Reducing Nutrients in the Mississippi River and the Gulf of Mexico

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EXECUTIVE SUMMARY

Hypoxia in the Gulf of Mexico emerged as a national concern nearly 15 years ago. Hypoxia is a condition in which dissolved oxygen levels are too low to sustain most marine life and is a consequence of nutrients – primarily nitrogen – from the Mississippi River basin over-enriching waters in the Northern Gulf. Hypoxia reduces the available habitat for species that are important both for the functioning of the ecosystem and for the Gulf's commercial fishing industry.

To address the issue of hypoxia, federal and state agencies created a Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. Over several years and multiple meetings and public hearings, the Task Force developed a basin-wide context for developing incentive-based, voluntary efforts to reduce the flux of nutrients in the Mississippi River. An Action Plan was released in January 2001 that provided a framework for reducing the five-year running average areal extent of the hypoxic zone to less than 5,000 km^2 by 2015 – a 75 percent reduction from the 20,000 km^2 that the hypoxic zone reached in 2002.

The Action Plan also proposed that, by 2005, the Task Force reassess the nutrient load reductions and the impact that those load reductions had on basin water quality and the hypoxic zone. Work is in progress to develop this report. But some have concerns that the funding needed to implement on-the-land management practices is lacking, and that the efforts of the Task Force are going under appreciated and reported. Further, there is a lack of a broader landscape vision in the approach taken by the Task Force and others attempting to find ways to lower nitrogen inputs.

Models indicate that the sharp reduction in the size of the hypoxic zone and the restoration of waters in the Mississippi River basin articulated in the Action Plan would require 30-45 percent lower nitrate output from the Mississippi-Atchafalaya River system. But the Action Plan goals likely cannot be achieved simply by implementing better management practices on current Midwest row crop agriculture. Certainly corn, soybean and other row crops will continue to be an important component of this agriculture, and efforts to tighten nutrient utilization in these systems should be supported and applauded. Yet while these efforts will reduce nutrient runoff, they are unlikely themselves to provide sufficient nutrient reductions needed to reduce Gulf hypoxia to 5,000 km^2 by 2015.

Many stakeholders are realizing that a different type of agriculture is needed, one that utilizes perennial crops and other continuous living cover systems. Some perennial agricultural systems,

such as grazing, are currently economical for many farmers, and the market for perennial-based agricultural systems is growing. In particular, perennial crops used for energy and fuel production may have the most potential for fostering perennial agricultural systems. But to make the necessary large-scale, landscape changes requires a long-term shift in federal policy that promotes perennial crop research and economic incentives.

Any effective solution to Gulf hypoxia will likely involve a combination of improved nutrient management practices, changes to cropping systems, and reconstructed and restored wetlands. Large-scale landscape change is needed, with a variety of short-term and long-term actions. Civil society has to be more proactive in pushing for actions and policies that protect the long-term sustainability of Midwest agriculture, Gulf fisheries, and the ecosystems on which these industries are built. Fortunately, a number of innovative partnerships have been developed between farm groups, environmental organizations, and university researchers. Strengthening these partnerships and demonstrating effective approaches to mitigating Gulf hypoxia is the best way for us to move forward – and eventually convince policymakers to act.

OVERVIEW OF HYPOXIA

Hypoxia – a condition in which dissolved oxygen levels are too low to sustain most marine life – is a growing environmental concern throughout the world. In fact, the United Nations Environment Program's March 2004 report (Global Environmental Outlook 3) identified hypoxic zones—also known as "dead zones"—as one of the worlds most significant environmental threats (see also Diaz, 2001). The Gulf of Mexico, the Chesapeake Bay, the Baltic Sea and the northern Adriatic Sea are the largest geographic areas of hypoxia, but over 150 significant hypoxic zones have been identified worldwide (Diaz, 2001). The U.N now puts the number at about 200, as reported in a recent meeting of marine experts in Beijing (http://www.gpa.unep.org/bin/php/igr/igr2/supporting.php).

Hypoxia is a consequence of the over-enrichment of nutrients in aquatic environments. Nutrients – primarily nitrogen – induce the growth of phytoplankton, which consume oxygen when their dead cells decompose and sink to the bottom of the water body. If this oxygen is not replenished by diffusion from the upper layers of water, its concentration in the lower layers declines. An area is considered hypoxic when dissolved oxygen concentrations reach levels insufficient for most marine life, generally regarded as less than two milligrams per liter (2 mg/l).

In estuaries such as the northern Gulf of Mexico, a layer of oxygen-rich freshwater overlies the denser, oxygen-depleted salt water. In the summertime, calm weather intensifies this stratification, with little mixing between the two layers. The result is a hypoxic zone in the Gulf. Many aquatic species cannot survive in hypoxic conditions. The spread of hypoxia reduces the available habitat for species that are important both for the functioning of the ecosystem and for the Gulf's commercial fishing industry.

Figure 1. The Mississippi River watershed, major tributary watersheds and the hypoxic zone. (Figure from Greene 2006).

Hypoxia in the Gulf of Mexico emerged as a national concern nearly 15 years ago. There is some evidence that the hypoxic zone has existed in the Gulf since the 1970's, although much smaller in size than the current zone (Rabalais et al, 2003). Detailed monitoring of the extent of the hypoxic zone began in 1985. While the area and volume of the hypoxic zone has varied, the zone increased from a running average of 8,300 km^2 in 1985-1992 to over 16,000 km^2 in 1993-2001. In 2002, it reached 20,000 km^2. (See Scavia et al., 2003, 2004). The rapid expansion of the Gulf hypoxia zone has alarmed many ecologists, oceanographers, environmentalists and politicians.

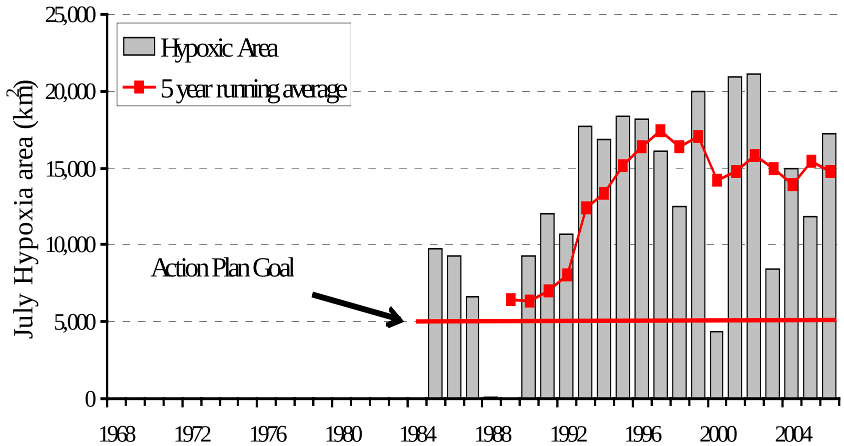

Figure 2. The five-year running average of Gulf of Mexico hypoxic zone. (Greene 2006).

THE HYPOXIA ACTION PLAN

To address the issue of hypoxia in the Gulf of Mexico, federal and state agencies created a Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (referred to here as the Task Force) in the mid-1990s. This was a Herculean effort, on the order of the Global Climate Change Task Force. Over several years and multiple meetings and public hearings, the Hypoxia Task Force developed a basin-wide context for developing incentive-based, voluntary efforts to reduce the flux of nutrients in the Mississippi River. An Action Plan was released in January 2001 that provided a framework for reducing the extent of the hypoxic zone in the Gulf of Mexico. (The plan is available at http://www.epa.gov/msbasin/taskforce/actionplan.htm.) It was based on the best available knowledge and models.

The Action Plan has three long-term goals:

- Coastal Goal: By the year 2015, subject to the availability of additional resources, to reduce the five-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 km^2 through implementation of specific, practical, and cost-effective voluntary actions by all states, tribes and all categories of sources and removals within the Mississippi/Atchafalaya River Basin to reduce the discharge of nitrogen into the Gulf.

- ❖ Within-Basin Goal: To restore and protect the waters of the 31 states and tribal lands within the Mississippi/Atchafalaya River Basin through implementation of nutrient and sediment reduction actions to protect public health and aquatic life as well as reduce negative impacts of water pollution on the Gulf of Mexico

- ❖ Quality of Life Goal: To improve the communities and economic conditions across the Mississippi/Atchafalaya River Basin, in particular the agriculture, fisheries, and recreation sectors through improved public and private land management and a cooperative, incentive-based approach.

The Action Plan also contains a number of actions and time frames, including the following:

- By Fall 2001 – Develop an integrated Gulf of Mexico Hypoxia Research Strategy to coordinate and promote necessary research.
- By Spring 2002 – Greatly expand the long-term monitoring program for the hypoxic zone
- By Fall 2002 – States, tribes and agencies will develop strategies for nutrient reduction, including reduction targets for nitrogen losses to surface waters, establishing a baseline for existing efforts, identifying opportunities to restore floodplain wetlands, and promoting additional funding.
- By Spring 2003 – Increase assistance to landowners for voluntary actions to restore, enhance, or create wetlands and vegetative or forested buffers, as well as increase assistance for the voluntary implementation of agricultural best management practices.

To track progress toward achieving its stated goals, the Action Plan also proposed that, by 2005, the Task Force assess nutrient load reductions and the impact that those load reductions had on basin water quality and the hypoxic zone. Specifically, the Action Plan stated,

> **"By December 2005, and every five years thereafter, the Task Force will assess the nutrient load reductions achieved and the response of the hypoxic zone, water quality throughout the Basin, and economic and social effects"** (Action Plan, page 14).

This report is significantly behind schedule. Part of the problem is that while there has been significant research, there has been little translation of research into action, both in policy and on-the-ground projects, toward reducing nutrient loads in the basin. The lack of action can be blamed in part on lack of funding, but perhaps also on the difficulty of implementing basin wide changes, and on the problems of delineating the most urgent needs and targeting areas of highest nutrient loading.

The scope of the reassessment has also changed. Whereas the original Action Plan proposed to assess nutrient load reductions and their effectiveness, the current reassessment focuses the bulk of its attention on evaluating the science behind hypoxia. As detailed in the Action Plan Reassessment Proposal, approved by the Task Force in June 2005,

> "The outcomes that will result by the end of 2007 from the Reassessment, in order to produce a revised Action Plan are as follows:

- A Peer Review of the August 2004, Region 4 White Paper on the role and phosphorus in causing Gulf Hypoxia
- A bibliography of all references pertinent to the science of Gulf hypoxia nutrients in the Mississippi River Basin
- A summary of available information on implementation of federal and management programs and activities
- An inventory of existing point sources throughout the Mississippi River
- A public science symposium on the causes of Gulf hypoxia to feed into Science Panel report.
- An Expert Science Panel report that describes the best scientific understanding the causes, sources, and controlling processes of the formation, extent duration of hypoxia in the northern Gulf of Mexico
- At least two sub-basin workshops on management science
- A synthesis of management recommendations and options revisions to Plan (which may include additional expert or peer review)
- Public participation and opportunities for comment and review

The science of Gulf hypoxia has continued to develop subsequent to the adoption of the Action Plan, and these developments need to be incorporated into the reassessment. However, some of the language used to describe the reassessment by Task Force agencies has suggested that a complete reassessment of the science of Gulf hypoxia will be attempted. If this is the case, the Task Force needs to explain clearly to the public why this complete reassessment of hypoxia science beyond the language of the reassessment contained in the Action Plan is necessary, especially in light of the conclusions of the peer review panel that evaluated the white paper released by EPA Region 4 (see below).

The new date of 2007 set for completion of the reassessment also raises the question of what actions will be taken in the interim. Clearly, delaying implementation actions for a further two years will set back progress on addressing hypoxia. This is not to say that research should halt; there are many opportunities for progress in research that will advance understanding of the process of hypoxia and ways to reduce nutrient input. But although there are shortfalls in the scientific understanding of hypoxia, we have more than enough information to begin implementing nutrient reduction strategies.

There are some disturbing trends. For example, the rate of nitrogen fertilizer application is up nearly 10% for 2001-2006 compared to 1980-1996. The area of fertilized row crops, particularly corn, continues to increase, and the recent policy decisions by federal and state governments to promote a rapid increase in the production of ethanol from corn makes it likely that the expansion of corn acreage will continue at least for the next decade. Is more corn in the vision of those that wish to reduce the hypoxic zone? Is there any hope of supporting grain ethanol and hypoxia reduction at the same time? The public needs some scientific and policy honesty as these questions are raised and addressed. While such a large shift in public policy is out of the purview of the Task Force, all must recognize its implications.

Perhaps one major favor the Task Force can do for the stakeholders is to address these issues and provide for us a shared vision and framework for action.

The lack of action on the Action Plan stems in part from a lack of funding. While the plan was initiated with a promise of considerable federal funding and matches from the states, the federal government has not lived up to its commitment. As the Upper Mississippi River Basin Association stated in its March 2006 testimony before the House Committee on Appropriations, Subcommittee on Interior, Environment, and Related Agencies (http://www.umrba.org/policy/testimony/epa.htm):

> **"While the states continue to support the goals and strategies set forth in the Action Plan, little progress will be made to reduce the Gulf hypoxic zone and improve water quality conditions throughout the basin without a major federal financial commitment.... The states of the Midwest heartland are being left to work largely through their existing programs, with limited resources, to reduce nutrient loading to the Gulf of Mexico. This approach is simply not adequate to make progress on a problem with the complexity and spatial scope of Gulf hypoxia."**

Stakeholders across the basin continue to support the implementation of the Action Plan. But to successfully address hypoxia, policymakers and other leaders must make action on hypoxia a priority.

THE SCIENCE OF HYPOXIA

Because of the complexities of hypoxia, as well as the prevalence of hypoxic zones all over the world, considerable scientific study has been devoted to the issue. A number of nutrients likely contribute to the growth of algae that reduce oxygen levels in the Gulf. While all of them need consideration, nitrogen loadings are considered the dominant driver of the growth in the hypoxic zone. Phosphorus loadings, which are a primary driver of water quality problems in freshwater, likely play a lesser role in the development of hypoxia.

Excellent reviews (Downing et al, 1999; Natural Research Council, 2000; Rabalais et. al, 2001, 2002) consistently implicate nitrogen as the primary driver of hypoxia in the northern Gulf of Mexico, as it is for most of the major estuarine hypoxic zones world-wide (Downing et al, 1999). Rabalais et al., 2002, in a seminal review, stated:

> **"Nutrient policy development for the Mississippi River watershed reflects the accumulated scientific evidence that the increase in nitrogen loading is the primary factor in the worsening of hypoxia in the northern Gulf of Mexico"**

The Action Plan also focuses on nitrogen, stating:

> **"The primary approaches to reduce hypoxia in the Gulf of Mexico appear to be to 1) reduce nitrogen loads from watersheds to streams and rivers in the Basin and 2) restore and enhance denitrification and nitrogen retention within the Basin and on the coastal plain of Louisiana"** (Action Plan page 8).

> **"The best current science indicates that sub-basin strategies, in the aggregate, should be aimed at achieving a 30% reduction (from the average discharge in the 1980-1996 time frame) in nitrogen discharges to the Gulf (on a 5-year running average) to be consistent with the Coastal Goal for reducing the areal extent of hypoxia in the Gulf"** (Action Plan page 21).

These clear statements of scientific fact and plans for action should be enough to give us the charge to move ahead.

The process of implementation was derailed, at least temporarily, by a controversy involving the role of phosphorus in the formation and spread of hypoxia. In January 2004, EPA scientists in Region 4 (Atlanta) conducted an internal assessment of the causes of hypoxia (U.S. EPA, 2004). Their assessment did not receive appropriate peer review prior to its release but was widely disseminated in the form of unsigned memos. The assessment concluded that phosphorus, rather than nitrogen, may be the limiting nutrient of Gulf hypoxia. EPA submitted a revised report, also unsigned, to the Task Force in August 2004, which suggested that both nutrients might play a role in the formation of hypoxia. After the paper received sharp critiques from an independent peer review, EPA decided not to prepare a final report. In contrast to widespread perceptions, the Action Plan had already included consideration of both nutrients, stating,

> **"While the primary focus of this strategy is on reducing nitrogen loads to the northern Gulf, many of the actions proposed throughout this plan will also achieve basin-wide improvements in surface-water quality by reducing phosphorus as well"** (Action Plan page 8).

However, the general consensus continues to be that nitrogen is the nutrient of utmost importance to primary productivity in the Gulf.

Addressing control of nitrate sources at the estuary level is much more difficult than in smaller watersheds because of the large geographical area involved. There has been little success reducing nitrate loads at any level, let alone in a basin that touches 31 states. The number of point and nonpoint sources of nitrate is enormous, regulatory control mechanisms have not been developed, and the mobility of nitrate creates a logistical challenge.

Goolsby et al. (2001) summarized the comprehensive monitoring studies conducted by the U.S. Geological Survey. In all cases, nitrate input was related closely to river flow, indicating that the nitrate came from non-point source runoff, largely from drainage of agricultural fields. They found that the principal source areas are basins in southern Minnesota, Iowa, Illinois, Indiana and Ohio. Significantly, their data show:

> **"The nitrogen discharged from all streams draining the states of Iowa and Illinois during the average years is estimated to account for about 35% of the nitrogen discharged to the Gulf"**

These two states, and contiguous areas of southern Minnesota, provide the best opportunity for achieving dramatic reductions in nitrate runoff, and are the most logical target areas for nitrogen source control.

HAS THERE BEEN MEASURABLE PROGRESS?

Recently published data indicate a sharp reduction in the average total nitrogen flux to the Gulf for the five years from 2000 to 2004 over a previous period of 1980-1996 (http://co.water.usgs.gov/hypoxia/html/nutrients_new.html). The data indicate that over the last five years a 32% reduction over years 1980-1996 has already been achieved -- well within the range of the target of the Action Plan. However, the size of the hypoxic zone has not responded accordingly; in fact, it reached a new high in 2006. The Action Plan goal of reducing the size of the hypoxic zone to less than 5000 km^2 remains distant.

When the flux data were analyzed by Dr. Brent Aulenbach of the U.S. Geological Survey's Georgia Water Science Survey Center, it was apparent that the difference in nitrogen inputs over time was largely the result of differences in flow (personal communication with Brent Aulenbach) -- i.e. not of actual reductions in nitrogen application. Dr. Aulenbach confirmed what many others have found -- that the concentrations of (nitrate + nitrite) –N increase with increasing flows; that is, years with lower runoff have lower N concentrations.

The 2000-2004 average nitrogen flow figure was also greatly influenced by the low nitrate flux in the year 2000, which was the lowest on record; these years also had an average flow over 13 percent lower than that between 1980 and 1996. Finally, timing is also important. The hypoxic zone is related more to the spring nitrogen input than it is to annual flux. However, the 32% reduction figure is based on yearly flux. This is also a problem with the Action Plan – it is based on annual flux, not seasonal. That deficiency is being recognized and addressed.

CAN WE ACHIEVE ACTION PLAN GOALS BY MAKING CURRENT CROPPING SYSTEMS MORE NITROGEN-EFFICIENT?

Over the past century, two significant changes in the Mississippi River basin have facilitated and exacerbated Gulf hypoxia. The first is the dramatic increase in nutrients emitted into the basin from anthropogenic sources. Municipal wastewater, industrial emissions and animal manure are all sources of these nutrients, but the most dramatic change has been the development of low-cost commercial nitrogen fertilizer after World War II and the concurrent increase in soybean acreage that led to a simple corn-soybean cropping sequence that limited sinks for nitrogen. Nitrogen fertilizer applications jumped dramatically over the next 30 years. While fertilizer applications have been relatively flat since then, because of the long lag times in the system we may just now be experiencing some of the impacts of nitrogen applications from years ago.

The second significant change has been in the hydrology of the basin. The Midwest has lost the majority of its wetlands, many of which have been converted to farm fields. Now, instead of having these wetlands capture and treat water naturally, underground tile lines quickly divert water to drainage ditches and streams. Many streams and rivers have also been channelized, and flood control and navigation structures rush the water downstream. The overall consequence of these changes is that we have not only increased the load of nutrients into the basin, we have limited the landscape's ability to naturally treat the excess nutrients.

Most hypoxia symposia and workshops spend considerable time assessing nitrogen load reductions using what is often termed "Best Management Practices" (BMPs). BMPs are available, understood and usually economical technologies known to lower nitrate output, either by controlling inputs or by removing nitrate from the output stream through plant uptake or denitrification.

BMPs can be grouped into two major approaches:

- Increased nitrogen efficiency through improved management

- Nitrate removal by wetlands, managed drainage, riparian zones, cover crops or living mulches.

The first approach is normally accomplished by using less fertilizer nitrogen or manure, slow release forms of fertilizer, and better timing and placement of fertilizer or manure. These practices are largely site-, weather- and crop-specific, and normally give improved results compared to standard practices. In other words, they can make poor nutrient management better. However, the potential for significantly limiting nitrate outputs through these practices is low (Randall and Sawyer, 2005).

Numerous lines of evidence support this conclusion. Carefully conducted leaching studies have consistently shown that nitrate leaching under the corn-soybean system is high, and that improved management systems do not greatly reduce the amount of nitrate-N lost in tile drainage (Randall and Mulla, 2001, Table 1; Dinnes et al., 2002). In general, proper nitrogen management BMPs improve nitrogen utilization, but they have not been able to mitigate high levels of nitrate in leachate from annual row crops.

The second approach – nitrate removal – helps mitigate nitrate output but also has many challenges. On-land practices that intercept tile flow or raise water tables offer promise of on-site treatment to remove nitrate largely by denitrification. Wetlands are quite effective under the appropriate conditions (Dinnes et al., 2002; Crumpton, 2001; 2005) but they must be properly sited (Crumpton, 2001). Reconstructing wetlands is a difficult challenge, not only because of the ecological challenges, but because some of the most fertile – and expensive – Midwest farmland is on these sites. Controlled water tables with gated tile drain outlets can be effective but are expensive and difficult to manage (Dinnes et al., 2002; Cooke et al., 2005). Similarly, buffers and vegetative filter strips are effective at removing sediment and sediment-bound nutrients, but generally are not sited in places that intercept the nitrate-rich tile water (Helmers et al., 2005). Cover crops and living mulches offer some opportunities to remove nitrate, especially during the times of the year when corn and soybean are not using nitrogen, but cover crops have management difficulties and are not popular with some upper Midwest farmers (Kaspar et al., 2005).

This lack of viable options presents a major conundrum for tile-drained row crop agriculture. Corn, soybean and other row crops will continue to be an important component of Midwest agriculture, and efforts to tighten nutrient utilization in these systems should be supported and applauded. Organizations like the Iowa Soybean Association have been a tremendous asset for farmers and have demonstrated that better nutrient management can provide both environmental and economic benefits.

Yet while implementing best management practices on Midwest row crops will reduce nutrient runoff, it is unlikely in itself to provide the nutrient reductions needed to reduce Gulf hypoxia to 5,000 square kilometers by 2015, as stated in the Action Plan. Model estimates indicate that this large of a reduction in the size of the hypoxic zone would require 30-45% lower nitrate output from the Mississippi-Atchafalaya River system (see Scavia et al., 2003; 2004; Bierman, 2005). Even if all Midwest farmers incorporated best management practices on their corn-soybean land, this likely would not result in a sufficient reduction in nitrate output to the Mississippi River to meet the Action Plan goals. If the focus is only on BMPs, a significant amount of time and money could be spent promoting appropriate nutrient management practices without having a significant impact on Gulf hypoxia.

ARE PERENNIAL CROPS THE ANSWER?

Achieving the necessary nitrate reductions to reach the Action Plan goals will not likely happen simply by implementing best management practices on current row crop agriculture. Many stakeholders are realizing that a different type of agriculture is needed, one that utilizes perennial crops and other continuous living cover systems.

Boody et al., (2005) modeled the environmental impacts of implementing four different scenarios in two Minnesota watersheds. The model projected the benefits that would result from continuing current practices, from implementing best management practices, and from increasing crop diversity and continuous cover. The reductions in nitrogen loadings were much higher in the two scenarios with high crop diversity and continuous cover. In fact, in the Chippewa River watershed, which has 81% of its land area covered by corn and soybeans, implementing best management practices resulted in only a 17% reduction in nitrogen – well below the reduction needed to achieve the Action Plan goals.

The market for perennial-based agricultural systems is growing. Consumer demand for grass-fed meat and dairy products has grown dramatically in the past decade. Some Midwest farmers are also finding markets for nut tree crops such as hazelnuts. Other farmers have found that they can make more money by managing their land for hunting then they can from crop production. Perennial crops used for energy and fuel production, however, may have the most potential for fostering perennial agricultural systems.

Among the many great efforts taking place throughout the basin, a new consortium has been developed to foster the transition to more perennial-based agriculture. Green Lands, Blue Waters (GLBW) is a long-term comprehensive effort whose mission is to support development of and transition to a new generation of agricultural systems in the Mississippi River Basin that integrate more perennial plants and other continuous living cover into the agricultural landscape.

GLBW is a unique collaboration between land grant universities, non-governmental organizations, and agency personnel that promotes perennial agricultural systems and has created farmer-learning groups to explore these innovative types of agriculture.

However, education about and promotion of perennial agricultural systems can only go so far in changing the agricultural landscape. These systems will not become a dominant component in Midwest agriculture without significant changes in agricultural policy, and research and outreach on crop development and management. A number of factors have shifted the playing field heavily in favor of row crop agriculture – from federal research funds to commodity programs to the structure of conservation programs and now grain ethanol and biodiesel. Some perennial agricultural systems, such as grazing, are currently economical for many farmers. But to make the necessary large-scale, landscape changes requires a long-term shift in federal policy that promotes perennial crop research and economic incentives.

CONCLUSIONS

Any effective solution to Gulf hypoxia will likely involve a combination of improved nutrient management practices, changes to cropping systems, and reconstructed and restored wetlands. Large-scale landscape change is needed, with a variety of short-term and long-term actions. The most promising plan of action in the short term may be to begin implementing a diversity of perennial crops into the row crop landscape.

The Action Plan would do a great service if proper consideration of the need for a more perennial agriculture were a major part of its output. This dramatic departure would require recommendations on policy shifts as well as differing directions of research and outreach at state and federal agricultural and outreach organizations. It is critical that we push for more proactive actions and policies that protect the long-term sustainability of Midwest agriculture, Gulf fisheries, and the ecosystems on which these industries are built. Fortunately, a number of innovative partnerships have been developed between farm groups, environmental organizations, and university researchers. Strengthening these partnerships and demonstrating effective approaches to mitigating Gulf hypoxia is the best way for us to move forward – and eventually convince policymakers to act.

REFERENCES

Bierman, V. J. Jr., D. Scavia, and D. Justic. 2005. Large-Scale Hypoxia in the Gulf of Mexico: When Did It Begin and How Much Nitrogen Reduction is Needed? Proceedings of the Gulf Hypoxia and Local Water Quality Concerns Workshop. Ames, Iowa. September 26-28, 2005.

Boody, G., B. Vondracek, D.A. Andow, M. Krinke, J. Westra, J. Zimmerman, and P. Welle, 2005. Multifunctional Agriculture in the United States. Bioscience: 55, no. 1.

Cooke, R. A., Sands, G. R., and Brown, L. C. 2005. Drainage water management: A practice for reducing nitrate loads from subsurface drainage systems. Proceedings of the Gulf Hypoxia and Local Water Quality Concerns Workshop. P. 27-34. Ames, Iowa. September 26-28, 2005

Crumpton, W. G. 2001. Using wetlands for water quality improvement in agricultural watersheds; the importance of a watershed scale perspective. Water Sci. Technol. 44:559-564.

Crumpton, W. G. 2005. Potential of wetlands to reduce agricultural nutrient export to water resources in the Corn Belt. Proceedings of the Gulf Hypoxia and Local Water Quality Concerns Workshop. P. 35-44. Ames, Iowa. September 26-28, 2005.

Diaz, R. J. 2001. Overview of Hypoxia around the World. J Environ. Qual. 30:275-281.

Dinnes, D. L., D. L. Karlen, D. B. Jaynes, T. C. Kaspar, J. L. Hatfield, T. S. Colvin, and C. A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching to tile-drained Midwestern soils. Agron. J. 94:153-171.

Downing, J. A. (chair) et al. 1999. Gulf of Mexico Hypoxia: Land and Sea Interactions. CAST Task Force. Report 134.

Global Environmental Outlook. 2004. GEO Yearbook 2004/2005. Coastal and Marine Areas. http://www.unep.org/geo/yearbook/yb2004/114.htm

Greene, R. State of the Science from Previous Symposia: Reassessment of the *Action Plan for Reducing, Mitigating and Controlling Hypoxia in the Northern Gulf of Mexico (2001).* Presented at Sources, Transport, and Fate of Nutrients in the Mississippi and Atchafalaya River Basins. Nov. 7-9. 2006. Millenium Hotel, Minneapolis, Minnesota.

Goolsby, D. A., W. A. Battaglin, B. T. Aulenbach, and R. P. Hooper. 2001. Nitrogen input to the Gulf of Mexico. J. Environ. Qual. 30:329-336.

Helmers, M. J., Isenhart and J. Strock. 2005. Buffers and vegetative filter strips. Proceedings of the Gulf Hypoxia and Local Water Quality Concerns Workshop. P. 45-58. Ames, Iowa. September 26-28, 2005.

Kaspar, T. C., E.J. Kladivko, and J. W. Singer. 2005. Potentials and limitations of cover crops, living mulches and perennials o reduce nutrient losses to water sources from agriculture soils. Proceedings of the Gulf Hypoxia and Local Water Quality Concerns Workshop. P. 125-140. Ames, Iowa. September 26-28, 2005

Keeney, D. 2002. Reducing nonpoint nitrogen to acceptable levels with emphasis on the upper Mississippi River Basin. Estuaries 25:720-726.

Mississippi River /Gulf of Mexico Watershed Nutrient Task Force. 2001. Action plan for reducing, mitigating, and controlling hypoxia in the Northern Gulf of Mexico. Washington D. C. www.epa.gov/msbasin

Mulla, D. J., N. Kitchen, and M.David. 2005. Evaluating the effectiveness of agriculture management practices at reducing nutrient losses to surface losses. Proceedings of the Gulf

Hypoxia and Local Water Quality Concerns Workshop. P. 171-193. Ames, Iowa. September 26-28, 2005

Natural Research Council. 2000. Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution. National Academy Press. Washington DC.

Rabalais, N. N. and R. E. Turner. 2001. Hypoxia in the northern Gulf of Mexico. Description, causes, and change. p. 1-36. *In* N. N. Rabalais and r. e. Turner, eds. Coastal and estuarine studies 58. American Geophysical Union.

Rabalais, N. N. R. Eugene Turner and W. W. Wiseman, Jr. 2001.Hypoxia in the Gulf of Mexico. J. Environ. Qual. 30:320-329.

Rabalais, R., E. Eugene Turner, and D.Scavia. 2002. Beyond science into policy: Gulf of Mexico hypoxia and the Mississippi River. Bioscience 52:129-142.

Randall, G. W. and D. J. Mulla. 2001. Nitrate nitrogen in surface waters as influenced by climatic conditions and agricultural practices J. Env. Qual. 30:337-344.

Randall, G.., and J. Sawyer. 2005. Nitrogen application rates and timing. Proceedings of the Gulf Hypoxia and Local Water Quality Concerns Workshop. P. 73-84. Ames Iowa. September 26-28. 2005.

Sawyer, J. E. and G. W. Randall. 2005. Nitrogen rates. Proceedings of the Gulf Hypoxia and Local Water Quality Concerns Workshop. P. 59-73. Ames Iowa. September 26-28. 2005.

Scavia, D., D. Justic, and V. J. Bierman, Jr. 2004. Reducing hypoxia in the Gulf of Mexico: Advice from three models. Estuaries 27:419-425.

Scavia, D., N. N. Rabalais, R. Eugene Turner, D. Justic, and W. W. Wiseman, Jr. 2003. Predicting the response of Gulf of Mexico hypoxia to variations in Mississippi River nitrogen load. Limnol. Oceanogr. 48:951-956.

U.S. Environmental Protection Agency 2002. Nutrient water quality criteria, summary table for the nutrient criteria documents. http://www.epa.gov/waterscience/criteria/nutriennt/ecoregions

U.S. Environmental Protection Agency Region 4. 2004. Evaluation of the role of nitrogen and phosphorus in causing or contributing to hypoxia in the northern gulf. August 2004

U.S. Environmental Protection Agency. 2005. External Peer Review of the Draft Region 4 Report, "Evaluation of the Role of Nitrogen and Phosphorus in Causing or Contributing to Hypoxia in the Northern Gulf, August, 2004." http://www.epa.gov/msbasin/taskforce/peer_review.htm