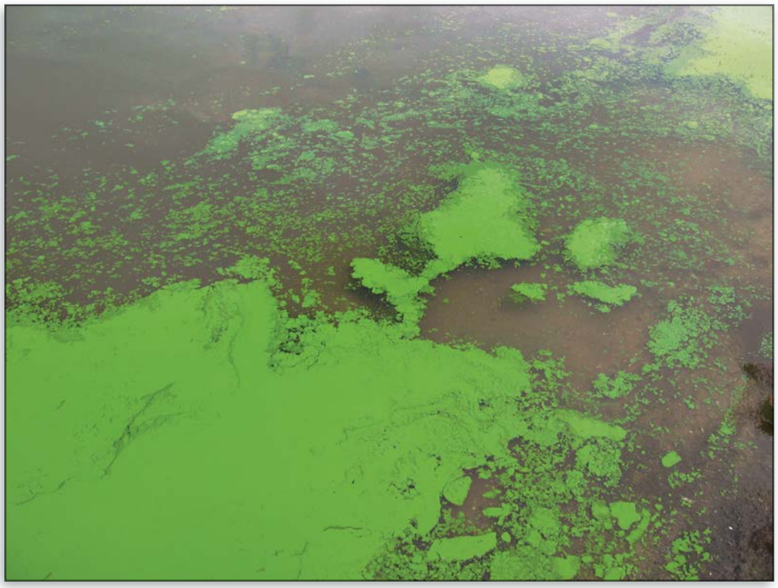
This scientific assessment of Action Item 5 provides an overview of the activities and major research findings that have occurred since the release of the 2008 Action Plan. It outlines the significant progress achieved on understanding the impacts of nutrients and hypoxia in the MARB and Gulf of Mexico. Because of the large volume of information presented, this section is organized into two major sections—studies of excessive nutrients impacts in the basin and understanding of hypoxia impacts in the Gulf of Mexico.

Impacts of Nutrients in the MARB

Pollution from excess nutrients (nitrogen and phosphorus) has been identified as one of the primary causes of water quality impairment in the nation. Nutrient loadings to surface waters trigger excessive algal growth, which as they die and decompose, deplete oxygen levels and cause the death of fish or other aquatic organisms. Sometimes these algal blooms can be toxic and generate a range of harmful effects. Excess nutrients also threaten ground water and surface water sources of drinking water. Ground water reserves, which supply drinking water to some 105 million people nationwide, can become contaminated by nutrients through soil leaching. Surface water sources of drinking water are also at risk because stormwater runoff carries nutrients directly to rivers, lakes, and reservoirs. Highly elevated nitrate levels in drinking water supplies and private wells can cause a decrease in the oxygen-carrying capacity of red blood

Nitrogen and phosphorus pollution can impact drinking water.

cells, which can cause serious illness and sometimes death in infants. Nitrogen and phosphorus pollution also threatens industries that rely on a sustainable source of clean water including tourism and fishing. More than 14,000 waters are impaired by excess nutrients, covering at least 2.5 million acres of lakes and reservoirs and spanning more than 80,000 miles of rivers and streams (USEPA 2009). These impacts of nitrogen and phosphorus on our waters lead to significant environmental and economic losses on all scales.


USGS

Binder Lake in Iowa covered in algal blooms.

Cost data associated with the human health, recreational, and economic impacts of nitrogen- and phosphorus-contaminated waters are limited, but USEPA data imply that they are significant and far-reaching. In the MARB, which represents 41 percent of the contiguous United States and includes 31 states, high levels of nutrients in drinking water—nitrate in particular—and elevated levels of by-products from disinfection agents used to treat the nitrate, have been linked with increased disease risks, illnesses, or even death (USEPA 2009). In addition to the public health costs and risks, the economic costs from treating impaired drinking water are considerable. One example is Chippewa Falls, Wisconsin, which had to develop an aggressive watershed management plan and install a costly nitrate removal system for a contaminated well that provided nearly 60 percent of the city's water. It cost the city at least $2.5 million to protect and treat its drinking water well from nitrates (USEPA 2009).

Grand Lake St. Marys, Ohio, which feeds the Wabash River that then flows to the Ohio River before joining the Mississippi, is an extraordinary example of the environmental and economic impacts of nitrogen and phosphorus pollution. Grand Lake St. Marys covers more than 13,000 acres and is Ohio's largest inland water body. However, in 2009, nutrient loading from farm runoff, failing septic systems, and lawn fertilizers triggered unprecedented blooms of toxic algae, leading to the death of fish, birds, and dogs, as well as illnesses of at least seven people (USEPA 2009). Since then, park revenues declined by more than $250,000/year. The lake regatta was cancelled, and five lakeside businesses were closed. Although local, state, and federal funds are actively being leveraged to restore the lake, the costs are steep. As of 2011, USEPA has provided $1.5 million for water quality improvements, and USDA has provided $3 million for implementing watershed agricultural BMPs. Conducting a full lake treatment to inactivate phosphorus is estimated to cost $8 million, while aerating just 2 percent of the lake surface is estimated to cost $12.7 million not including the annual operation and maintenance costs (USEPA 2009).

While these examples highlight the scope and costs of nutrient pollution, much work remains to be done on better quantifying the socioeconomic costs and benefits of nutrient reduction.

Impacts of the Hypoxic Zone in the Gulf of Mexico

Development of the quantitative relationship between nutrients, hypoxia, and living resource populations represents an important milestone that will allow for improved goal setting and nutrient reduction targets. During the scientific reassessment that preceded the 2008 Action Plan, understanding of the living resource impacts of hypoxia in the Gulf of Mexico was relatively limited, and quantification of population level impacts proved elusive (Rose et al. 2009). This relative lack of knowledge was reflected in the science reassessment by USEPA's Science Advisory Board (SAB) (USEPA 2008). The SAB limited much of its review of impacts to a brief discussion of possible ecosystem regime shifts based largely on findings from other systems that experience seasonal hypoxia along with abstracts provided in an appendix. However, many of the studies represented in the SAB report provided fundamental information required to make some of the significant advances that have been seen in recent years.

Much of the progress on understanding living resource impacts since 2008 can be traced to a NOAA sponsored workshop convened in 2007. This workshop was the result of a growing recognition during the last scientific reassessment of the need to advance impacts research and focused on developing a state of knowledge and outlining future research priorities. The workshop resulted in several significant outputs. On the basis of science advances identified at the workshop, a special issue of the *Journal of Experimental Marine Biology and Ecology* (Kidwell et al. 2009) was published with peer-reviewed articles on the latest research of hypoxia impacts. Research and management priorities identified at the workshop informed the activities and critical needs outlined in Action Item 5 of the 2008 Action Plan. These priorities were also used to inform the development of a 2009 Federal Funding Opportunity that resulted in the funding of three large multi-institution, multidisciplinary research studies that directly address Action Item 5 science needs.

Living resource impacts have been the focus of the Hypoxia Research Coordination Workshops in 2010 and 2012. These workshops centered on coordinating ongoing research activities, sharing findings and outputs, and engaging the management community. To improve capabilities to examine hypoxia impacts, these workshops have leveraged existing research projects, particularly those focused on characterizing and modeling the hypoxic zone, to improve year-to-year research capabilities and provide realistic modeling scenarios. In 2012 the workshop focused on providing an update on the state of the science and remaining research priorities to inform the scientific reassessment of the 2008 Action Plan. Findings from the **2012 workshop** (www.ncddc.noaa.gov/activities/healthy-oceans/gulf-hypoxia-stakeholders/workshop-2012/) were integrated with peer-reviewed literature to develop the following assessment of research findings and remaining science needs related to hypoxia impacts.

Significant Research Findings

Altered Spatial Distribution and Composition

It has been well documented that bottom-dwelling species, particularly Atlantic croaker and brown shrimp, are displaced from optimal habitat along the Louisiana shelf as a result of hypoxia (Craig and Crowder 2005). This displacement often results in a congregation of species around the edges of the hypoxic zone, creating what has been termed the halo-effect, with many species being pushed both offshore and inshore of the hypoxic zone. Bottom-dwelling species are typically displaced horizontally; pelagic species are typically forced higher in the water column.

Craig (2012) quantified this displacement for several species and found that many were found relatively close to the 2 milligrams per liter (mg/L) hypoxic edge, often within 1 to 2 kilometers (km). While most individuals for each species were found within this range, or farther from the edge, a smaller number can be found within the hypoxic zone proper. Craig (2012) found avoidance thresholds for the 10 species analyzed were often below 2 mg/L. For example, Atlantic croaker, shrimp, and Atlantic bumper typically avoid waters with dissolved oxygen concentrations of 1.24 to 2.04 mg/L, 1.07 to 1.57 mg/L, and 0.66 to 1.31 mg/L, respectively. Much of the range of avoidance reflects interannual variability that is possibly a response to varying severity of hypoxia (i.e., areal extent). While the low avoidance thresholds for most species may indicate a relative tolerance to hypoxic conditions or ability to vertically migrate, these threshold values are likely close to the minimum dissolved oxygen levels required to avoid mortality for many species. Further, mortality avoidance thresholds of dissolved oxygen appear to be significantly lower than thresholds for sublethal physiological effects (P. Thomas, 2012, personal communication).

In addition to horizontal displacement, studies indicate that many species, particularly plankton, are vertically displaced. Zooplankton typically make daily vertical migrations in association with diel cycles, inhabiting deeper, darker waters in daylight hours to avoid predation and migrating to surface waters at night to feed. However, zooplankton found over hypoxic bottom waters limited their daytime depth to an average of 7 meters (m) higher in the water column than zooplankton inhabiting normoxic waters (Roman et al. 2012). The forcing of hypoxia higher into the water column likely increases their susceptibility to predation and might improve, at least temporarily, food availability for planktivorous fish. This vertical displacement of zooplankton is not uniform, however, and is likely dependent on the severity and percent of water column that is hypoxic (Pierson et al. 2009). Acoustical scans also found aggregations of pelagic fish concentrated higher in the water column in hypoxia relative to normoxic waters (Hazen et al. 2009).

Sublethal Physiological Effects

Mounting evidence indicates that Atlantic croaker, a species considered hypoxia-tolerant, is exhibiting a suite of sub-physiological impacts when aggregated along the edges of the hypoxic zone, where waters often contain suboptimal oxygen levels. Comparative field and laboratory studies have isolated and established the expression of the hypoxia inducible-factor (HIF) 1α as a useful biomarker for hypoxia exposure in Atlantic croaker (Thomas et al. 2007; Murphy et al. 2009; Thomas and Rahman 2009a, 2010). Upregulation of the HIF mRNA and proteins serves as a mechanism for suppression of aerobic metabolism under low oxygen conditions (Thomas and Rahman 2009a, 2010) and can lead to significant increases in reactive oxygen species that have been associated with cell damage and other oxidative stresses (Rahman and Thomas 2011). Molecular analysis has shown that the hypoxic-induced oxidative stress can affect the regulation of CYP1A, an enzyme indicative of a toxicity response to chemical contaminants (Rahman and Thomas 2012). Although these efforts have focused on the relatively hypoxia-tolerant Atlantic croaker, it is likely this biomarker or physiological response is not species specific or limited to the Gulf. For example, expression of the HIF 1α biomarker was also recently found in mantis shrimp and dragonet exposed to hypoxia in Tokyo Bay, Japan (Kodama et al. 2012a, 2012b).

Additional research on the physiological impacts of hypoxia has focused on endocrine disruption and reproductive impairment. Exposure to suboptimal dissolved oxygen conditions, varying from just below to just above 2 mg/L, has been attributed to disruption of the key enzyme tryptophan hydroxylase in the hypothalamus of Atlantic croaker (Thomas et al. 2007; Rahman and Thomas 2009; Rahman et al. 2011). This disruption of the endocrine system responsible for regulating the gonadal system can have significant effects on reproduction that can be widespread. Thomas and Rahman (2010) found that male Atlantic croaker collected from sites associated with the Gulf hypoxic zone had significant testicular impairment relative to male Atlantic croaker collected from normoxic reference sites. Males from the hypoxic zone had 26.2 percent fewer sperm than males from references sites, leading to an approximately 50 percent decrease in testicular growth. Subsequent analysis of female croaker from the hypoxic zone found similar impairments. While ovaries of female Atlantic croaker from normoxic sites were normal, 19 percent of croaker ovaries from hypoxic sites contained male germ cells, a sign of masculinization. In addition, croaker ovaries from hypoxic sites were smaller, less developed, and produced fewer viable eggs. These findings were confirmed through laboratory experiments, which also showed that ovaries did not recover once normal dissolved oxygen conditions returned. Further, a spawning trial indicated that impaired gamete maturation was accompanied by a dramatic decline in numbers of fertilized eggs (Thomas and Rahman 2009b). Widespread analysis of croaker sex ratios indicates a strong bias toward males around the hypoxic zone relative to croaker from normoxic waters (Thomas and Rahman 2011). As expected, affected masculinized female croaker exhibited significantly reduced endocrine function and aromatase, an enzyme responsible for the production of estrogen.

With high spatial overlap with other additional fish species (Craig 2012), Craig and Bosman (2013) suggest that the sublethal impacts found in croaker likely extend to the broader demersal, and possibly pelagic, community.

Evidence for Fisheries and Socioeconomic Effects

Research into the socioeconomic impacts of hypoxia in the Gulf of Mexico has primarily focused on brown shrimp, and results remain preliminary. However, research on the economic impacts of hypoxia on the brown shrimp fishery in the Neuse River, North Carolina, likely provides a useful perspective to the Gulf. In the Neuse River, Huang et al. (2010) estimated a 12 to 15 percent increase in revenues to the shrimp fishery if hypoxia were eliminated. However, in a later study, Huang et al. (2012) suggests the effect of eliminated hypoxia would actually be lower because of many other factors affect shrimp stocks and prices. When the shrimp supply in the United States is dominated by imports, improvements in the Neuse River fishery would likely have no effect on overall shrimp prices. For shrimpers, any gains in shrimp harvest would likely be short-lived or minimal because of current fishery management policies and because shrimpers typically respond to a suite of factors in addition to shrimp supply (e.g., weather and prices). Note that these analyses examined only the Neuse River fishery, although hypoxia likely affects a broader suite of species and ecosystem functions. Therefore, the economic benefits of nutrient reductions would have to be integrated across multiple factors (K. Craig, 2012, personal communication).

A broader analysis of the socioeconomic effects on the shrimp fishery in the Gulf of Mexico is underway, including developing a suite of economic models. Preliminary results from this study have found that shrimpers in the northern Gulf respond to hypoxia in a similar pattern to shrimp and croaker, with shrimpers fishing in a halo pattern around the edge of hypoxic zone (K. Craig, 2012, personal communication). The large congregation of demersal species around the hypoxic zone coupled with targeted fishing along the edge by shrimpers has been suggested to cause an increase in bycatch of non-target species (Craig 2012). In addition, alterations in movements have also been observed in Gulf menhaden fisheries and studies are underway (Craig 2012) to examine the role of hypoxia in movements of the menhaden fishing fleet (J. Rester Gulf States Marine Fisheries Commission, 2012, personal communication).


NOAA

Shrimp trawler.

Next Steps and Remaining Needs

Although the connection between upstream nutrient loads and the relative size of the hypoxic zone in the Gulf is well established, broader ecological effects on the Gulf ecosystem that could reach even beyond the Gulf will continue to be evaluated. Since the last reassessment that culminated in the 2008 Action Plan, knowledge of the ecological impacts of hypoxia has increased greatly and many research efforts are beginning to mature. Many of these efforts are beginning to transition their findings from laboratory and field-based assessments into integrative modeling platforms that will allow for examination of multiple stressors and hypoxia scenarios. For example, results on reproductive impairments in croaker coupled with data on distribution relative to the hypoxic zone are being integrated into an individual-based model of Atlantic croaker in the northern Gulf of Mexico (S. Creekmore and K. Rose, Louisiana State University, 2012, personal communication). Once fully developed, this model will allow an examination of hypoxia effects on croaker populations under varying scenarios and provide a framework for modeling impacts to additional Gulf species. Similarly, ecosystem-based models such as EcoSim with EcoPath and Atlantis are being developed that allow for multi-species assessments of hypoxia impacts, trophic dynamics, and nutrient effects.

In addition, integration of these modeling efforts with physical/biogeochemical hypoxia models will also allow for a holistic assessment of ecosystem effects from nutrient abatement and reduced hypoxia. While it is widely accepted that a reduced hypoxic area will improve overall ecosystem health, an emerging theory indicates there will be possible tradeoffs with some species benefiting more than others. In Lake Erie, Brandt et al. (2011) suggest that walleye, an important recreational fishery, might be benefiting from hypoxia as a result of concentrated plankton biomass above hypoxic waters. Similar theories have been suggested for planktivorous fish in the Gulf, such as juvenile menhaden, anchovies, and Atlantic bumper, although the additive effect of fishing pressure remains a critical unknown. Elucidating these ecosystem-wide implications through integrated model applications represents a critical frontier in hypoxia impacts research.

To enable these modeling capabilities, a suite of targeted research needs remains a priority. In general, these needs center on expanding the suite of species analyzed for hypoxia impacts and on improving ecological modeling capabilities. Most of the needs identified in Kidwell et al. (2009) remain gaps in research and should be addressed. However, advancement of the field has resulted in the identification of specific priority needs required to advance modeling efforts. These needs include the following:

1. Refined assessments of Atlantic croaker sublethal and indirect hypoxia impacts and targeted research to examine possible sublethal impacts in additional species.
2. Multi-stressor assessments of cumulative ecosystem and species impacts.
3. Improved quantification of long-term population-level impacts of key living resources, such as brown shrimp and red snapper.
4. Integration into regional ecosystem planning and fisheries management efforts.
5. Improved species modeling capabilities, including incorporation of movement patterns in relation to the hypoxic zone and bioenergetic implications of altered foraging habits and suboptimal oxygen levels.
6. Refinement of ecosystem modeling capabilities that incorporates spatially explicit effects of hypoxia and subsequent changes in predator-prey relationships.
7. Refined quantification of socioeconomic effects and expansion to additional species.
8. Coupling of ecological models with scenario-based hypoxia models.
9. Improved understanding of the relationship between nutrient loads, hypoxia spatial and temporal dynamics, and living marine resources through integrated modeling and assessments.

Action Item 6

Data Access and Collection

“Coordinate, consolidate, and improve access to data collected by State and Federal agencies on Gulf Hypoxia and Mississippi/ Atchafalaya River Basin program activities and results.”

Action Item 6 focuses on coordinating, consolidating, and improving access to data collected by state and federal agencies on Gulf hypoxia and nitrogen and phosphorus fate and transport in the MARB. The Integrated Assessment (1999) reports that a comprehensive monitoring, research, and modeling approach was needed to evaluate which BMPs are most effective. Fundamentally, the Task Force agencies have progressed on Action Item 6 over the years; nevertheless, gaps in data and information remain, and these agencies continue to strive for extensive data collection, consolidation, and access.

Basin Data

USGS has provided **annual streamflow and nutrient flux** (http://toxics.usgs.gov/hypoxia/mississippi/flux_ests/index.html) data since 1980 for the MARB and nine major subbasins (Aulenbach et al. 2007). Preliminary spring estimates of monthly streamflow and nutrient fluxes from the Mississippi and Atchafalaya rivers to the Gulf of Mexico are provided in June each year. NOAA-supported researchers incorporate the spring nutrient load estimates into a suite of models to forecast the **size of the hypoxic zone in the Gulf of Mexico** (www.cop.noaa.gov/gulf_hypoxia_forecast/).

The Task Force agencies are also focused on improving the access to a wealth of existing monitoring data that are critical to measuring progress of nutrient reduction actions. In 2012 USEPA, USGS, and the National Water Quality Monitoring Council released a collaborative **Water Quality Portal** (www.waterqualitydata.us/). The Portal provides consolidated, publicly available water quality data from USEPA’s Storage and Retrieval (STORET) Data Warehouse and USGS’s National Water Information Systems (NWIS) in one central location. This combination of STORET and NWIS data is a significant source of water quality information from water resource management groups, state and local governments, public and private utilities, private citizens, and other groups. USDA ARS is working with USGS and USEPA to include in the Water Quality Portal the Sustaining the Earth’s Watersheds: Agricultural Research Data System, a Web-based system providing access to soil, water, climate, land-management, and socioeconomic

The Water Quality Portal (WQP) is a cooperative service sponsored by the United States Geological Survey (USGS), the Environmental Protection Agency (EPA), and the National Water Quality Monitoring Council (NWQMC).

Water Quality Portal website.

data from CEAP projects. While most monitoring data are stored in some type of online system, not all current long-term monitoring data are stored in one of these three national databases. The inclusion of all available water quality monitoring data in a common format through one portal, especially sites with long-term information, is critical to developing a MARB monitoring network.

At the spring 2012 Task Force meeting, a MARB Monitoring Collaborative chaired by USGS and NOAA was formed to identify the monitoring objectives and funding needed to establish an integrated long-term, multiscale MARB water quality monitoring network using existing sites and resources. This workgroup includes representatives from each Task Force state and federal agency. Water quality data have been retrieved from multiple agencies in the Task Force states. Preliminary assessments indicate that at least 325 active sites have at least 10 years of water quality data (at least quarterly sampling) that were collected at or near an active stream gauge. About 140 of those sites have more than 20 years of data. The collaborative continues to identify new sites, discuss data storage and monitoring procedures, and explore opportunities for standardizing data collection and storage procedures. New long-term monitoring networks established in the past 5 years, such as the 81 sites in the Minnesota **Watershed Pollutant Load Monitoring Network** (www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/streams-and-rivers/watershed-pollutant-load-monitoring-network.html), will be added to the monitoring collaborative as they are identified.

The MARB Monitoring Collaborative is also working with other groups throughout the watershed to assess water quality monitoring activities and needs. For instance, the Upper Mississippi River Basin Association embarked on a two-year project in 2012 to develop an Upper Mississippi River monitoring strategy to aid the Upper Mississippi River states in moving forward with more comprehensive, consistent, and accurate Clean Water Act assessments of the Mississippi River, leading to both a better understanding of its condition and the status of water quality improvements. This work will also serve as a foundation for seeking long-term, stable funding to support Upper Mississippi River Water Quality monitoring goals (Yoder et al. 2012).

The USEPA **Nitrogen and Phosphorus Pollution Data Access Tool (NPDAT)** (http://www2.epa.gov/nutrient-policy-data/nitrogen-and-phosphorus-pollution-data-access-tool) provides access to key information on the extent and magnitude of nitrogen and phosphorus pollution in streams. Additional data needs in the MARB include improving access to scientific research and refinements to existing spatial data sets on nutrient sources, conservation practices, and land use or land cover. These data are needed to develop nutrient budgets and enhance our understanding of why water quality conditions change over time. For example, tracking nutrient inputs from point sources helps to evaluate whether changes in technology and policy have reduced nutrient loads from point sources.

The USEPA **DMR Pollutant Loading Tool** (http://cfpub.epa.gov/dmr/index.cfm) provides access to point source nutrient information from 2007 to 2011 and can calculate pollutant loadings from permit and DMR data. The tool can also track the percentage of the point source load estimated using DMR data and modeled estimates. This tool provides a uniform method to track point source inputs at local, state, and MARB scales; however, some data verification issues must be addressed to improve the accuracy of nutrient estimates using this tool.

To better understand whether the actions states and federal agencies are taking are sufficient to improve both local and downstream water quality, improvements in point source estimates and spatial data sets on nutrient inputs from agricultural (amounts, timing, and inputs of manure and fertilizer), atmospheric (including source apportionment from various sources), and urban sources are needed. These improvements will enhance estimates of nutrient budgets, and the calibration and validation of watershed models.

Following are the monitoring and data needs for the MARB:

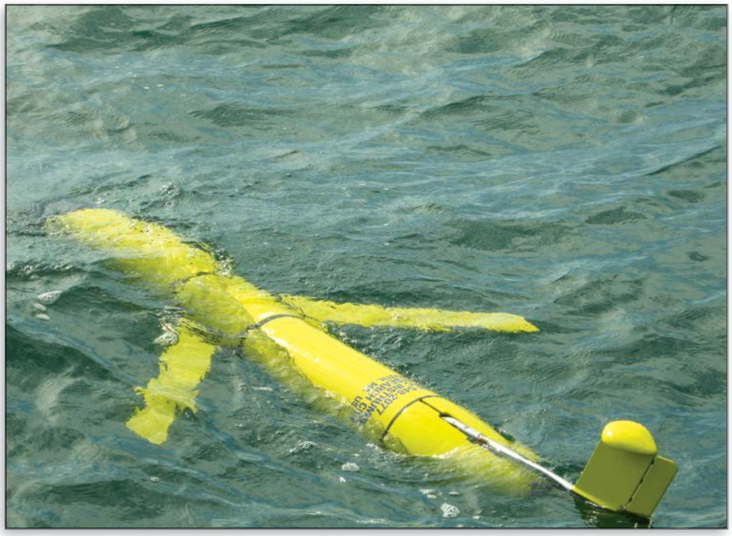
- Annual and seasonal estimates of nutrient loads from watersheds identified as part of the MARB Monitoring Collaborative.
- Expand intensive, long-term monitoring at multiple scales, but especially target small HUC-12 watersheds.
- Ensure all long-term water quality data are available through one Web portal, such as the Water Quality Portal.
- Increase the number of sites with real-time nutrient data accessible via the Web.
- Increase water quality monitoring at HUC-8 and HUC-12 scales in USDA MRBI watersheds and other watersheds where conservation practices are being implemented.
- Develop annual reports of nutrient inputs from point sources and continue to reduce the uncertainty of point source nutrient loads by increasing point source monitoring requirements for nutrients and verifying flow and nutrient information in the USEPA DMR Pollutant Loading Tool.

Coastal Data

In 2012 NOAA updated the 2009 Gulf Hypoxia Monitoring Implementation Plan, which outlines requirements for comprehensive characterization of the Gulf hypoxic zone. Updates to the plan were a primary outcome of the 2011 Gulf Hypoxia Research Coordination Workshop, which is held annually to coordinate hypoxia research and monitoring activities. The 2012 update focuses on core monitoring requirements and includes the following:

- Expanded spatial boundaries of shelf-wide surveys (80–90 sites).
- Increased number of monthly shelf-wide surveys (April, May, June, July, August, and September).
- Increased number of observational systems.
- Cross-shelf transects to address temporal gaps of shelf-wide surveys.
- Deployments of autonomous underwater vehicles (AUVs) with dissolved oxygen sensors.
- Inclusion of hypoxic volume measurements on shelf-wide surveys.
- Continued in situ observational systems and assurance that all are outfitted with dissolved oxygen sensors.
- Data portal to maximize accessibility to, and exchange of, hypoxia data.
- Dissemination of relevant data and findings to management community.

In response to the 2009 Monitoring Implementation Plan, NOAA has continued funding for the mid-summer survey by the Louisiana Universities Marine Consortium (LUMCON; Rabalais et al.



Kjell Gundersen

Webb Teledyne Glider at surface during a trial run to measure dissolved oxygen levels in the Mississippi Bight. The Webb Glider is owned and operated by Dr. Stephan Howden, Department of Marine Science, University of Southern Mississippi.

2007) that measures the areal extent of the hypoxic zone and serves as the primary metric for assessing progress toward the 2008 Action Plan goal. NOAA has also continued taking dissolved oxygen measurements in conjunction with the summer groundfish survey of the Southeast Area Monitoring and Assessment Program (SEAMAP). Though not synoptic, this survey provides near real-time data through **Hypoxia Watch** (www.ncddc.noaa.gov/hypoxia/) to inform hypoxic zone modeling efforts. Since 2009, NOAA has also funded two additional complementary surveys of the areal extent of the hypoxic zone. Led by Texas A&M University (TAMU) and conducted in June and August, these surveys provide critical context to the mid-summer LUMCON survey. Since 2009, NOAA funded surveys have produced further information regarding the behavior of dissolved oxygen in near-shore Gulf waters and increased resolution on the extent and duration of hypoxic episodes.

NOAA has released the first phase in developing a **Gulf of Mexico Data Atlas** (http://gulfatlas.noaa.gov/) to highlight six categories of data: physical, biotic, living marine resources, economic activity, environmental quality, and jurisdictions. Historical dissolved oxygen data collected through the SEAMAP surveys are accessible through the Atlas, while historical data collected through the LUMCON and TAMU surveys will be accessible in phase two of the Atlas. These data sets will also be combined with the SEAMAP data to construct annual dissolved oxygen climatologies and time-series simulations of the hypoxic zone. Efforts to develop a hypoxia data portal are ongoing in collaboration with the Gulf of Mexico Coastal Ocean Observing System.

Action Item 7

Track Interim Progress on Program Actions to Reduce Nitrogen and Phosphorus

"Track interim progress on the actions to reduce nitrogen and phosphorus by producing an annual report on federal and state program nutrient reduction activities and results."

The Task Force has been instrumental in helping advance the science and synthesis needed to understand the nature of the hypoxia problem in the Mississippi River and Gulf of Mexico. It also continues to provide executive level support for coordinating the actions of participating states and federal agencies working on nutrient management in the watershed. The Task Force has produced two Action Plans to date. The 2008 Action Plan has three overarching goals: (1) the Coastal Goal to reduce the size of hypoxic zone to less than 5,000 km^2 by 2015; (2) the Within Basin Goal to restore and protect waters in the MARB; and (3) the Quality of Life Goal to improve communities and economic conditions across the MARB. However, the lack of shorter, more specific and quantifiable measures in the Action Plan limits the Task Force's ability to routinely and accurately assess progress toward these goals. It also creates challenges to be more action-oriented and accountable.

To better focus its missions and goals, the Task Force formed an Accountability Work Group, and discussed an Accountability Framework at the Tunica, Mississippi meeting in September 2010. In the context of the Task Force, the framework defines accountability as "the ability to objectively measure and report on progress toward quantitative environmental management goals, where possible, related to reducing nutrient pollution in-basin and its downstream impacts in the northern Gulf of Mexico." The framework identified actions required of the Task Force to be more accountable. One action was to establish a workgroup composed of technical experts to develop reasonable and scientifically defensible recommendations that quantify progress toward each of the goals described above. Soon after the Tunica meeting, the Task Force established a Measures Work Group.

The Measures Work Group examined a broad range of indicators on the basis of their fiscal and technical feasibility that could be used to measure and track progress in implementing the Action Plan. Some of the indicators considered included: TP and TN loads in pounds/year from major municipal and industrial NPDES dischargers; estimated phosphorus and nitrogen load reductions on the basis of agricultural practices; and nutrient loads in water bodies. The Task Force is still discussing ways to effectively estimate phosphorus and nitrogen load reductions from agricultural conservation practices.

For point sources, USEPA has developed a Web-based DMR Pollutant Loading Tool to help users determine who is discharging what pollutant, where, and by how much. This will help enhance access to DMR data for the general public interested in their local watersheds and assist technical users like permit writers or watershed modelers. For the Task Force states, the loading tool includes a new search function that provides the same information as the general tool (i.e., dischargers, pollutants, location, amounts) but limits the results to nitrogen and phosphorus data. This function also presents aggregated nutrient loads for facilities required to report discharges through DMR data and from facilities that are likely to discharge nitrogen or phosphorus but are not reporting it on their DMRs. (Modeling of loads for facilities without data was accomplished by using information from similar facilities that do report nutrient loads.) USEPA is refining the Task Force function to produce various reports that break up annual loadings not only by state and watershed, but also into a number of other categories. Additionally, the function will generate reports and counts on effluent limits, and monitoring requirements by geographic areas and categories.


USDA NRCS

Wildlife find habitat in a restored wetland in Iowa.

To evaluate the effectiveness of conservation practices, one effort is the coordinated monitoring between multiple state and federal agencies in a subset of the MRBI watersheds. Through the MRBI, USDA NRCS aims to improve the health of the MARB, including water quality and wildlife habitat, by helping producers in priority watersheds voluntarily implement nutrient conservation practices. A comprehensive and integrated multitiered monitoring plan in priority watersheds is being developed to track the progress of these practices toward reducing nutrients and improving water quality. Fifteen small watersheds in Arkansas, Iowa, Minnesota, Mississippi, Missouri, and Wisconsin were selected for intensive monitoring under the MRBI monitoring initiative. The information gathered and lessons learned from these watersheds will help NRCS update its technical standard for water quality monitoring and help the Task Force show progress in a representative sample of HUC-12 watersheds.

Another example of a coordinated monitoring effort to address the need for data and tracking interim progress is the new MARB Monitoring Collaborative chartered by the Task Force in 2012. This collaborative aims to establish a shared reporting network of already existing sites with long-term nutrient monitoring and streamflow records. Historic and future data collected from this network will prove invaluable for evaluating where the overall impact of conservation practices and policies is, and to help target where new or improved nutrient reduction strategies need to be established. Action Item 6 also provides more detail on the monitoring collaborative.

Various tools have been developed to help Task Force states with their nutrient reduction strategies. USEPA designed NPDAT to support states and other partners in prioritizing watersheds on a statewide basis for nitrogen and phosphorus load reductions and for setting watershed load reduction goals, which are the first two elements recommended by the USEPA framework memo, which is summarized in Action Item 1. NPDAT can also help states analyze nitrogen and phosphorus pollution by providing data on the extent and magnitude of nitrogen and phosphorus pollution, related water quality problems, and potential pollution sources in a format that is readily accessible and easy to use.

While NPDAT focuses on watershed prioritization and load reduction goals and the Loading Tool on point sources, a modeling tool by NRCS known as Agricultural Policy/Environmental eXtender (APEX) is now available to evaluate the impacts of conservation management decisions on environmental and production issues. APEX can estimate the sustainability of land management strategies for cropland, grazing, and pasture land with respect to factors like erosion, water quantity and quality, and soil quality. The management strategies that can be simulated include tillage, buffer strips, nutrient application, crop rotation, and more. A unique feature of APEX is its capacity to subdivide farms to arrive at a homogenous field scenario with respect to soil, climate, and management. NRCS is developing a method to use APEX for characterizing the HUC-12 watersheds. These efforts to enhance APEX present another critical tool for measuring success by states in reducing nutrients loads.

The Task Force states will also incorporate into their nutrient reduction strategies accountability and verification measures and tracking of biannual load reductions and environmental impacts in targeted watersheds. These components of the strategies will enhance the quantification and tracking of program and management efforts toward nutrient load reductions.

While the above collaborations and tools help track interim progress, the following section provides a few examples of the progress already made and success stories related to nutrient impairments since 2008, based on information provided by the states.

Examples of State Success Stories

Arkansas

The Arkansas-Oklahoma Arkansas River Compact adopted a 40 percent reduction goal for phosphorus loading in the Illinois River Watershed. Baseline loading was established to track progress. At each monitoring site, five-year rolling average concentrations are trending downward. The Illinois River Watershed Partnership leveraged more than $2,241,000 in nongovernmental funds for conservation and phosphorus reduction efforts. In addition, northwest Arkansas cities invested over $225,000,000 in POTWs (2010: 0.37 mg/L average concentration for all POTWs). Cities and developers in the watershed are investing substantially in non-agricultural stormwater controls.

Illinois

The Champaign County Soil & Water Conservation District worked with local agribusinesses and producers to minimize soil and nutrients from moving into local streams and drainage ditches through the adoption of strip till and deep placement of fertilizer in crop production. A program was implemented to make specialized farm equipment available to producers in Champaign County and to provide cost share payments to producers to implement strip-till, strip-till with deep nutrient placement, and soil testing. The program resulted in about 10,000 acres of farmland being planted with strip-till or strip-till with deep nutrient placement. The load reductions are in the table below. The project covered Champaign County with special emphasis on the Salt Fork Vermilion River, Embarrass River, and the Little Vermilion River segments in the county.

Estimated Load Reductions				
BMP code	**BMP name**	**Sediment (tons/year)**	**Phosphorus (pounds/year)**	**Nitrogen (pounds/year)**
329	Conservation tillage	21,461	23,691	47,169

Indiana

CREP and Lake and River Enhancement have BMP cost-share funds specifically for improving water quality on agricultural lands and along water bodies. One project of note in CREP was an 84-acre riparian buffer stretching nearly 2 miles as a single project. This project establishes a buffer for surrounding agricultural and residential areas and is a sounding board for the success of CREP in protecting water quality. Both Indiana's Departments of Agriculture and Environmental Management use the USEPA Region 5 model to estimate load reductions. All Clean Water Act Section 319 projects and Clean Water Indiana funded practices, such as the CREP buffer, are included in these load reductions. On the basis of this model, the estimated load reductions for 2012 from practices installed under the CREP program were 86,470 pounds of nitrogen, 43,732 tons of sediment, and 44,370 pounds of phosphorus statewide. The Conservation Cropping Systems Initiative has also been very proactive in addressing nutrient management by working with farmers to improve soil health while promoting the use of no-till and cover crops, keeping more nutrient and sediment on the fields, and increasing nutrient uptake by the plants.

Louisiana

The Ouachita and Mermentau River Basins are two basins identified through USGS SPAtially Referenced Regressions On Watershed attributes (SPARROW) modeling as contributing high nitrogen and phosphorus loads to in-stream and Gulf waters. In these basins, nitrogen and phosphorus trends have declined as a result of point source and nonpoint source programs. LDEQ is examining water quality trends in other basins to determine if similar reductions have occurred over the period of record in which LDEQ has collected ambient water quality data. In addition to seeing successful nutrient reductions in two key basins, the Louisiana Environmental Leadership Program recognizes voluntary pollution reductions, including those for nutrients.

Minnesota

The **Sauk River Chain of Lakes** (http://water.epa.gov/polwaste/nps/success319/state_mn.cfm) is impaired by phosphorus and total suspended solids from row cropping and livestock operations, and discharges from on-site septic systems. Agricultural BMPs and upgrades to septic systems and municipal wastewater treatment facilities throughout the watershed have reduced TP concentrations to 176 µg/L—nearly achieving the regional goal of 100–150 µg/L—representing a 48 percent decrease in TP loading.

Additionally, the **Minneapolis Chain of Lakes** (http://water.epa.gov/polwaste/nps/success319/mn_chain.cfm) receives urban runoff delivering high levels of phosphorus and sediment from its fully developed watershed. Through implementing a widespread public education campaign, sediment control measures, and other practices throughout the 7,000-acre watershed, the Minneapolis Chain of Lakes Clean Water Partnership achieved significant in-stream reductions in sediment and phosphorus. This has helped most of the lakes stay off the 303(d) list of impaired waters.

Missouri

In 2010 the Generations Program, an innovative Future Farmers of America partnership supported by USEPA Gulf of Mexico Program funds, was implemented in five Bootheel counties in southeast Missouri. This program paired youths (the next generation of farmers) with agricultural professionals and corn producers to collect cornstalk samples, test them for nitrate content, and assist producers in making fertilizer decisions.

Additionally, following the passage of House Bill 250, the Missouri Soil and Water Conservation Cost-Share Program expanded its docket of farm conservation practices from 17 to 49 practices in 2009. These new practices included enhanced sediment erosion control measures and practices that reduce nutrient, bacteria, and pesticide loads. Before the passage of House Bill 250, the program's practices addressed only sheet, rill, and gully erosion.

Ohio

Ohio EPA conducts biological and water quality surveys on major river basins throughout the state and follows up with generating TMDLs for waters that are impaired. A survey of the Little Miami River, a National Scenic River and tributary to the Ohio River, conducted in 1998 revealed impairment of aquatic life uses. Elevated TP (median in-stream TP concentration ~0.3 mg/L) was a contributing cause, and the subsequent TMDL resulted in the imposition of 1 mg/L effluent limits for TP at major wastewater treatment plants. Following plant upgrades and operational changes, these facilities are in compliance with their effluent limits. Load duration analysis demonstrated that the new NPDES permit limits had reduced the ambient river TP concentration to a value near the TMDL target by 2008. Follow-up stream survey work in 2011 showed in-stream phosphorus concentrations have been reduced by over 50 percent compared to 1998 levels. Equally important, the biological condition of the river has improved, and the Little Miami River is now in full attainment of its aquatic life use designation.

Wisconsin

The state-enacted phosphorus technology-based effluent limits have resulted in a 67 percent load reduction from municipal and industrial wastewater facilities in Wisconsin. In specific HUC-8 areas, such as the central portion of the Wisconsin River Basin or the Upper Rock River Basin, where point sources were the dominant contributors of phosphorus, attaining the limit has resulted in a substantial reduction in load.

Year	Point source (data from DMR, in lbs/year)	Nonpoint source (data from SPARROW, in lbs/year)	Total
La Crosse–Pine watershed			
1995 (baseline)	255,094	119,466	374,560
2013	84,331	107,519	191,850
Castle–Rock watershed			
1995 (baseline)	514,524	353,684	868,208
2013	118,066	318,316	436,385

Action Item 8

Decrease Scientific Uncertainty on Source, Fate, and Transport of Nitrogen and Phosphorus

“Continue to reduce existing scientific uncertainties identified in the Science Advisory Board and MMR workgroup reports regarding source, fate, and transport of nitrogen and phosphorus in the surface waters of the Mississippi/Atchafalaya River Basin.”

Adaptive management provides a framework to move forward on nutrient related hypoxia issues in the Gulf of Mexico recognizing the scientific uncertainties of nutrient source, fate, and transport assessments. Key components of adaptive management include model flexibility and compatibility between watershed models, economic models, and Gulf of Mexico hypoxia models (USEPA 2008), while striving to reduce uncertainty. While significant progress has been made to refine our understanding and reduce the uncertainty of nutrient sources and transport throughout the MARB that were identified in the Integrated Assessment and the 2004 Science Assessment (Goolsby et al. 1999; USGS 2004), numerous challenges remain. Tomer and Locke (2011) and Sprague and Gronberg (2012) describe some key challenges of measuring the benefits of conservation practices in watersheds and highlight the importance of continued integration of long-term monitoring and observational and modeling studies to inform adaptive management of nutrient reduction strategies.

An extensive list of models that have been applied to enhance the understanding of source, fate, and transport of nutrients from the field to regional and basin scales in the MARB are described in the SAB report (USEPA 2008). Many of these models address needs identified in the 1999 Integrated Assessment, which include a better understanding of nitrogen dynamics in soils and streams, the dynamics and timing of nitrate transport in small watersheds (drained and undrained), and atmospheric deposition. These field-scale results highlight spatial and temporal variability in nutrient processing that can enhance the development of state, regional, and basin scale assessments that can be used to evaluate how various management strategies across the MARB affect nutrient delivery to the Gulf of Mexico.

Regional and Basin-wide Scale Assessments of Nutrient Sources and Transport to Gulf

Basin-wide assessments have enhanced our understanding of nutrient delivery and transport within the MARB. Results from a variety of recent basin-scale models are in general agreement with the 1999 Integrated Assessment that row-crop agriculture is the dominant source of nutrients exported to the Gulf and that nutrient hot spots throughout the corn belt contribute a large percentage of the annual/spring nutrient loads, but they occupy a relatively small portion of the MARB watershed area (Table 2) (David et al. 2010; Alexander et al. 2008; Booth and Campbell 2007). Tile drainage in these nutrient hot spot areas has also been identified as a key factor accelerating nitrate export (David et al. 2010; Raymond et al. 2012; Schilling et al. 2012). Point sources are estimated to represent about 7 to 14 percent of the annual or spring nitrogen load and 9 to 27 percent of the annual or spring phosphorus load to the Gulf (USEPA 2008). To obtain a significant reduction in nutrient flux to the Gulf and reduce the size of the hypoxic zone, nutrient reduction strategies aimed at both nonpoint and point sources will be crucial.

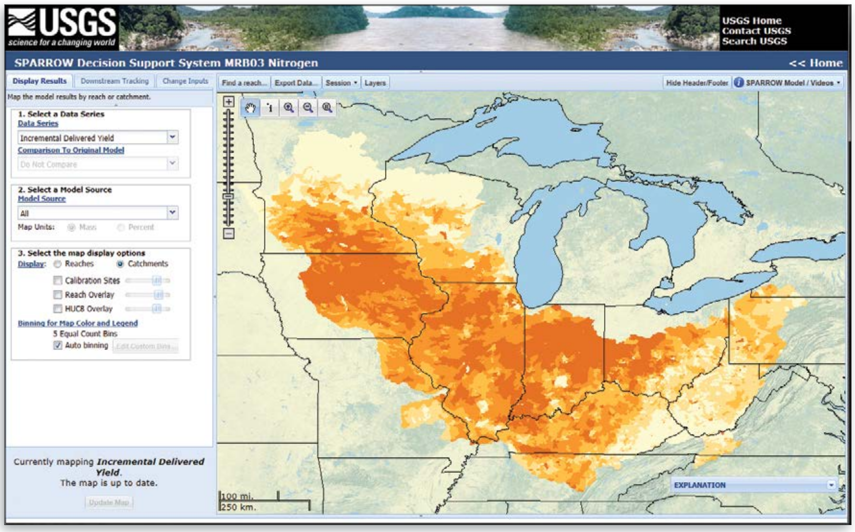
Each of these models offers new insights on the sources, landscape, and hydrological factors affecting nutrient delivery. Numerous models have improved our understanding of nutrient dynamics and transport, which can be used to evaluate various management strategies. A few examples of basin-wide model applications are described below that highlight key factors influencing both the annual and spring flux of nitrate to the Gulf. Similar models are also available for phosphorus.

Table 2. Estimates of basin-wide source contributions to annual and spring nitrate export from the MARB

	Integrated Assessment 1999	David et al. 2010	Alexander et al. 2008	Booth and Campbell 2007
Major Sources of Nitrate/TN	**Annual Nitrate Flux to Gulf**	**Winter–Spring Nitrate Flux from Counties**	**Annual TN Flux to Gulf**	**Spring Nitrate Flux to Gulf**
Fertilizer Runoff or Agricultural Crops	50%	76%	66%	59%
Human Consumption or Urban and Population Sources or Municipal Waste	11%	7%	9%	11%
Animal Manure	15%		5%	13%
Atmospheric Deposition	24%		16%	17%
Tile Drainage		17%		
Natural Land			4%	

David et al. (2010) correlate agricultural and human inputs of nitrogen to winter-spring (January–June) riverine nitrate export for each of the 1,768 counties in the MARB. Winter-spring nitrate export was averaged from 1997 to 2006 at 153 watersheds in the MARB. The dominant factors correlated to spring nitrate transport included runoff times fertilizer nitrogen inputs (76 percent), tile drainage (17 percent), and human consumption of nitrogen (7 percent) (Table 2). Fertilized crops on tile drained watersheds contributed to the highest nitrate yields. The top 259 counties contributing greater than 7.5 kg nitrogen ha^{-1} that were identified for focused nutrient reduction actions were mostly in the corn belt from southern Minnesota, the Des Moines lobe of Iowa, northern central Illinois, Indiana, and Ohio. David et al. (2010) report that these counties have high crop and drainage fractions, high fertilizer inputs, and greater nitrogen balances compared with other counties throughout the MARB. Jacobson et al. (2011) use a similar approach to determine critical factors describing phosphorus loss and identify counties with the highest phosphorus yields throughout the MARB.

The USGS SPARROW model integrates water quality monitoring data from local, state, and other federal agencies with detailed geospatial information to explain patterns in relation to human activities and natural processes. Alexander et al. (2008) applied a national SPARROW model, based on 1992 and 2002 nutrient inputs, with about 400 calibration sites, to assess annual nitrogen and phosphorus delivery to the Gulf of Mexico. Model estimates indicate that 52 percent of the nitrogen and 25 percent of the phosphorus entering the Gulf of Mexico from the MARB is from lands cultivated in corn and soybeans. Urban and population-related sources contributed about 9 percent nitrogen and 12 percent phosphorus. Uncertainties in the nutrient yield estimates from this model, updated with 2002 nutrient inputs, were incorporated into a statistical ranking procedure to determine the probability that a watershed could be placed in or out of the top 150 watersheds that deliver the highest nitrogen or phosphorus yields to the Gulf of Mexico. Robertson et al. (2009) report that while only four HUC-8 watersheds could be reliably placed in the top 150 category for nitrogen with 95 percent confidence, 54 percent of the HUC-8 MARB watersheds are reliably placed outside the top 150 category with 95 percent certainty. Most of them are in the western parts of the MARB in Kansas, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, and Wyoming. Incorporating uncertainty in nutrient yield estimates in watershed rankings is critical to implementing a robust nutrient reduction strategy that accounts for long-term variability and model uncertainty. These rankings are based on estimated nutrient yields delivered to the Gulf and would change if a manager was interested in ranking watershed contributions to an upstream reservoir or major tributary where point source contributions could be an important source of nutrients locally. Regional SPARROW models for TN and TP for the Upper Mississippi Basin, Missouri River Basin, and Lower Mississippi-Texas Gulf, based on 2002 nutrient inputs, included major advancements in significantly increasing the number of stream load calibration sites to about 900 sites in the MARB. This was accomplished by including data from 47 local, state, and other federal agencies, developing a database for describing effluent discharges from industrial and municipal wastewater treatment facilities, and including regional factors that are important in explaining nutrient transport (Brown et al. 2011; Rebich et al. 2011; Robertson and Saad 2011). An online interactive decision support system can be used to identify which sources and which catchments contribute the largest amounts of nutrients to downstream waters and evaluate alternative nutrient reduction scenarios and develop science-based estimates of how changes in nutrient sources affect the transport of nutrients to downstream waters (Booth et al. 2011).



Map the model results by reach or catchment.

1. Select a Data Series
Data Series: Incremental Delivered Yield
Comparison To Original Model: Do Not Compare

2. Select a Model Source
Model Source: All
Map Units: ● Mass ○ Percent

3. Select the map display options
Display: ○ Reaches ● Catchments
☐ Calibration Sites
☐ Reach Overlay
☐ HUC8 Overlay
Binning for Map Color and Legend
5 Equal Count Bins
☑ Auto binning

Currently mapping *Incremental Delivered Yield*.
The map is up to date.

The SPARROW model can be used to predict amounts and sources of nutrients that are delivered to downstream water bodies. The **online decision support system** (*http://cida.usgs.gov/sparrow/*) can be used to map sources and watersheds contributing the largest amounts of nutrients to a downstream reservoir or estuary and evaluate effects of user specified nutrient reduction scenarios.

Booth and Campbell (2007) use a regression model to describe the relation between spring nitrate export from the MARB and runoff, fertilizer inputs, population, animal waste inputs, and atmospheric deposition. Spring nitrate export was estimated using data from 1990 to 2002 at 27 sites throughout the MARB. The dominant sources of nitrate correlated to the spring nitrate flux were fertilizer runoff (59 percent), which includes overland runoff and transport in tile drains and from groundwater, atmospheric deposition (17 percent), animal waste (13 percent), and municipal waste (11 percent) (Table 2). Regression model results indicate that about 20 percent of the MARB drainage area accounts for about 90 percent of the spring nitrate flux to the Gulf of Mexico. Watersheds with the highest spring nitrate yields also had the lowest amount of land enrolled in federal conservation programs. Booth and Campbell (2007) suggest scaling conservation actions in proportion to fertilizer use intensity as one alternative to reducing nitrate flux.

Donner et al. (2004) applied a dynamic, process-based modeling system (Integrated Biosphere terrestrial ecosystem model and the Hydrological Routing Algorithm aquatic transport model) to examine how agricultural practices and climate influenced nitrate export from the MARB. Annual nitrate export was estimated using data from 1960 to 1994 at 29 sites. A doubling of nitrate export from the MARB from 1960 to 1990 was attributed to an increase in fertilizer use, an increase in runoff, and expansion of soybean cultivation. Model estimates for the 1990s indicate that fertilized cropland accounts for 86 percent of the nitrate export, despite representing only 20 percent of the MARB watershed area.

The NRCS CEAP assessments of the Upper Mississippi, Ohio/Tennessee, and Missouri River Basins combined the APEX field-scale model with the Hydrologic Unit Model for the United States (HUMUS/SWAT) watershed model to estimate the basin-wide environmental benefits of conservation practices (Arnold et al. 1998; Neitsch et al. 2002; USDA 2011, 2012a, 2012b; Williams et al. 2008). Conservation practices in use in 2003 to 2006 were generally more effective in reducing nutrient losses in the Missouri River Basin than in the other two basins. For example, TN loss (all loss pathways) has been reduced by 39 percent by conservation practices in the Missouri River Basin, compared to only 20 percent in the Upper MARB and 17 percent in the Ohio-Tennessee River Basin. These model scenarios demonstrate the benefits of conservation practices, and they highlight that nutrient reductions could be increased if additional conservation practices were applied to undertreated acres. Overall, the Upper MARB has about twice as many undertreated cropped acres (35.2 million undertreated acres, 60 percent of cropped acres) as the Missouri River Basin (15.3 million undertreated acres, 18 percent of cropped acres) or the Ohio-Tennessee River Basin (17.5 million undertreated acres, 70 percent of cropped acres). Numerous challenges exist to linking conservation actions to water quality benefits at these large scales and at smaller scales. Osmond et al. (2012) highlight 15 important lessons learned from 13 NIFA—CEAP locations to increase the environmental and economic effectiveness of conservation programs.

Nutrient Load Estimation and Trends

USGS provides annual estimates of the spring and annual loads and the 95 percent confidence interval for the mainstem and large tributary sites of the MARB (Aulenbach et al. 2007). Load estimation techniques have been modified since 2002 to reduce the bias in the regression models. The current regression model uses Load Estimator (LOADEST) (Runkel et al. 2004) with an adjusted maximum likelihood estimator and a five-year moving window to estimate annual and spring loads. Battaglin et al. (2009) summarize changes in streamflow and flux of nutrients in the Mississippi from 1980 to 2007 comparing baseline conditions of 1980–1997 and five-year moving averages. Stenback et al. (2011) highlight bias and precision issues regarding the use of LOADEST to predict nitrate and TP in streams in Iowa and provide some indicators to check for regression model performance. Load predictions in Iowa varied from 10 to 25 percent of the measured values. Garrett (2012) improved LOADEST estimates for Iowa streams by including additional streamflow variability terms in the model. Sprague et al. (2011) used a new statistical technique to demonstrate that despite efforts to reduce nitrate levels in the MARB, little consistent progress has been made in reducing riverine nitrate concentrations or flux at four mainstem sites and four large tributary sites since 1980. This new technique for analyzing trends removes the variation from precipitation and streamflow, accommodates evolving nitrate behavior over time, and provides greater insights into the effects of conservation practices. At most mainstem and large tributary sites, concentrations increased more at low and moderate streamflows than at high streamflows, suggesting that increasing groundwater concentrations are having an effect on river concentrations. Increasing trends of nitrate have also been observed in some groundwater monitoring networks. For instance, nitrate concentrations increased more than 2 mg/L from 1996 to 2006 in eight shallow wells overlain by urban land uses in the Glacial aquifer system in Minnesota (Lindsey and Rupert 2012). Nitrate concentrations in shallow groundwater are most affected by redox conditions, followed by nitrogen inputs (Burow et al. 2010). Enhanced mapping of redox conditions and drainage modifications in high nitrogen input areas would enhance the understanding of nitrogen transport to shallow groundwater and streams.

Providing a finer level of detail to help states develop and implement nutrient reduction strategies, and assess strategy success, will depend on the continued development and comparison of suites of models to improve nutrient source characterization, nutrient transport and delivery, nutrient targeting, conservation practice evaluation, and potential lag-time at multiple scales.

Research Needs

- Continue and expand research to improve estimates of nitrogen fixation, manure denitrification, and soil nitrogen pool changes to improve estimates of the nitrogen budget at the MARB scale (USEPA 2008).
- Enhance estimates of levels of conservation intensity required to see a quantifiable change in water quality. What are the costs of implementing these conservation actions to meet a range of reduction targets?
- Improve understanding of underlying processes causing a lag between BMP implementation and change in water quality in streams.
- Incorporate lag response into regional and basin-scale models.
- Further research into why flow weighted concentrations and flux of TP are increasing in the Missouri River Basin and the Upper MARB.
- Develop decision support tools that incorporate suites of models so managers can evaluate potential response to proposed nutrient reduction strategies.
- Continue to develop easy-to-use, field-scale conservation assessment tools that incorporate estimates of nutrient reduction benefits and installation and maintenance costs.
- Use model estimates that include confidence limits for nutrient source and load estimates.
- Identify key metrics and time frames to evaluate how nutrient flux is changing over time at multiple scales in the MARB in comparison to the baseline.
- Enhance our understanding of how climate change and weather patterns may affect nutrient reduction tracking and goals.

Information Needs

- Increase the specificity and regularity of data acquisition for fertilizer application to major agricultural crops and manure and biosolids applied to land in terms of timing, source, placement, and rates at a sufficiently small scale to better inform decision making about policies and mitigation options (USEPA 2011).
- Refinements of point source contributions based on direct measurements instead of estimated concentrations (USEPA 2008).
- Spatial information on conservation practice intensity to enhance understanding of linkages between conservation actions and changes in stream water quality.
- Changes in policies and commodity practices can significantly alter nutrient inputs and export. Frequent basin-wide surveys of land cover/land use changes are needed to document the rate of land use change and what/where changes are occurring to help explain observed changes in water quality (Wright and Wimberly 2013).
- Refinements of tile drainage intensity and extent using the Soil Survey Geographic Database and new techniques to enhance the understanding of how tile drainage affects nutrient transport (Jaynes and James 2007).
- Real-time nitrate monitoring of nutrients at multiple scales to provide critical information on how nutrients change over short time scales.
- Intensive, long-term monitoring at multiple scales, but especially in small watersheds, to track changes in water quality and inform watershed models. Monitoring data should be accessible through a single Web portal (i.e., Water Quality Portal) for the MARB.


USDA NRCS

Liquid manure from a hog feeding operation in northeast Iowa is being pumped onto cropland with a honey wagon.

Action Item 9

Decrease Scientific Uncertainty of Nitrogen and Phosphorus Effects on Hypoxia

"Continue to reduce uncertainty about the relationship between nitrogen and phosphorus loads and the formation, extent, duration, and severity of the hypoxic zone, to best monitor progress toward, and inform adaptive management of the Coastal Goal."

Over the past three years, NOAA has convened annual **Gulf Hypoxia Research Coordination Workshops** (www.ncddc.noaa.gov/activities/healthy-oceans/gulf-hypoxia-stakeholders/) with objectives to (1) coordinate hypoxia monitoring and modeling research; (2) provide a forum to discuss the state-of-knowledge on Gulf hypoxic zone research; and (3) inform activities of the Task Force and other regional ecosystem management efforts. For the third annual workshop, NOAA focused on two thematic areas where significant gaps in understanding existed when the 2008 Action Plan was produced. The first area targeted the understanding of how hypoxia affects living resources to inform reassessment of Action Item 5; the second focused on biogeochemical processing to inform reassessment of Action Item 9.

Participants in the biogeochemical processes workgroup assessed the state-of-knowledge and information gaps on the biogeochemical pathways that process and recycle nutrients and carbon and ultimately lead to generation and maintenance of hypoxia. This information is key to advancing development of, and validating results from ecosystem scenario-based models that inform the nutrient reduction strategies central to the Coastal Goal of the 2008 Action Plan. Research on the Gulf ecosystem since the last science reassessment (2005–2007) has led to a more comprehensive understanding of factors regulating hypoxia, and more explicit delineation of natural and anthropogenic drivers has reinforced the central tenet of the 2008 Action Plan mitigation strategy that "reducing nutrient loadings from the various sources in the Basin addresses the most critical and controllable cause of hypoxia." At the same time, these advancements are leading to an enhanced ability of models to inform refinement of nutrient reduction targets and evaluate them in the context of additional ecosystem drivers.

The **2012 workshop findings** (www.ncddc.noaa.gov/activities/healthy-oceans/gulf-hypoxia-stakeholders/workshop-2012/), which are limited to the attendees and are not necessarily informed by research conducted or published since the meeting, are presented below.

Summary of Key Points

- Processing studies and statistical assessments reinforce the strong relationship between springtime nutrient loading, water column primary production, mid-water and benthic hypoxia, and hypoxic zone areal extent, thus validating watershed nutrient load reduction as the most effective management practice to mitigate hypoxia.
- Physical processes (local wind strength, wind duration, river discharge volume) are also correlated with hypoxic zone areal extent, and are important factors influencing spatial and temporal patterns in nutrient flux, water column stratification, and consequently hypoxic zone properties.
- Nitrogen limitation is generally more important than phosphorus limitation in controlling primary production. When nitrogen and phosphorus co-limitation occurs, nitrogen typically has a greater effect than phosphorus on the co-limitation. These results validate the need to focus on nitrogen mitigation in the longer term but to target both nitrogen and phosphorus in watershed nutrient reduction strategies.
- In plume waters, strong net autotrophy is observed, but farther offshore (e.g., at more than 15 m depths), photosynthesis and respiration are often balanced or net heterotrophy is observed, and nutrient regenerative processes are favored. Trophic dynamics driven by nutrient regeneration is consistent with prolongation of hypoxia into the summer (i.e., although the Mississippi River delivers more than 5 times more nutrients than needed to fuel offshore hypoxia, most of the surface net autotrophy needed to fuel hypoxia occurs in the winter or spring).
- Sediment oxygen consumption accounted for 20–40 percent of sub-pycnocline respiration on average. Thus, the lower water column has higher integrated respiration rates than do the sediments, but the proportion varies seasonally.
- Water column nutrient availability is the predominant source for phytoplankton production; nutrient fluxes from sediment transformations supply only a minor fraction of nitrogen and phosphorus demand.
- Benthic microbial processes scavenge phosphate from bottom waters, which may accentuate phosphorus limitation on the continental shelf. During severely hypoxic conditions, phosphorus release from sediments is likely.
- Coupled nitrification/denitrification is a strong driver of sediment/water nitrogen dynamics under hypoxic conditions; anammox and dissimilatory nitrate reduction to ammonium (DNRA) are less important. Denitrification causes apparent nitrogen limitation of microbial processes in bottom waters of hypoxic area.
- However, one study observed net release of ammonium from sediments during hypoxic conditions; the released ammonium can support primary production (and oxygen production) in the lower water column if sufficient light is available, ameliorating the hypoxia. However, net release of ammonium from sediments might also promote enhanced nitrification (and oxygen consumption), which would exacerbate hypoxia.
- Evidence for potential benthic photosynthesis exists, but no studies have adequately quantified the importance of the process. This area needs further research because of the implications for hypoxia formation and persistence.

- Organic matter in the sediment of the hypoxic area was relatively consolidated, suggesting that moderate or energetic storms would be required for mobilization. However, another study found spatial variability in the importance of sediment resuspension, and suggested that in these *patches*, buried organic matter could be mobilized with low physical forcing. The resolution of sediment mobility has important implications for the potential influence of organic matter burial as a source of stored carbon for hypoxia formation in subsequent years.

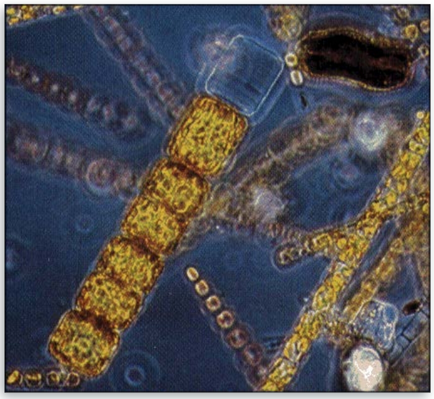
State of Knowledge

Relationship of primary production to nutrient loading: Historical accounts suggest that highest primary productivity is observed closest to the river source, whereas less productive waters are observed at locations furthest from the source (Lohrenz et al. 1990, 1994, 1997, 1999). Prior studies also indicate that primary production and chlorophyll *a* biomass peaks are related to nitrate-nitrogen load and concentration, and they occur at salinities of 15 to 25 where turbidity limitations for phytoplankton growth are reduced and sufficient nutrients remain to support elevated primary production (Lohrenz et al. 1997; Rabalais et al. 2002; Walker and Rabalais 2006). Recent studies have confirmed that chlorophyll *a* concentrations and primary production were significantly higher in surface waters of plume versus non-plume regions for the eastern shelf (Lohrenz et al. 2008; Lehrter et al. 2009; Quigg et al. 2011), but west of the Atchafalaya, primary production rates are similarly high in plume and non-plume waters (Lehrter et al. 2009; Quigg et al. 2011). Similar spatial patterns have been reproduced by recent modeling studies (e.g., Eldridge and Roelke 2010; Fennel et al. 2011).

Primary production rates correlated most strongly with inorganic nitrogen concentration and loading, but also were related to phosphorus loading and freshwater discharge (Turner and Rabalais 2013). Nutrient-enhanced primary production and sinking of organic matter below the pycnocline are considered the main anthropogenic driver for benthic hypoxia. Mid-depth low oxygen concentrations are not only affected by the sources of the water controlled by physical factors but are also associated with the respiration of fluxed surface water organic matter to an upper water column pycnocline (Turner and Rabalais 2013).

The relationship between the input of terrestrially derived nutrients into coastal ecosystems and coastal hypoxia is well documented (Diaz and Rosenberg 2008). Several studies have shown statistically significant correlations between total nutrient loading from the Mississippi River and the mid-summer areal extent of hypoxia (USEPA 2008; Rabalais et al. 2007; Greene et al. 2009; Turner et al. 2012). Recent investigations (Forrest et al. 2011; Feng et al. 2012) indicate that physical processes related to local wind strength, wind duration, and river discharge volume are correlated with mid-summer hypoxic areal extent and that the strength of correlation is on the order of that because of nutrient loading. This observation indicates that observed hypoxic area might be influenced by multiple, integrated processes. These processes influence the flux and distribution of nutrients into the coastal system, thus also the distribution of new carbon production that is available for oxidation. Further, these processes influence the distribution of freshwater and stratification and, thereby, the ventilation of oxygen-poor subpycnocline water with relatively oxygen-rich surface water.

Light and nutrient limitation: Patterns of nutrient limitation are consistent annually and seasonally. On the basis of a series of nutrient bioassay experiments, water column primary production was most often limited by nitrogen alone or nitrogen+phosphorus shelfwide; phosphorus limitation was observed less frequently (Turner and Rabalais 2013). A consistent definition of nutrient limitation was applied by Turner and Rabalais (2013) to other published studies of nutrient bioassay experiments and resulted in similar findings. Studies examining shelf wide light and nutrient limitation indicated that phosphorus limitation of phytoplankton delays the assimilation of riverine dissolved inorganic nitrogen in the summer as the plume spreads across the shelf, thereby pushing primary production over a larger region (Sylvan et al. 2007, 2011; Quigg et al. 2011). Also, the mode of limitation varies temporally and spatially (Dortch and Whitledge 1992; Laurent et al. 2012; Roberts et al. 2012 unpublished data; Turner and Rabalais 2013). The type of limitation changes along the salinity gradient, with transition from light limitation (salinity less than 15, turbid waters), to nitrogen with some phosphorus (relatively nutrient-rich), and then to mostly nitrogen+phosphorus (most dilute) that might be synergistic (Quigg et al. 2011; Laurent et al. 2012; Turner and Rabalais 2013). However, silica limitation also might become important and ultimately influence hypoxia formation given the importance of diatoms (Turner et al. 1998; Dortch et al. 2001). Model generated 3-D nutrient limitation patterns indicate that at salinity of less than 25, nitrogen, phosphorus, or light was limiting, while at salinity of more than 25, mostly nitrogen was limiting (Eldridge and Roelke 2010; Fennel et al. 2011; Laurent et al. 2012).


NASA

Photomicrograph of various diatom species.

Strong dissolved inorganic carbon deficits occur in surface plume waters caused by net primary production (Cai 2003; Lohrenz and Cai 2006; Cai and Lohrenz 2010; Guo et al. 2012; Fry et al. unpublished data). This observation provides evidence that mixed layer primary production dynamics are tied to river nutrient inputs, but the zone of high productivity is spatially restricted to near the river mouth. However, a well-documented lag occurs in river discharge, nutrient load, and formation of hypoxia, in which the high spring discharge and nutrient loads are most relevant to formation of hypoxia (Justić et al. 1993, 2002). Extreme flooding events, as seen in 2011, can lead to conditions in the northern Gulf that shift the continental shelf from a net sink to a net source of carbon dioxide to the atmosphere (Bianchi et al. 2013).

Water column photosynthesis vs. respiration: Most offshore stations at more than 15-m depth have surface mixed layers where photosynthesis and respiration are nearly balanced, with more stations slightly net heterotrophic than slightly net autotrophic (Murrell et al. 2013; Fry, unpublished data). Surface mixed layers were primarily net autotrophic on an annual basis with some net heterotrophy observed in summer at one 20-m deep station 100 km west of the Mississippi River (C6 off Terrebonne Bay) (Justić et al. 1994). On the basis of patterns observed from other continental shelf systems, the deeper stations are likely nutrient limited, which would favor nutrient regenerative processes and nearly balanced photosynthesis and respiration (Fry et al. unpublished data). Similar to the dissolved inorganic carbon patterns discussed above, where nutrients are higher in plume waters, strong net autotrophy is observed. Calculations indicate that the Mississippi River delivers more than 5 times the nutrients needed to fuel offshore hypoxia, but probably most of the surface net autotrophy required to fuel benthic heterotrophy occurs in the winter and spring at times of high river discharge (Fry et al. unpublished data).

Water column respiration rates can span a wide range. According to samples collected along the C and F cross-shelf transects in spring through summer of 2010 and 2011, water column rates ranged from 3.7 to 177 mmol O_2 m^{-2} d^{-1}, with both mean and median surface water rates (38.0 and 23.3, respectively) being over twice those of bottom water rates (17.1 and 10.9, respectively) (Roberts et al. 2012). In that study, resource-limitation enrichment bioassays suggested primary limitation of respiration by carbon, with greatest stimulation when carbon, nitrogen, and phosphorus were added together but respiration only responded to nitrogen when both carbon and phosphorus were also added. Murrell et al. (2013) reported plankton community respiration measurements from ten cruises at sites distributed across the shelf. Volumetric respiration rates ranged from below detection to 99.3 mmol O_2 m^{-3} d^{-1} and showed strongly coherent vertical and horizontal variability, being highest in shallow surface waters and declining offshore. Surface layer samples consistently had higher respiration than bottom layer samples collected at the same site, a pattern observed all across the shelf in spring, summer, and fall months. Water column integrated rates were strongly dependent on the integration depth, averaging 121 mmol O_2 m^{-2} d^{-1} at sites less than 10 m deep to 239 mmol O_2 m^{-2} d^{-1} at sites more than 40 m deep.

Vertical flux of primary productivity: Diatom flux into moored sediment traps is higher when diatom abundance dominates the surface water phytoplankton community (Dortch et al. 2001). Over a period from April to December, the carbon associated with fecal pellet flux into moored sediment traps exceeded the carbon contribution from diatoms (Qureshi 1995), but the traps were not deployed in the late winter when diatoms might have been more dominant in the settled material. There is likely an annual cycle of flux by diatoms, diatoms and fecal pellets, and fecal pellets as the source of organic matter reaching the lower water column and sediment surface, and this cycle varies by nutrient loading, availability of nutrients, geographic location, depth of water column, and a range of physical and biological factors. [See research need below.] Diagnostic pigments from HPLC analysis indicate that the ratio of dinoflagellates to diatoms decreased from 1.3 at the shallowest station to about 0.37 at the deepest station, but despite these differences, sequence analysis suggests that calanoid copepods across the Louisiana shelf were feeding mostly on diatoms (Sinclair et al. unpublished data).

Benthic respiration: Temperature can help predict benthic respiration rates in the Atchafalaya River Delta Estuary (ARDE) and along a transect out to 30-m deep locations in the northern Gulf off of the Atchafalaya River (Roberts et al. 2012), in the 15- to 20-m depths on a transect off Terrebonne Bay within 100 km of the Mississippi River delta (Baustian 2011; Baustian et al. submitted), and across the Louisiana shelf area (Nunnally et al. in press and references therein). There is high variability (more than threefold) in benthic respiration with distance offshore. The maximum benthic respiration along the *F Transect* extending cross-shelf off of the Atchafalaya River (greatest frequency of hypoxia observance) does not occur until ~60 km from the ARDE at the 20 m isobaths. This result is consistent with previous findings from the ARDE showing that despite high inputs of river nutrients and organic matter, ARDE benthic respiration rates as far as 20 km offshore of the river deltas were not higher than other published rates for the northern Gulf of Mexico due to *unstable* sediments high in sand and low in organic matter content (Roberts et al. 2012). The spatial gradient of respiration on the inner continental shelf is inshore (higher rates) to offshore (lower rates) (Murrell and Lehrter 2011; Murrell et al. 2013).

Sediment oxygen consumption rates in summer vary primarily as a function of bottom-water oxygen and are typical of other estuarine and coastal systems (Baustian 2011; Murrell and Lehrter 2011; Nunnally et al. in press; Baustian et al. submitted). On average, sediment oxygen consumption accounts for 20 percent of sub-pycnocline respiration, and sediment oxygen consumption was a minor component of water-column respiration. Murrell and Lehrter (2011) found that most respiration occurs in the lower water column (~75 percent) versus the sediment-water interface (~25 percent), in contrast to Quiñones-Rivera et al. (2010). Several factors might contribute to the differences among published studies quantifying relative respiration rates in the water column and the sediments, including the limited number of incubations that can be completed on a single cruise, the time of the year, geographic location of the stations, ambient physical and biotic conditions, methodology (change in oxygen concentration, isotopes, respiration), and assumptions in calculations. Much more work is needed that is focused on improving our understanding of oxygen consumption dynamics on the Louisiana shelf where hypoxia occurs.

Sediment/water boundary nitrogen transformation: Some nutrient fluxes are strongly coupled to oxygen concentrations (Rabalais and Turner 2006; Baustian 2011; Lehrter et al. 2012; Roberts et al. 2012; Nunnally et al. in press; Baustian et al. submitted). Silicate, phosphate, and ammonium fluxes from the sediment to the overlying water are higher under lower oxygen conditions and concentrations of these inorganic nutrients are relatively high in bottom water. Nitrate is mostly taken up by sediments year-round. Nutrient flux measurements suggest that sediments supply only a minor fraction of water-column nitrogen and phosphorus demand by phytoplankton (Lehrter et al. 2012). Fluxes were potentially a more significant source beneath the pycnocline.

Nunnally et al. (in press) found that during summer hypoxia, benthic microbial processes resulted in net consumption of nitrate and nitrite and production of ammonium. Elevated sediment community oxygen consumption and nutrient remineralization occurred near terrestrial river inputs associated with the Mississippi and Atchafalaya rivers. Net release of dissolved inorganic nitrogen, in the form of ammonium, peaked in late summer. The authors suggest that released ammonium might be a source of nutrients for primary production in bottom waters, and can provide reduced nitrogen for nitrification and microbial respiration, both of which might reinforce the intensity and duration of hypoxia. On the basis of chamber results, benthic microbes actively scavenged phosphate from the bottom waters and released silicate. The results of Nunnally et al. (in press) suggest that addition of reactive nitrogen and removal of phosphorus due to benthic community metabolism could be accentuating phosphorus limitation on the continental shelf.

Denitrification occurred primarily through coupled nitrification-denitrification; mean denitrification rate = 1.4 mmol nitrogen m^{-2} d^{-1}. If extrapolated to the area of the shelf (to the 200-m contour), this nitrogen sink represents 39 percent of the river TN load (Lehrter et al. 2012). The nitrification/denitrification cycle dominates the sediment/water nitrogen dynamics under hypoxic conditions; Anammox and DNRA are less important than denitrification (Gardner and McCarthy 2012). Sediment ammonium demand is often high at the sediment-water-interface, implying that microbial processes are often nitrogen-limited because of nitrification/denitrification, even though excessive nutrient input led initially to the high primary production that, in turn, caused the high respiration and hypoxia in bottom waters (Lin et al. 2011). Thus, denitrification causes apparent nitrogen limitation at times in bottom waters of the hypoxic region.

Subpycnocline and benthic photosynthesis: Light attenuation was correlated with wind, discharge, and nutrients (Schaeffer et al. 2012). Estimated euphotic depths (as defined by the 1 percent light depth) were often greater than the bottom depth (Lehrter et al. 2009; Schaeffer et al. 2012). However, differing levels of light penetration occurred in different years of shelfwide and seasonal oxygen isotope studies (Quiñones-Rivera et al. 2007, 2010). The seasonal abundance and biomass of microphytobenthos along one frequently hypoxic transect ~100 km west of the Mississippi River delta were correlated with relatively higher photosynthetically active radiation levels, warmer temperatures, and the higher salinity of the bottom water (Baustian et al. 2011). Thus, light might be a significant factor regulating bottom-water oxygen in this system. The light availability beneath the pycnocline allows for substantial sub-pycnocline water-column primary production, averaging 25 to 50 percent of the total water-column production during spring and early summer (Lehrter et al. 2009). Baustian et al. (submitted), however, found little evidence for bottom generated oxygen in benthic incubations at ambient light levels and by isotopic uptake indicating primary production. They suggest that any oxygen generated under extremely low oxygen conditions is likely consumed immediately through sediment oxygen demand or chemical oxygen demand. Schaeffer et al. (2012) also determined that the euphotic depth was correlated to the depth at which the water column turned hypoxic on the shelf. Thus, hypoxic water development could be influenced by decreased light availability below the pycnocline in addition to other physical and biological forcing. In summary, these results suggest that freshwater and nutrient inputs are important regulators of shelf-wide light attenuation and, consequently, the vertical distribution of primary production. The incidence of below-pycnocline primary production has potentially important implications about the formation and persistence of hypoxia on the Louisiana continental shelf and warrants further study.

An organic layer of particles occurred in the bottom waters at some sites distant from the river mouth, suggesting that, once out of the more turbid plume waters, there is enough photosynthetically active radiation to penetrate down 15 m or so to possibly support a low light phytoplankton community (Baustian et al. 2011, 2013). The sediment algal community (cells more than 3 µm) found during hypoxia differed from those in the water column and were primarily benthic (58 to 88 percent) (Baustian et al. 2011). The abundance of benthic cells was correlated with light levels at the seafloor and with sediment chlorophyll *a* values. The presence of a viable community of microphytobenthos during hypoxia indicates that the potential for photosynthetic oxygen production exists and might influence the oxygen dynamics in the hypoxic zone (Grippo et al. 2009, 2010; Baustian et al. 2011, 2013).

Sediment resuspension, erodibility: On the basis of field measurements, Xu et al. (2011a) conclude that sediment under the hypoxic water in the northern Gulf of Mexico was fairly consolidated whereas muds next to the Mississippi Delta and Atchafalaya Bay mouth were more mobile, and therefore seemed to be more recently deposited or reworked. Xu et al. (2011a) also found sediment in the northern Gulf of Mexico to be more consolidated and less erodible than that measured at other locations, such as the Adriatic Sea (Stevens et al. 2007) and in the turbidity maxima at the York River, Chesapeake Bay (Dickhudt et al. 2009). This result could indicate that organic matter buried in sediment in the northern Gulf of Mexico requires moderate or energetic storms to be mobilized.

A three-dimensional hydrodynamic and sediment-transport model represented dispersal of fluvially delivered sediment on the Louisiana shelf (Xu et al. 2011b). In the one-year time scale modeled, much of the modeled fluvial sediment accumulation was localized with deposition focused near sediment sources. Little fluvial sediment could be transported into the vicinity of the hypoxic zone in the seasonal or annual time frame considered. In storm conditions, strong winds helped mix the water column vertically over the entire shelf (up to the 100-m isobath), and wave shear stress dominated total bed stress. In other storm conditions (e.g., Hurricane Katrina), the water column at some stations west of the storm center were mixed to only 15 m of the 20-m water column (Rabalais unpublished data). The ability for a tropical storm to disrupt hypoxia or resuspend sediments depends on the size of the storm, the transit speed, the pressure of the system, and the quickness of transit across the shelf (Rabalais et al. unpublished data for bottom oxygen series). During fair-weather conditions, however, the freshwater plumes spread onto a stratified water column, and combined wave-current shear stress exceeded the threshold for suspending sediment in only the inner-most part of the shelf. On the basis of a long-term record of sediment samples compiled by Williams et al. (2006), a mud band that was formed probably in the late Holocene exists on the Louisiana-Texas shelf between the 10- and 50-m isobaths, and centered along the 20-m isobaths. In a storm event in March 1993, the model indicated that this mud band experienced enhanced erosion depths relative to sediment seaward and shoreward of it (Xu et al. 2011b). On its shallow boundary, sediment texture played a key role; the shoals offshore of Atchafalaya Bay resisted erosion because of the higher critical shear stress assumed by the model for the sands there. Seaward of 50 m, wave energy attenuated, decreasing the frequency and magnitude of erosion. The boundaries of the mud band followed the landward and seaward boundary of hypoxia, especially along the sand-mud boundary south of the sandy shoals, implying that resuspension could affect the formation and duration of hypoxia on the Louisiana-Texas shelf (Xu et al. 2011b).


NASA

Sediment load carried by the Mississippi River into the Gulf of Mexico.

Modeling work with high-resolution oxygen profiles suggests that respiration sources shift with depth in the water column, with resuspended sediments becoming more important with depth in the water column than at the surface (Fry, unpublished results). These results suggest that more attention should be given to how sediments are resuspended because this process might be critically important for hypoxia and could occur in patches and with low physical forcing. The findings also suggest that buried organic matter can store *memory* in the sea floor that would support respiration in a subsequent year (as modeled by Turner et al. 2012). Water and nutrient discharge from the Mississippi River play a role in the formation of hypoxic water, but the discharge from several previous years might also be important.

Research/Information Needs
(as identified by workshop attendees)

Processes related to production and respiration

- Better understanding of how controls on oxygen consumption vary in space and time.
- Role of phytoplankton sinking, fecal pellet flux, and marine aggregates in the transfer of surface water organic matter to the lower water column and sediments over a broad geographic area within the hypoxic zone.
- Rates of surface and bottom water respiration rates, sediment oxygen consumption, and their controls.
- Integration of water column and sediment rates of oxygen production and consumption into coupled physical and biological models of hypoxia dynamics.
- Continued examination of benthic photosynthesis and associate physical and biotic variables.
- Role of benthic micro-algae in sediment carbon, oxygen, and nutrient cycling dynamics.

Nutrient limitation

- Spatial and temporal limitation of phytoplankton growth by multiple nutrients, inorganic and organic.
- Shifts in stoichiometric ratios of nutrients and loads and concentrations of nutrients on phytoplankton community composition and subsequent flux of materials.

Biogeochemical pathways

- Better spatial and temporal measurements of nitrogen cycling in sediments and the benthic boundary layer.
- More small-scale mechanistic studies of the interactions of carbon, oxygen, and nitrogen at the sediment-water interface and overlying water; for example the relationship between potential and net ammonium uptake.
- Better understanding of cycling of nitrogen, phosphorus, carbon, and elements such as iron, mercury, and manganese between sediments and water column.
- Benthic remineralization and time scales of benthic cycles.
- Carbon cycling—burial, remineralization, transformation—in sediments.
- Release of H_2S, CH_4, NH_4, and Fe(II) from the sediments as oxygen sinks.
- Importance of benthic fauna as bio-irrigators in mediating the sediment exchanges of oxygen-consuming chemical species.

Physical and geological processes

- Role of vertical mixing and stratification in dynamic, 3-D physical models.
- Role of internal waves at the pycnocline and with regard to sediment resuspension and transport.
- Role of vertical mixing and lateral and horizontal transport across the area of the shelf that is subject to hypoxia.

- Importance of inner shelf sandy shoals to circulation patterns.
- Influence of physical processes on biogeochemical processes.
- Role of resuspended sediments in oxygen dynamics.

Potential effects of climate change *(conceptually modeled in Rabalais et al. 2009, 2010)*

- Changes in hydrology related to Intergovernmental Panel on Climate Change predictions for the Mississippi River watershed; changed hydrograph of the Mississippi River; extreme events.
- Effects of higher water temperatures on stratification, solubility of dissolved oxygen, pH, biological rates, floral and faunal communities, winds, and currents.
- Effects of apparent sea-level rise on coastal landscape subsequent effect on dynamics of hypoxia.
- Ocean acidification interactions with hypoxia (Cai et al. 2011).

Hypoxia monitoring

- The **Hypoxia Monitoring Implementation Plan** (http://www.ncddc.noaa.gov/activities/healthy-oceans/gulf-hypoxia-stakeholders/) has a strategy for tiers of information needed to address the needs of the Task Force.
- Basic need for the Hypoxia Action Plan is the midsummer baseline condition of hypoxic zone area. Additional spatial and temporal resolution has been recommended.
- Additional tiers of information can be addressed through improved understanding of biogeochemical processes and integration into 3-D, dynamic physical-biological coupled models.
- Better understanding of the distribution of hypoxia east of Mississippi River delta, which is complicated by multiple freshwater inputs and interaction with shelf edge processes.
- Consideration of AUVs and gliders for some aspects of hypoxia monitoring; proof of concept needed.
- Additional measures of hypoxia other than bottom area (as outlined in Rabalais et al. 2007), such as volume, oxygen deficit, duration, intensity, and application of different values of oxygen stress (e.g., less than 1 mg/L, less than 2 mg/L), use of oxygen saturation values rather than concentration.
- Additional data management needs.

Other issues

- Implications of coastal restoration projects in Louisiana with regard to river diversions, changes in hydrology.
- Integration of remote sensing products into observations relevant to oxygen dynamics and hypoxia dynamics models.
- Response to extreme events, such as storms, droughts, and floods with regard to hypoxia dynamics.


USDA NRCS

Flooded cropland in southwest Iowa.

Action Item 10

Communications

"Promote effective communications to increase awareness of hypoxia and support the activities of the Task Force."

Under Action Item 10 of the 2008 Action Plan, the Task Force is tasked with promoting effective communications to increase awareness of hypoxia and nutrient pollution. The Action Plan identifies three key actions to achieve this objective: (1) manage a website to highlight Task Force activities, status, and plans; (2) develop and distribute an annual report describing the condition of the MARB and Gulf hypoxic zone, actions accomplished, and objectives for the next year; and (3) promote existing communication tools for outreach and education.

Since 2008, the Task Force has taken on a variety of initiatives to enhance communication and public awareness on hypoxia and nutrients. As specified by the Action Plan, the Task Force actively maintains and updates a **website** (http://water.epa.gov/type/watersheds/named/msbasin/index.cfm) designed to provide relevant information on Task Force meetings, on hypoxia and nutrient pollution research, and on the implementation of the Action Plan. Website visitors can find a variety of reports, archived webcasts, and introductory lessons on hypoxia and nutrient pollution. Among the reports are three **annual reports** (http://water.epa.gov/type/watersheds/named/msbasin/implementation.cfm#report) produced in accordance with the Action Plan. These annual reports are collections of relevant indicators of programmatic outputs and environmental outcomes, along with timely and relevant success stories. They help evaluate the effectiveness of programs and management efforts on reducing hypoxia and the in-basin effects of nitrogen and phosphorus pollution. The annual reports and other outreach materials developed by the Task Force have generally been nontechnical and seek to target a broad audience.

Past Annual Reports from the Hypoxia Task Force.

In addition to the annual reports, the Task Force produced an **annual operating plan** (http://water.epa.gov/type/watersheds/named/msbasin/implementation.cfm#report) each year from 2008 through 2011. The plans convey a variety of information about the efforts of Task Force states and federal agencies, such as tracking progress on the prior year's activities, which has helped to make all member organizations more accountable for their actions. In that manner, the plans provide Task Force member organizations the opportunity to include information on needed future funding and technical assistance. The plans are also a valuable vehicle for members to communicate actions accomplished and identify activities planned for the upcoming year. Because of the high level of detail in the annual operation plans, however, beginning in 2013, Task Force intends to consolidate and merge the content of the annual operating plans into the annual reports. All this information will be available on the website.

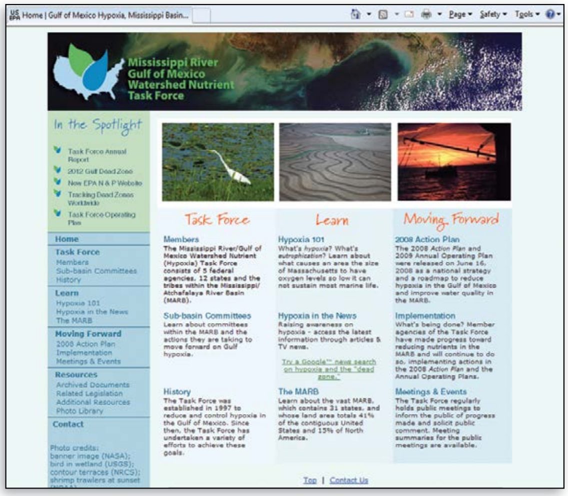


Photo credits: banner image (NASA); bird in wetland (USGS); contour terraces (NRCS); shrimp trawlers at sunset

Members
The Mississippi River/Gulf of Mexico Watershed Nutrient (Hypoxia) Task Force consists of 5 federal agencies, 12 states and the tribes within the Mississippi/Atchafalaya River Basin (MARB).

Sub-basin Committees
Learn about committees within the MARB and the actions they are taking to move forward on Gulf hypoxia.

History
The Task Force was established in 1997 to reduce and control hypoxia in the Gulf of Mexico. Since then, the Task Force has undertaken a variety of efforts to achieve these goals.

Hypoxia 101
What's *hypoxia*? What's *eutrophication*? Learn about what causes an area the size of Massachusetts to have oxygen levels so low it can not sustain most marine life.

Hypoxia in the News
Raising awareness on hypoxia - access the latest information through articles & TV news.

Try a Google™ news search on hypoxia and the "dead zone."

The MARB
Learn about the vast MARB, which contains 31 states, and whose land area totals 41% of the contiguous United States and 15% of North America.

2008 Action Plan
The 2008 *Action Plan* and 2009 Annual Operating Plan were released on June 16, 2008 as a national strategy and a roadmap to reduce hypoxia in the Gulf of Mexico and improve water quality in the MARB.

Implementation
What's being done? Member agencies of the Task Force have made progress toward reducing nutrients in the MARB and will continue to do so, implementing actions in the 2008 *Action Plan* and the Annual Operating Plans.

Meetings & Events
The Task Force regularly holds public meetings to inform the public of progress made and solicit public comment. Meeting summaries for the public meetings are available.

Task Force website.

Other broad efforts by the Task Force to educate and inform have been accomplished by using webinars and online virtual workshops. Both federal and state Task Force members have held numerous public webinar sessions on topics as varied as USDA's MRBI, USGS's SPARROW Decision Support System, and the impacts of harmful algal blooms in lakes. A special series of the USEPA's Watershed Academy Webcasts, known as the Nitrogen and Phosphorus Pollution Series, has focused on the causes, impacts, and solutions to nutrient water quality issues and has attracted thousands of participants. Another Task Force activity relevant to enhancing information exchange is the development of a series of virtual webinar workshops that brings together member state water quality, agriculture, and natural resource agencies to share approaches for addressing different elements of state nutrient reduction strategies. These have included identifying priority watersheds, ensuring the effectiveness of point source permits, and addressing agricultural sources of nutrients in state strategies.

Some Task Force members are also maintaining their own websites, separate from the Task Force-wide website, to house information on activities toward reducing hypoxia and nutrient pollution, educational materials, and associated monitoring and research plans. For example, the Lower Mississippi River Sub-basin Committee has a **web page** (www.epa.gov/gmpo/lmrsbc/) on the USEPA Gulf of Mexico Program Office website and continues to actively educate and engage the public on nutrient issues. Furthermore, LDEQ has published a **website link** (http://lanutrientmanagement.org/) with a plethora of hypoxia-related materials on the Gulf of Mexico and Mississippi River. Louisiana also has a Facebook page for the **Louisiana Hypoxia Working Group** (www.facebook.com/pages/Louisiana-Hypoxia-Working-Group/114808855347180), which serves as a forum for agencies, researchers, and stakeholders to share information on their activities and projects. The working group has also met monthly since 2003 to help facilitate action and communication in Louisiana on nutrient issues.

You are here: HOME » Gulf of Mexico and Mississippi River

Gulf of Mexico and Mississippi River

Louisiana Hypoxia Working Group

You are here: EPA Home » Gulf of Mexico Program » Lower Mississippi River Sub-Basin Committee on Gulf Hypoxia

Lower Mississippi River Sub-Basin Committee on Gulf Hypoxia

Sub-Basin Committee Mission Statement

Lower Mississippi River Sub-basin Nutrient Reduction Strategies (PDF) (29 pp, 575K, about PDF)

A Summary of Data Sources on Nutrient Loading and Removal in the Lower Mississippi River Subbasin (PDF) (34 pp, 665K, about PDF)

Action Plan for Reducing, Controlling, and Mitigating Hypoxia in the Northern Gulf of Mexico (PDF) (64 pp, 6.6MB, about PDF)

Informative Task Force member websites.

Minnesota Pollution Control Agency's (MPCA's) website highlights the collaborations among nine state agencies and multiple sectors in developing the state's nutrient strategy. This website helps the MPCA disseminate information and connect their work, and their partners' efforts, to the public. In 2009 the research station and the Science Museum of Minnesota won the Gulf Guardian Award for their efforts to spread the word about water conservation and environmental stewardship issues to their many audiences. Their efforts certainly have shown that despite being thousands of miles from the Gulf, there is a high level of public interest on Gulf hypoxia in Minnesota.

Beyond the virtual communications, the Task Force continues to host biannual, in-person meetings throughout the MARB for member organizations to publicly share their progress and highlight barriers in their efforts to reduce nutrient loadings. For example, in August 2011, the Task Force met in conjunction with GOMA, holding joint sessions on issues that are priorities for both groups—developing and implementing nutrient reduction strategies and advancing education and outreach on nutrient pollution and Gulf hypoxia. In September 2012, the Task Force met in conjunction with the National Association of State Departments of Agriculture. The meeting included a joint Technology Day at Iowa State University with scientific posters and industry booths about nutrient reduction research and methods. The Task Force April 2013 meeting featured a panel of land grant university administrators sharing relevant research efforts and learning about the technical needs of Task Force states and federal agencies. Given the land grant universities' expertise in many aspects of agricultural research, including agronomy, ecology, social sciences, and economics, the meeting also included a dialogue between both groups on key opportunities for joint collaboration. These parts of the Task Force meetings build relationships between people who provide the research and materials needed to do nutrient reductions and those who are encouraging their implementation. The Task Force is also planning to pursue more partnerships with groups that have similar objectives, such as those groups whose interest in improving the Mississippi River includes reducing nutrient loads to improve water quality. Reaching out to these types of groups provides opportunities to leverage resources, time, and effort for addressing nutrient pollution in the MARB and, ultimately, the Gulf of Mexico.

References

Alexander, R.B., R.A. Smith, G.E. Schwarz, E.W. Boyer, J.V. Nolan, and J.W. Brakebill. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. *Environmental Science & Technology* 42:822–830.

Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J. R. Williams. 1998. Large area hydrologic modeling and assessment part I: Model development. *Journal of the American Water Resources Association* 34(1):73–89.

Aulenbach, B.T., H.T., Buxton, W.A. Battaglin, and R.H. Coupe. 2007. *Streamflow and Nutrient Fluxes of the Mississippi-Atchafalaya River Basin and Subbasins for the Period of Record through 2005.* U.S. Geological Survey Open-File Report 2007–1080. U.S. Geological Survey, Reston, VA.

Baker, J.M., T.J. Griffis, and T.E. Ochsner. 2012. Coupling landscape water storage and supplemental irrigation to increase productivity and improve environmental stewardship in the US Midwest. *Water Resources Research* 48(5):W05301. doi:10.1029/2011WR011780.

Battaglin, W.A., B.T. Aulenbach, A. Vecchia, and H.T. Buxton. 2009. *Changes in Streamflow and the Flux of Nutrients in the Mississippi-Atchafalaya River Basin*, USA, 1980-2007. U.S. Geological Survey Scientific Investigations Report 2009–5164. U.S. Geological Survey, Reston, VA.

Baustian, M.M. 2011. *Microphytobenthos of the Northern Gulf of Mexico Hypoxic Area and Their Role in Oxygen Dynamics*. Ph.D. dissertation. Louisiana State University, Department of Oceanography and Coastal Sciences, Baton Rouge, LA.

Baustian, M.M., N.N. Rabalais, W.L. Morrison, and R.E. Turner. 2011. Seasonal microphytobenthos on the hypoxic northern Gulf of Mexico continental shelf. *Marine Ecological Progress Series* 436:51–66.

Baustian, M.M., N.N. Rabalais, W.L. Morrison, and R.E. Turner. 2013. Microphytobenthos along the Louisiana continental shelf during mid-summer hypoxia. *Continental Shelf Research* 52:108–118. doi:10.1016/j.csr.2012.10.014.

Bianchi, T.S., F. Garcia-Tigreros, S.A. Yvon-Lewis, M. Shields, H.J. Mills, D. Butman, C. Osburn, P. Raymond, G.C. Shank, S.F. DiMarco, N. Walker, B.K. Reese, R. Mullins-Perry, A. Quigg, G.R. Aiken, and E.L. Grossman. 2013. Enhanced transfer of terrestrially derived carbon to the atmosphere in a flooding event. *Geophysical Research Letters* 40:116–122. doi:10.1029/2012GL054145.

Booth, M.S., and C. Campbell. 2007. Spring nitrate flux in the Mississippi River Basin: A landscape model with conservation applications. *Environmental Science & Technology* 41(15):5410–5418.

Booth, N.L., E.J. Everman, I.-L. Kuo, L. Sprague, and L. Murphy. 2011. A Web-based decision support system for assessing regional water quality conditions and management actions. *Journal of the American Water Resources Association* 47:1136–1150. doi:10.1111/j.1752-1688.2011.00573.x.

Brandt, S.B., M. Constantini, S.E. Kolesar, S.A. Ludsin, D.M. Mason, C.M. Rae, and H. Zhang. 2011. Does hypoxia improve habitat quality for Lake Erie walleye? A bioenergetics perspective. *Canadian Journal of Fisheries and Aquatics Sciences* 68:857–879.

Brown, J.B., L.A. Sprague, and J.A. Dupree. 2011. Nutrient sources and transport in the Missouri River Basin, with emphasis on the effects of irrigation and reservoirs. *Journal of the American Water Resources Association* 47:1034–1060. doi:10.1111/j.1752-1688.2011.00584.x.

Burow, K., B.T. Nolan, M.G. Rupert, and N.M. Dubrovsky. 2010. Nitrate in groundwater of the United States, 1991–2003. *Environmental Science & Technology* 44:4988–4997.

Cai, W.-J. 2003. Riverine inorganic carbon flux and rate of biological uptake in the Mississippi River plume. *Geophysical Research Letters* 30:1032. doi:1010.1029/2002GL016312.

Cai, W.-J., and S.E. Lohrenz. 2010. The Mississippi River plume and adjacent margin in the Gulf of Mexico. In *Carbon and Nutrient Fluxes in the Continental Margin*s, ed. K.-K. Liu, L.P. Atkinson, R. Quinones, and L. Talaue-McManus, pp.406–422. Springer, Berlin.

Cai, W.-J., X. Hu, W.-J. Huang, M.C. Murrell, J.C. Lehrter, S.E. Lohrenz, W.-C. Chou, W. Zhai, J.T. Hollibaugh, Y. Wang, P. Zhao, X. Guo, K. Gundersen, M. Dai, and G.-C. Gong. 2011. Acidification of subsurface coastal waters enhanced by eutrophication. *Nature Geoscience* 4:766-770.

Craig, J.K. 2012. Aggregation on the edge: Effects of hypoxia avoidance on the spatial distribution of brown shrimp and demersal fishes in the northern Gulf of Mexico. *Marine Ecological Progress Series* 445:75–95.

Craig, J.K., and S.H. Bosman. 2013. Small spatial scale variation in fish assemblage structure in the vicinity of the northwestern Gulf of Mexico hypoxic zone. *Estuaries and Coasts* 36(2):268–285. doi:10.1007/s12237-012-9577-9.

Craig, J.K., and L.B. Crowder. 2005. Hypoxia-induced habitat shifts and energetic consequences in the Atlantic croaker and brown shrimp on the Gulf of Mexico shelf. *Inter-Research Marine Ecology Progress Series* 294:79–94.

David, M.B., L.E. Drinkwater, and G.F. McIsaac. 2010. Sources of nitrate yields in the Mississippi River Basin. *Journal of Environmental Quality* 39:1657–1667.

Diaz, R.J., and R. Rosenberg. 2008. Spreading dead zones and consequences for marine ecosystems. *Science* 321:926–928.

Dickhudt, P.J., C.T. Friedrichs, L.C. Schaffner, and L.P. Sanford. 2009. Spatial and temporal variation in cohesive sediment erodibility in the York River estuary: A biologically influenced equilibrium modified by seasonal deposition. *Marine Geology* 267:128–140.

Donner, S.D., C.J. Kucharik, and J.A. Foley. 2004. Impact of changing land use practices on nitrate export by the Mississippi River. *Global Biogeochemical Cycles* 18:GB1028. doi:10.1029/2003GB002093.

Dortch, Q., and T.E. Whitledge. 1992. Does nitrogen or silicon limit phytoplankton production in the Mississippi River plume and nearby regions? *Continental Shelf Research* 12:1293–1309.

Dortch, Q., N.N. Rabalais, R.E. Turner, and N.A. Qureshi. 2001. Impacts of changing Si/N ratios and phytoplankton species composition. In *Coastal Hypoxia: Consequences for Living Resources and Ecosystems*, ed. N.N. Rabalais and R.E. Turner, pp. 37-48. Coastal and Estuarine Studies 58. American Geophysical Union, Washington, D.C.

Eldridge, P.M., and D.L. Roelke. 2010. Origins and scales of hypoxia on the Louisiana shelf: Importance of seasonal plankton dynamics and river nutrients and discharge. *Ecological Modelling* 221:1028–1042.

Feng, Y., S.F. DiMarco, and G.A. Jackson. 2012. The relative role of upwelling favorable wind and Mississippi River forcing of the northern Gulf of Mexico hypoxia. *Geophysical Research Letters* 39. doi:10.1029/2012GL051192, L09601.

Fennel, K., R. Hetland, Y. Feng, and S. DiMarco. 2011. A coupled physical-biological model of the Northern Gulf of Mexico shelf: Model description, validation and analysis of phytoplankton variability. *Biogeosciences* 8:1881–1899.

Forrest, D.R., R.D. Heltand, and S.F. DiMarco. 2011. Multivariable statistical regression models of the areal extent of hypoxia over the Texas-Louisiana continental shelf. *Environmental Research Letters* 6:045002. doi:10.1088/1748-9326/6/4/045002framework.

Gardner, W.S., and M.J. McCarthy. 2012. Nitrogen transformation and respiration rates in the water-column and sediments of selected NGOMEX sites. Presentation at the 3rd Annual Hypoxia Coordination Workshop, March 27–28, 2012, Bay St. Louis, MS.

Garrett, J.D. 2012. *Concentrations, Loads, and Yields of Select Constituents from Major Tributaries of the Mississippi and Missouri Rivers in Iowa, Water Years 2004–2008*. U.S. Geological Survey Scientific Investigations Report 2012–5240. U.S. Geological Survey, Reston, VA.

Greene, R.M., J.C. Lehrter, and J.D. Hagy. 2009. Multiple regression models for hindcasting and forecasting midsummer hypoxia in the Gulf of Mexico. *Ecological Applications* 19:1161–1175.

Grippo, M.A., J.W. Fleeger, R. Condrey, and K.R. Carman. 2009. High benthic microalgal biomass found on Ship Shoal, north-central Gulf of Mexico. *Bulletin of Marine Science* 84:237–256.

Grippo, M.A., J.W. Fleeger, N.N. Rabalais, R. Condrey, and K.R. Carman. 2010. Contribution of phytoplankton and benthic microalgae to inner shelf sediments of the north-central Gulf of Mexico. *Continental Shelf Research* 30:456–466.

Goolsby, D.A., W.A. Battaglin, G.B. Lawrence, R.S. Artz, B.T. Aulenbach, R.P. Hooper, D.R. Keeney, and G.J. Stensland. 1999. *Flux and Sources of Nutrients in the Mississippi-Atchafalaya River Basin*. NOAA Coastal Ocean Program Decision Analysis Series No. 17. NOAA Coastal Ocean Program, Silver Spring, MD.

Guo, X.-H., W.-J. Cai, W.-J. Huang, Y.-C. Wang, F.-H. Chen, M.C. Murrell, S.E. Lohrenz, L.-Q. Jiang, M.-H. Dai, J. Hartmann, Q. Lin, and R. Culp. 2012. Carbon dynamics and community production in the Mississippi River plume. *Limnology and Oceanography* 57:1–17.

Hazen, E.L., J.K. Craig, C.P. Good, and L.B. Crowder. 2009. Vertical distribution of fish biomass in hypoxic waters on the Gulf of Mexico shelf. *Marine Ecological Progress Series* 375:195–207.

Huang, L., M.D. Smith, and J.K. Craig. 2010. Quantifying the economic effects of hypoxia on a fishery for brown shrimp *Fafantepenaeus aztecus*. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 2:232–248.

Huang, L., L.A.B. Nichols, J.K. Craig, and M.D. Smith. 2012. Measuring welfare losses from hypoxia: The case of the North Carolina brown shrimp. *Marine Resource Economics* 27:3–23.

Jacobson, L.M., M.B. David, and L.E. Drinkwater. 2011. A spatial analysis of phosphorus in the Mississippi River Basin. *Journal of Environmental Quality* 40:931–941. doi:10.2134/jeq2010.0386.

Jaynes, D.B., and D.E. James. 2007. *The Extent of Farm Drainage in the United States*. U.S. Department of Agriculture, Washington, DC.

Justić, D., N.N. Rabalais, R.E. Turner, and W.J. Wiseman, Jr. 1993. Seasonal coupling between riverborne nutrients, net productivity and hypoxia. *Marine Pollution Bulletin* 26:184–189.

Justić, D., N.N. Rabalais, and R.E. Turner. 1994. Riverborne nutrients, hypoxia and coastal ecosystem evolution: Biological responses to long-term changes in nutrient loads carried by the Po and Mississippi Rivers. In *Changes in Fluxes in Estuaries: Implications from Science to Management*, ed. K.R. Dyer and R.J. Orth, pp. 161–167. Olsen & Olsen, Fredensborg, Denmark.

Justić, D., N.N. Rabalais, and R.E. Turner. 2002. Modeling the impacts off decadal changes in riverine nutrient fluxes on coastal eutrophication near the Mississippi River Delta. *Ecological Modelling* 152:33–46.

Kidwell, D.M., A.J. Lewitus, E.B. Jewett, S. Brandt, and D.M. Mason. 2009. Ecological impacts of hypoxia on living resources. *Journal of Experimental Marine Biology and Ecology* 381(S1):S1–S3.

Kodama, K., Md.S. Rahman, T. Horiguchi, and P. Thomas. 2012a. Assessment of hypoxia-inducible factor-1α mRNA expression in mantis shrimp as a biomarker of environmental hypoxia exposure. *Biology Letters* 8:278–281.

Kodama, K., Md.S. Rahman, T. Horiguchi, and P. Thomas. 2012b. Effects of environmental hypoxia exposure on transcript levels of two hypoxia-inducible factor α genes (HIF-1α and HIF 2-α) in a marine teleost dragonet *Callionymus valenciennei* from Tokyo Bay. *Marine Pollution Bulletin* 64:1339–1347.

Laurent, A., K. Fennel, J. Hu, and R. Hetland. 2012. Simulating the effects of phosphorus limitation in the Mississippi and Atchafalaya River plumes. *Biogeosciences* 9:4707–4723.

Lehrter, J.C., M.C. Murrell, and J.C. Kurtz. 2009. Interactions between freshwater input, light, and phytoplankton dynamics on the Louisiana continental shelf. *Continental Shelf Research* 29:1861–1872.

Lehrter, J.C., D.L. Beddick, R. Devereux, D.F. Yates, and M.C. Murrell. 2012. Sediment-water fluxes of dissolved inorganic carbon, O2, nutrients, and N2 from the hypoxic region of the Louisiana continental shelf. *Biogeochemistry* 109(1–3):233–252. doi:10.1007/s10533-011-9623-x.

Lin, X., M.J. McCarthy, S.A. Carini, and W.S. Gardner. 2011. Net, actual, and potential sediment-water interface NH4+ fluxes in the northern Gulf of Mexico (NGOMEX): Evidence for NH4+ limitation of microbial dynamics. *Continental Shelf Research* 31:120–128.

Lindsey, B.L., and M.G. Rupert. 2012. *Methods for Evaluating Temporal Groundwater Quality Data and Results of Decadal-scale Changes in Chloride, Dissolved Solids, and Nitrate Concentrations in Groundwater in the United States, 1988–2010*. U.S. Geological Survey Scientific Investigations Report 2012-5049, Groundwater Trends. http://water.usgs.gov/nawqa/studies/gwtrends/.

Lohrenz, S.E., and W.-J. Cai. 2006. Satellite ocean color assessment of air-sea fluxes of CO_2 in a river-dominated coastal margin. *Geophysical Research Letters* 33:L01601. doi:10.1029/2005GL023942.

Lohrenz, S.E., M.J. Dagg, and T.E. Whitledge. 1990. Enhanced primary production at the plume/oceanic interface of the Mississippi River. *Continental Shelf Research* 10:639–664.

Lohrenz, S.E., G.L. Fahnenstiel, and D.G. Redalje. 1994. Spatial and temporal variations of photosynthetic parameters in relation to environmental conditions in northern Gulf of Mexico coastal waters. *Estuaries* 17:779–795.

Lohrenz, S.E., G.L. Fahnenstiel, D.G. Redalje, G.A. Lang, X. Chen, and M.J. Dagg. 1997. Variations in primary production of northern Gulf of Mexico continental shelf waters linked to nutrient inputs from the Mississippi River. *Marine Ecology Progress Series* 155:45–54.

Lohrenz, S.E., G.L. Fahnenstiel, D.G. Redalje, G.A. Lang, M.J. Dagg, T.E. Whitledge, and Q. Dortch. 1999. Nutrients, irradiance, and mixing as factors regulating primary production in coastal waters impacted by the Mississippi River plume. *Continental Shelf Research* 19:1113–1141.

Lohrenz, S.E., D.G. Redalje, W.-J. Cai, J. Acker, and M. Dagg. 2008. A retrospective analysis of nutrients and phytoplankton productivity in the Mississippi River plume. *Continental Shelf Research* 28:1466–1475.

Moriasi, D.N., J.G. Arnold, G.G. Vazquez-Amabile, and B.A. Engel. 2011. Shallow water table depth algorithm in SWAT: Recent developments. *Transactions of the American Society of Agricultural and Biological Engineers* 54(5):1705–1711.

Murphy, C.A., K.A. Rose, M.S. Rahman, and P. Thomas. 2009. Testing and applying a fish vitellogenesis model to evaluate laboratory and field biomarkers of endocrine disruption in Atlantic croaker (*Micropogonias undulates*) exposed to hypoxia. *Environmental Toxicology and Chemistry* 28(6):1288–1303.

Murrell, M.C., and J.C. Lehrter. 2011. Sediment and lower water-column oxygen consumption in the seasonally hypoxic region of the Louisiana continental shelf. *Estuaries and Coasts* 34:912–924.

Murrell, M.C., R.S. Stanley, J.C. Lehrter, and J.D. Hagy. 2013. Plankton community respiration, net ecosystem metabolism, and oxygen dynamics on the Louisiana continental shelf: Implications for hypoxia. *Continental Shelf Research* 52:27–38.

Neitsch, S.L., G. Arnold, J.R. Kiniry, J.R. Williams, K.W. King. 2002. *Soil and Water Assessment Tool—Theoretical Documentation, Version 2000*, GSWRL Report 09-01 and BRC Report 02-05. U.S. Department of Agriculture, ARS, Grassland, Soils and Water Research Laboratory and the TAES Blackland and Extension Center, Temple, TX.

Nunnally, C.C., G.T. Rowe, A. Quigg, and D. Thornton. In press. Oxygen consumption and nutrient regeneration from shipboard core incubations in the Northern Gulf of Mexico Hypoxic Zone. *Journal of Coastal Research* 63.

Osmond, D., D. Meals, D. Hoag, M. Arabi, A. Luloff, G. Jennings, M. McFarland, J. Spooner, A. Sharpley, and D. Line. 2012. Improving conservation practices programming to protect water quality in agricultural watersheds: Lessons learned from the National Institute of Food and Agriculture—Conservation Effects Assessment Project. *Journal of Soil & Water Conservation* 67(5):122A–127A. doi:10.2489/jswc.67.5.122A.

Pierson, J.J., M.R. Roman, D.G. Kimmel, W.C. Boicourt, and X. Zhang. 2009. Quantifying changes in the vertical distribution on mesozpoplankton. *Journal of Experimental Marine Biology and Ecology* 381:S74–S79.

Qi, Z., M. Helmers, R.W. Malone, and K.R. Thorp. 2011. Simulating long-term impacts of winter rye cover crop on hydrologic cycling and nitrogen dynamics for a corn-soybean crop system. *Transactions of the American Society of Agricultural and Biological Engineers* 54:1575–1588.

Quigg, A., J.B. Sylvan, A.B. Gustafson, T.R. Fisher, S. Tozzi, and J.W. Ammerman. 2011. Going west: Phosphorus limitation of primary production in the Northern Gulf of Mexico and the importance of the Atchafalaya River. *Aquatic Geochemistry* 17:519–544.

Quiñones-Rivera, Z.J., B. Wissel, D. Justić, and B. Fry. 2007. Partitioning oxygen sources and sinks in a stratified, eutrophic coastal ecosystem using stable oxygen isotopes. *Marine Ecology Progress Series* 342:69–83.

Quiñones-Rivera, Z.J., B. Wissel, N.N. Rabalais, and D. Justić. 2010. Effects of biological and physical factors on seasonal oxygen dynamics in a stratified, eutrophic coastal ecosystem. *Limnology and Oceanography* 55:289–304.

Qureshi, N.A. 1995. *The Role of Fecal Pellets in the Flux of Carbon to the Sea Floor on a River-influenced Continental Shelf Subject to Hypoxia*. Ph.D. dissertation. Louisiana State University, Department of Oceanography and Coastal Sciences, Baton Rouge, LA.

Rabalais, N.N., and R.E. Turner. 2006. Oxygen depletion in the Gulf of Mexico adjacent to the Mississippi River. In *Past and Present Marine Water Column Anoxia*, ed. L.N. Neretin, pp.225–245. NATO Science Series: IV-Earth and Environmental Sciences. Kluwer, Dordrecht, The Netherlands.

Rabalais, N.N., R.E. Turner, Q. Dortch, D. Justić, V.J. Bierman Jr., and W.J. Wiseman, Jr. 2002. Nutrient-enhanced productivity in the northern Gulf of Mexico: Past, present and future. *Hydrobiologia* 475/476:39–63.

Rabalais, N.N., R.E. Turner, B.K. Sen Gupta, D.F. Boesch, P. Chapman, and M.C. Murrell. 2007. Characterization and long-term trends of hypoxia in the northern Gulf of Mexico: Does the science support the Action Plan? *Estuaries* 30:753–772.

Rabalais, N.N., R.E. Turner, D. Justić, and R.J. Díaz. 2009. Global change and eutrophication of coastal waters. ICES *Journal of Marine Science* 66:1528–1537.

Rabalais, N.N., R.J. Díaz, L.A. Levin, R.E. Turner, D. Gilbert, and J. Zhang. 2010. Dynamics and distribution of natural and human-caused coastal hypoxia. *Biogeosciences* 7:585–619.

Rahman, Md.S., and P. Thomas. 2009. Molecular cloning, characterization and expression of two tryptophan hydroxylase (TPH-1 and TPH-2) genes in the hypothalamus of Atlantic croaker: Down-regulation after chronic exposure to hypoxia. *Neuroscience* 158(2):751–765.

Rahman, Md.S., and P. Thomas. 2011. Characterization of three IGFBP mRNAs in Atlantic croaker and their regulation during hypoxic stress: Potential mechanisms of their upregulation by hypoxia. *American Journal of Physiology-Endocrinology and Metabolism* 301:E637–E648.

Rahman, Md.S., and P. Thomas. 2012. Effects of hypoxia exposure on hepatic cytochrome P450 (CYP1A) expression in Atlantic croaker: Molecular mechanisms of CYP1A down-regulation. *PLOS One* 7(7):e40285.

Rahman, Md.S., I.A. Khan, P. Thomas. 2011. Tryptophan hydroxylase: A target for neuroendocrine disruption. *Journal of Toxicology and Environmental Health, Part B* 14:473–494.

Raymond, P.A., M.B. David, and J.E. Saiers. 2012. The impact of fertilization and hydrology on nitrate fluxes from Mississippi watersheds. *Current Opinion in Environmental Sustainability* 4:212–218.

Rebich, R.A., N.A. Houston, S.V. Mize, D.K. Pearson, P.B. Ging, and C.E. Hornig. 2011. Sources and delivery of nutrients to the northwestern Gulf of Mexico from streams in the south-central United States. *Journal of the American Water Resources Association* 47:1061–1086. doi:10.1111/j.1752-1688.2011.00583.x.

Roberts, B.J., W. Morrison, N.N. Rabalais, and R.E. Turner. 2012. Spatial and temporal patterns in carbon, oxygen, and nutrient cycling in the northern Gulf of Mexico hypoxic zone. Presentation at the 3rd Annual Hypoxia Coordination Workshop, March 27–28, 2012, Bay St. Louis, MS.

Robertson, D.M., G.E. Schwarz, D.A. Saad, and R.B. Alexander. 2009. Incorporating uncertainty into the ranking of SPARROW model nutrient yields from Mississippi/Atchafalaya River Basin watersheds. *Journal of the American Water Resources Association* 45(2):534–549.

Robertson, D.M., and D.A. Saad. 2011. Nutrient inputs to the Laurentian Great Lakes by source and watershed estimated using SPARROW watershed models. *Journal of the American Water Resources Association* 47(5):1011–1033. doi:10.1111/j.1752-1688.2011.00574.x.

Roman, M.R., J.J. Pierson, D.G. Kimmel, W.C. Boicort, and X. Zhang. 2012. Impacts of hypoxia on zooplankton spatial distribution in the northern Gulf of Mexico. *Estuaries and Coasts* 35(5):1261–1269.

Rose, K.A., A.T. Adamack, C.A. Murphy, S.E. Sable, S.E. Kolesar, J.K. Craig, D.L. Breitburg, P. Thomas, M.H. Brouwer, C.E. Cerco, and S. Diamond. 2009. Does hypoxia have population-level effects on coastal fish? Musing from the virtual world. *Journal of Experimental Marine Biology and Ecology* 381(S1):S188–S203.

Runkel, R.L., C.G. Crawford, and T.A. Cohn. 2004. *Load Estimator (LOADEST)—A FORTRAN Program for Estimating Constituent Loads in Streams and Rivers*. U.S. Geological Survey Techniques and Methods, Book 4, Chapter A5, 69 p.

Schaeffer, B.A, G.A. Sinclair, J.C. Lehrter, M.C. Murrell, J.C. Kurtz, R.W. Gould, and D.F. Yates. 2012. An analysis of diffuse attenuation in the northern Gulf of Mexico hypoxic zone using the SeaWiFS satellite data record. *Remote Sensing of the Environment* 115:3748–3757.

Schilling, K.E., C.S. Jones, A. Seeman, E. Bader, and J. Filipiak. 2012. Nitrate-nitrogen patterns in engineered catchments in the upper Mississippi River basin. *Journal of Ecological Engineering* 42:1–9.

Skaggs, R.A., M.A. Youssef, and G.M. Chescheir. 2012. DRAINMOD: Model Use, Calibration, and Validation. *Transaction of the American Society of Agricultural and Biological Engineers* 55(4):1509–1522.

Sprague, L.A., and J.A. Gronberg. 2012. Relating management practices and nutrient export in agricultural watersheds of the United States. *Journal of Environmental Quality* 41(6):1939–50. doi:10.2134/jeq2012.0073.

Sprague, L.A., R.M. Hirsch, and B.T. Aulenbach. 2011. Nitrate in the Mississippi River and its tributaries, 1980 to 2008: Are we making progress? *Environmental Science & Technology* 45(17):7209–7216.

Stenback, G.A., W.G. Crumpton, K.E. Schilling, and M.J. Helmers. 2011. Rating curve estimation of nutrient loads in Iowa rivers. *Journal of Hydrology* 396:158–169. doi:10.1016/j.jhydrol.2010.11.006.

Stevens, A.W., R.A. Wheatcroft, and P.L. Wiberg. 2007. Seabed properties and sediment erodibility along the western Adriatic margin, Italy. *Continental Shelf Research* 27(3–4):400–416.

Sylvan, J.B., A. Quigg, S. Tozzi, and J.W. Ammerman. 2007. Eutrophication induced phosphorus limitation in the Mississippi River Plume: Evidence from fast repetition rate fluorometry. *Limnology and Oceanography* 52:2679–2685.

Sylvan, J.B., A. Quigg, S. Tozzi, and J.W. Ammerman. 2011. Mapping phytoplankton community physiology on a river impacted continental shelf: Testing a multifaceted approach. *Estuaries and Coasts* 34:1220–1233.

Thomas, P., and M.S. Rahman. 2009a. Biomarkers of hypoxia exposure and reproductive function in Atlantic croaker: A review with some preliminary findings from the northern Gulf of Mexico hypoxic zone. *Journal of Experimental Marine Biology and Ecology* 381:S38–S50.

Thomas, P., and M.S. Rahman. 2009b. Chronic hypoxia impairs gamete maturation in Atlantic croaker induced by progestins through nongenomic mechanisms resulting in reduced reproductive success. *Environmental Science & Technology* 43:4175−4180.

Thomas, P., and M.S. Rahman. 2010. Region-wide impairment of Atlantic croaker testicular development and sperm production in the northern Gulf of Mexico hypoxic zone. *Marine Environmental Research* 69(Supplement 1):S59–S62.

Thomas, P., and M.S. Rahman. 2011. Extensive reproductive disruption, ovarian masculinization, and aromatase suppression in Atlantic croaker in the northern Gulf of Mexico hypoxic zone. *Proceedings of the Royal Society B* 279(1726):28–38.

Thomas, P., Md.S. Rahman, I.A. Khan, J.A. Kummer. 2007. Widespread endocrine disruption and reproductive impairment in an estuarine fish population exposed to seasonal hypoxia. *Proceedings of the Royal Society B* 274:2693–2701.

Tomer, M.D., and M.A. Locke. 2011. The challenge of documenting water quality benefits of conservation practices: a review of USDA-ARS's conservation effects assessment project watershed studies. *Water Science & Technology* 64(1):300–310.

Turner, R.E., and N.N. Rabalais. 2013. N and P phytoplankton growth limitation, northern Gulf of Mexico. *Aquatic Microbial Ecology* 68:159–169.

Turner, R.E., N. Qureshi, N.N. Rabalais, Q. Dortch, D. Justić, R.F. Shaw, and J. Cope. 1998. Fluctuating silicate: Nitrate ratios and coastal plankton food webs. *Proceedings of the National Academy of Sciences of the United States of America* 95:13048–13051.

Turner, R.E., N.N. Rabalais, and D. Justić. 2012. Predicting summer hypoxia in the northern Gulf of Mexico: Redux. *Marine Pollution Bulletin* 64(2):319–24. doi:10.1016/j.marpolbul.2011.11.008.

USDA. 2011. *Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Ohio-Tennessee River Basin*. U.S. Department of Agriculture, Natural Resources Conservation Service.

USDA. 2012a. *Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Upper Mississippi River Basin*. U.S. Department of Agriculture, Natural Resources Conservation Service.

USDA. 2012b. *Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Missouri River Basin*. U.S. Department of Agriculture, Natural Resources Conservation Service.

USEPA. 2008. *Hypoxia in the Northern Gulf of Mexico: An Update by the EPA Science Advisory Board.* EPA-SAB-08-003. U.S. Environmental Protection Agency, Washington, DC.

USEPA. 2009. *An Urgent Call to Action – Report of the State-EPA Nutrient Innovations Task Group.* U.S. Environmental Protection Agency, Washington, DC.

USEPA. 2011. *Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options*. EPA-SAB-11-013. U.S. Environmental Protection Agency, Washington, DC.

USGS. 2004. *A Science Strategy to Support Management Decisions Related to Hypoxia in the Northern Gulf of Mexico and Excess Nutrients in the Mississippi River Basin*. U.S. Geological Survey Circular 1270. U.S. Geological Survey, Reston, VA.

Walker, N.D., and N.N. Rabalais. 2006. Relationships among satellite chlorophyll *a*, river inputs and hypoxia on the Louisiana continental shelf, Gulf of Mexico. *Estuaries and Coasts* 29(6B):1081–1093.

Williams, S.J., M.A. Arsenault, B.J. Buczkowski, J.A. Reid, J.G. Flocks, M.A. Kulp, S. Penland, and C.J. Jenkins. 2006. *Surficial Sediment Character Offshore of the Louisiana Continental Shelf Region: A GIS Compilation*. U.S. Geological Survey Open-File Report 2006–1195. http://pubs.usgs.gov/of/2006/1195/index.htm.

Williams, J.W., R.C. Izaurralde, and E.M. Steglich. 2008. *Agricultural Policy/Environmental Extender Model: Theoretical Documentation, Version 0604 June 2008*. BREC Report #2008–17. AgriLife Research Texas A&M System.

Wright, C.K., and M.C. Wimberly. 2013. Recent land use change in the western corn belt threatens grasslands and wetlands. *Proceedings of the National Academy of Sciences of the United States of America* 110(10):4134–4139.

Xu, K.H., K.B. Briggs, G.M. Cartwright, C.T. Friedrichs, and C.K. Harris. 2011a. Spatial and temporal variations of sea bed sediment erodibility on the Texas-Louisiana shelf and their implications to the formation of hypoxic water. 21st Biennial Conference of the Coastal and Estuarine Research Federation Societies, Daytona Beach, FL.

Xu, K., C.K. Harris, R.D. Hetland, and J. Kaihatu. 2011b. Dispersal of Mississippi and Atchafalaya sediment on the Texas–Louisiana shelf: Model estimates for the year 1993. *Continental Shelf Research* 31(15):1558–1575.

Yoder, C.O., M.L. Micacchion, B. Bond, V.L. Gordon, E.T. Rankin, and D.K. Hokanson. 2012. *Upper Mississippi River Clean Water Act Monitoring Strategy: 2013–2022, Draft*. Midwest Biodiversity Institute, Columbus OH.

Zhang, X., R. Srinivasan, J.G. Arnold, R.C. Izaurralde, and D.D. Bosch. 2011. Simultaneous calibration of surface flow and baseflow simulations: A revisit of the SWAT model calibration framework. *Hydrological Processes* 25(14):2313–2320.

Mississippi River
Gulf of Mexico
Watershed Nutrient
Task Force

U.S. Environmental Protection Agency
Office of Wetlands, Oceans, and Watersheds (4501T)
1200 Pennsylvania Avenue, NW, Washington, DC 20460
E-mail: ow-hypoxia@epa.gov
Website: www.epa.gov/msbasin