HYPOXIA IN THE NORTHERN GULF OF MEXICO - A 2006 UPDATE

Clifford S. Snyder, Ph.D., CCA
PPI Southeast Region Director

Introduction and Background

Based on several science reports and opinions, hypoxia (dissolved oxygen < 2 mg/L) in the Gulf of Mexico was previously thought to be caused by excessive loads or discharge of nitrogen (N) - primarily as nitrate plus nitrite-N (hereafter referred to as nitrate-N), and exacerbated by fertilizer N inputs (CENR, 2000). These science reports estimated that about 90% of the nitrate load to the Gulf was from nonpoint sources in the Mississippi and Atchafalaya River Basin (MARB). They also estimated about 56% of the nitrate-N load enters the Mississippi River above the Ohio River, while the Ohio River Basin adds 34%. The cooperating federal and state agencies making up the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (hereafter referred to as the Task Force) which formed in 1997, stated: "***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***"(Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2001). In the Task Force Action Plan, the following goals were adopted:

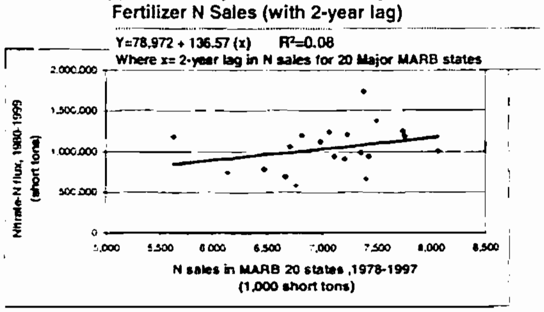
1. *Coastal Goal:* By the year 2015, subject to the availability of additional resources, reduce the 5-year running average areal extent of the Gulf of Mexico hypoxic zone to less than 5,000 square kilometers (1,930 square miles) through implementation of specific, practical, and cost effective voluntary actions

2. *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

3. *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.

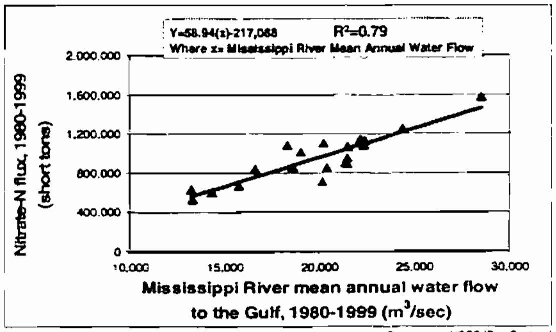
Following the release of the six CENR (White House Committee on Environment and Natural Resources) reports, the Integrated Assessment, and the Task Force Action Plan, strong control of fertilizer N use was advocated by many who failed to recognize the recent trends in fertilizer N use in the United States; especially in the 20 major states within the Mississippi-Atchafalaya River Basin (MARB). We used existing data to illustrate the lack of a significant relationship between fertilizer N consumption (sales) in the 20 major MARB states and the annual size of the hypoxic zone (**Figure 1**), and communicated these results to members of the Task Force, many scientists and stakeholders. We also showed that the flow of freshwater into the Gulf from the MARB, which contributes to increased stratification of freshwater over the saltwater, had a much stronger relationship than annual fertilizer N sales to the annual size of the hypoxia zone (**Figure 2**) (Snyder, 2003).

Fig. 1 - Nitrate-N Discharge (flux) to the Gulf of Mexico vs. Mississippi-Atchafalaya River Basin Major 20-State Fertilizer N Sales (with 2-year lag)



Data sources: USGS (Don Goolsby), TFI, and MARB 20 states used in CENR Topic Report #3

Fig. 2 - Nitrate-N Discharge (flux) to the Gulf of Mexico vs. Mississippi River Mean Annual Water Flow



Data source: USGS (Don Goolsby)

Subsequent evaluations

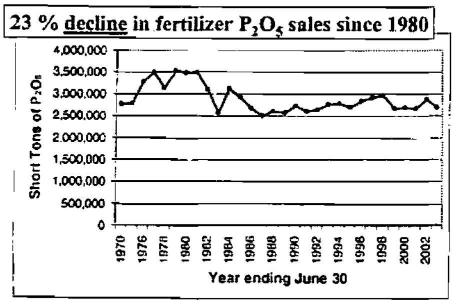
A new evaluation of the causes of hypoxia in the northern Gulf of Mexico was released by the EPA region 4 office (Atlanta, Georgia) in the spring of 2005 (August 2004- Evaluation of the role of nitrogen and phosphorus in causing or contributing to hypoxia in the northern Gulf of Mexico URL: http://www.epa.gov/msbasin/taskforce/2006symposia/Reg4whitepaper0408.pdf). The evaluation paper reported that the Redfield ratios for the Mississippi River System, especially in spring and early summer, are well above the 16:1 molar ratio associated with a balanced nutrient condition. The analysis in the Topic 1 CENR report (Rabalais et al., 1999) based the Mississippi River System nutrient ratio on dissolved inorganic N (DIN) and total P (TP). The DIN:TP ratios usually range around 14-15:1, and some have used these numbers to assert the River is in nutrient balance as compared to the Redfield ratio traditionally calculated using DIP. The EPA Region IV report indicated the DIN: DIP elemental ratios for the Mississippi River system have an annual average of 39.5 and a spring season average of 49.5, which the authors interpreted as a nutrient imbalance. These new observations may indicate that any increase in inorganic P loading could be the dominant factor contributing to increased phytoplankton blooms in the Gulf.

The following statements were made by EPA as a result of the August 2004 EPA Region 4 white paper, its peer review, and the public comments:

> "The concept of a balanced approach to managing both N and P at their source and during transport to decrease loads, which are "significantly" above historic background levels or to restore water quality throughout the Mississippi-Atchafalaya River Basin (MARB), as well as to decrease Gulf hypoxia is scientifically sound and desirable.
>
> Reducing ALL nutrient loading by at least 30%, if not significantly greater, rather than attempting to focus on one nutrient (N or P), is recommended.
>
> Action must be taken to reduce BOTH N and P in receiving waters of the Mississippi River. Lack of action will maintain, or worsen the status quo, with dire consequences for our coastal waters. "

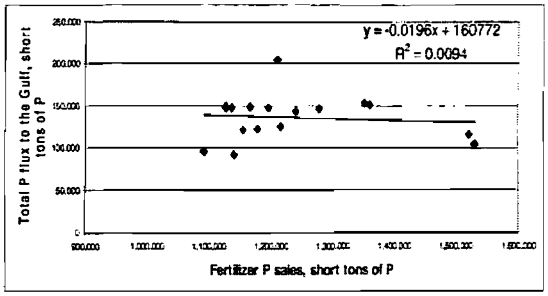
To address the perception that fertilizer phosphorus (P) sales in the MARB may be considered a principal factor causing annual variations in the size of hypoxia, we evaluated the trends in fertilizer P consumption (sales) in the 20 major MARB states. Unlike the relatively static fertilizer N sales, P fertilizer sales have declined by 23% since 1980 (**Figure 3**) (Snyder and Herz, 2005). A comparison of fertilizer P sales within the 20 major MARB states and annual total P flux or discharge to the Gulf of Mexico showed virtually no relationship (**Figure 4**).

Fig. 3 - Trend in P_2O_5 Consumption in 20 Major MARB States, 1970-2003



Data source: TFI, and MARB 20 states listed in CENR Topic Report #3

Fig. 4 - Total P flux vs. fertilizer P sales in 20 major Mississippi River Basin states, 1980-1996



An evaluation of the P balance in the 20 major MARB states showed that as a whole, there is eight percent more P being removed than is being applied as fertilizer and manure (**Table 1**- from Snyder and Herz, 2005). However, there is considerable variation among states. Some states are mining much more P than is being applied, while crop harvest is removing less than ¾ of the P applied in other states.

Table 1 – Phosphorus balance in the 20 major Mississippi-Atchafalaya River Basin states (avg. of 1998-2000).

State	Crop removal*	Applied fertilizer***	Recoverable manure****	Balance		Removal to use ratios	
	(R)	(F)	(M)	F-R	F+M-R	R/F	R/(F+M)
	-------------- P_2O_5, million lbs --------------						
AR	215.3	188	155	-27.3	127.7	1.15	0.63
CO	199.3	108	81	-91.3	-10.3	1.85	1.05
IL	1033.2	705	77	-328.2	-251.2	1.47	1.32
IN	541.3	384	91	-157.3	-66.3	1.41	1.14
IA	1154.1	621	234	-533.1	-299.1	1.86	1.35
KS	643.5	427	149	-216.5	-67.5	1.51	1.12
KY	171.7	226	33	54.3	87.3	0.76	0.66
LA	102.4	107	15	4.6	19.6	0.96	0.84
MN	825.9	515	195	-310.9	-115.9	1.60	1.16
MS	108.7	103	64	-5.7	58.3	1.06	0.65
MO	391.3	358	120	-33.3	86.7	1.09	0.82
MT	168.9	153	6.9	-15.9	-9.0	1.10	1.06
NE	749.5	438	179	-311.5	-132.5	1.71	1.21
OH	418.4	338	79	-80.4	-1.4	1.24	1.00
OK	169.1	144	62	-25.1	36.9	1.17	0.82
SD	486.4	280	57	-206.4	-149.4	1.74	1.44
TN	119.1	186	29	66.9	95.9	0.64	0.55
WV	16.3	14.8	15.3	-1.5	13.8	1.10	0.54
WI	360.0	206	129	-154.0	-25.0	1.75	1.07
WY	48.1	61	9.2	12.9	22.1	0.79	0.69
MARB	**7,923**	**5,563**	**1,780**	**-2,360**	**-579**	**1.42**	**1.08**
Tons P	**1,742,964**	**1,223,816**	**391,688**	**-519,148**	**-127,460**	**1.42**	**1.08**

* From Appendix table 4.1. With 0.38 lb P_2O_5/bu for corn.
*** Terry and Kirby, 2000, 2001.
**** Kellogg et al., 2000 (1997 production).

Based on data in the 2005 Soil Test Summary by the Potash & Phosphate Institute there are more soil samples with soil P testing in the agronomically responsive range than in the nonresponsive range. More than 78% of the soil samples tested below 50 parts per million (ppm) in Bray 1 equivalent-extractable P and 94% tested 100 ppm or below (**Figure 5a and b**). One might conclude that elevated soil test P is a relatively minor issue in most of these MARB states (Snyder, 2006b)

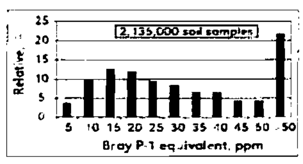


Fig. 5a – Soil test P frequency distribution for the 20 major MARB states in 2005

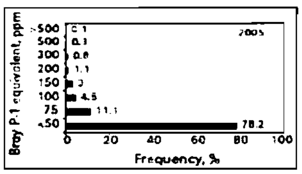


Fig. 5b – Soil test P frequency distribution for the 20 major MARB states in 2005

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Rabalais et al. (1999) reported, "The proportions of dissolved Si, N, and P in the lower Mississippi River have changed historically such that they now closely approximate the Redfield ratio (molar basis) (Si:N:P = 16:16:1)." There is some belief that the dams and impoundments on the Missouri and Arkansas rivers has resulted in less delivery of dissolved silicon (Si) to the Gulf, a decline in certain diatoms, and conditions favoring certain phytoplankton species. This possible species shift may be contributing to the onset, increased size, and duration of hypoxia. So, while N and P continue to receive attention, Si has been relatively ignored.

Since September of 2005, there have been four science symposia sponsored by EPA, the Task Force, and/or Sub-Basin hypoxia committees (http://www.epa.gov/msbasin/news/index.htm):

1. Gulf Hypoxia and Local Water Quality Concerns Workshop. September 26-28, 2005, Ames, IA (URL: http://www.umrshnc.org/index.php?option=com_content&task=view&id=17&Itemid=46)
2. Mississippi River Nutrients Science Workshop. October 4-6, 2005, St. Louis, MO. (URL: http://www.epa.gov/msbasin/taskforce/nutrient_workshop/index.htm)
3. Hypoxia in the Northern Gulf of Mexico: Assessing the State of the Science. April 25-27, 2006, New Orleans, LA. (URL: http://www.tetratech-ffx.com/hypoxia_ngm/agenda.htm)
4. Nutrient Loading & Removal in the Lower Mississippi River Basin: Data, Trends & Opportunities. April 25-27, 2006, New Orleans, LA. (URL: http://www.tetratech-ffx.com/lower_miss/agenda.htm)

Some of the new science exposed and questions raised at these meetings include:

- Coastal currents, circulation patterns and winds help trap the waters with high phytoplankton productivity near the Louisiana coast and prevent mixing and oxygenation. These physical processes primarily impact water in the area typically mapped as the hypoxic zone. According to DiMarco et al. (2006), "Timing and strength of forcing events and processes can have dramatic effects on hypoxia formation and breakdown." Detection of significant shelf waves in 2004 raised questions about effects of onshore and offshore flows on the oxygen levels of the bottom waters.
- Reduction in nutrients delivered to the Gulf from the MARB will not result in a proportionate (1:1) reduction in organic matter sedimentation (Dagg et al., 2006). Other sources and processes mentioned as significant and in need of further study included: effects of coastal wetlands (and their loss), the discharge from the Atchafalaya distributary of the Mississippi River, coastal upwelling, and vertical exchange of nutrients through the pycnocline (salinity or density stratification). The main Mississippi River discharge area in the northern Gulf system may be "P limited" instead of "N limited" during high Mississippi River flow periods
- "Seasonal phosphorus limitation of phytoplankton production during the spring and early summer was demonstrated on the Louisiana continental shelf during a series of cruises in 2001 (March, May, July, and September), 2002 (July), and 2004 (March, May, and July)." "The chlorophyll *a* response to orthophosphate additions in bioassay experiments was much greater than the response to other nutrients from March through July. By September, however, all indicators suggested that the Louisiana shelf was N-limited." "The observed seasonal P-limitation coincides with both the Mississippi's high flow period during the spring and early summer and the period of high productivity that contributes to the annual summer

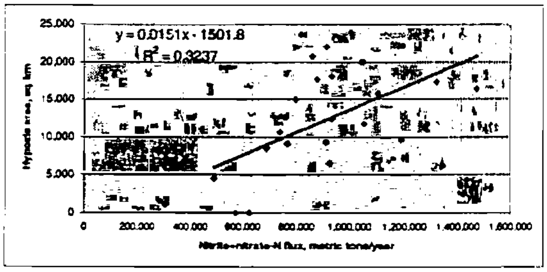
hypoxia. Nitrogen loading from the Mississippi River may have shifted the Louisiana shelf into spring P-limitation" (Ammerman, 2005).

- Isotopic evidence indicates the nitrate-N introduced in the upper watershed remains, and is not denitrified, before it reaches the Gulf. Processes in the river appear to have minimal effect on concentrations reaching the Gulf of Mexico.
- The Atchafalaya is the nation's largest wetland, but because of channelized flow- attributed to a 30% diversion of the Mississippi River flow over a year's time (mandated by law), many scientists believe there is little net reduction of nitrate-N in the Atchafalaya wetlands before discharge to the Gulf of Mexico.
- "Much of the particulate organic matter entering the Gulf is derived from in-stream productivity (plankton, bacteria, and macrophytes), and since it is biologically labile. may be an important, but overlooked, contributor to hypoxia in the Gulf" (Kendall et al., 2005).
- Total P and N concentrations increase with stream flow in some agricultural and agricultural-forested watersheds with tributaries to the Ohio River. Yet, total nutrient loads are dominated by high flow periods (Richards et al., 2005).
- Royer et al. (2005) evaluated data from the Embarras, Kaskaskia, and Sangamon: watersheds with N loads (dominated by nitrate-N) among the highest in the MARB at greater than 18 lb/A/year. Both nitrogen loads and concentrations are correlated with tile flow and discharge. They found 10% of the days accounted for 50 to 60% of the nitrate-N discharge, while 50% of the days accounted for 97 to 99% of the nitrate-N discharge. They stated: "To be successful, any effort to reduce N export from the Corn-belt to the Mississippi River must be directed specifically at periods of high flow during late winter and spring."

Recent PPI hypoxia evaluations

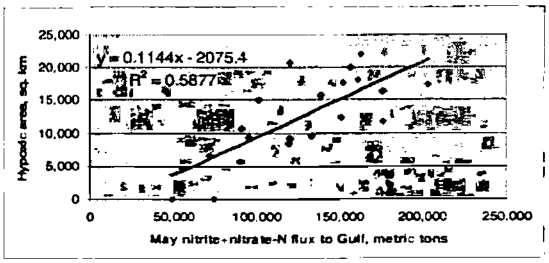
Using the available U.S. Geological Survey data (http://co.water.usgs.gov/hypoxia/html/nutrients_new.html), earlier this year we (Snyder, 2006a) showed that the relationship between the annual discharge of nitrate-N to the Gulf and the annual size of the hypoxic zone (**Figure 6**) was not as strong as the relationship between the May discharge of nitrate-N and the annual size of hypoxia (**Figure 7**) for the measured years 1985-2004. We also found that more of the variation in the annual size of the hypoxic zone was explained by annual ortho-P discharge (**Figure 8**) than annual nitrate-N discharge. Further, ortho-P discharge in May explained more variation in the annual size of the hypoxic zone (**Figure 9**) than did May discharge of nitrate-N. These data indicate the importance of seasonal discharge of both nitrate-N and ortho-P, and they point to the opportunities to reduce loss of both nutrients from farm fields, especially in April and May each year.

Fig. 6 – Hypoxic area in the Gulf of Mexico vs. annual nitrate-N discharge by the Mississippi River, 1985-2004



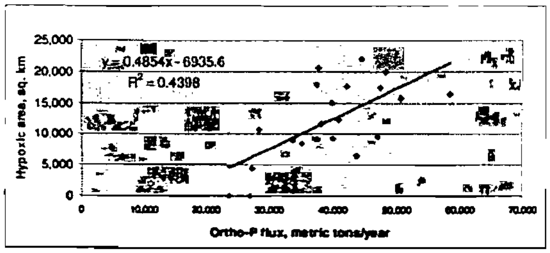
Snyder – Lower Miss. Sub-Basin Nutrients Symposium (2006)
Source of discharge data: (http://co.water.usgs.gov/hypoxia/html/nutrients_new.html)

Fig. 7 - Hypoxic area in the Gulf of Mexico vs. nitrate-N discharge in May by the Mississippi River, 1985-2004



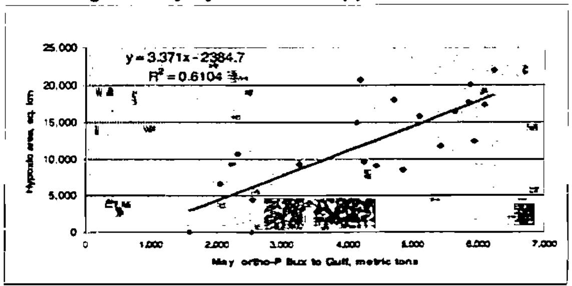
Snyder - Lower Miss. Sub-Basin Nutrients Symposium (2006)
Source of discharge data: (http://co.water.usgs.gov/hypoxia/html/nutrients_new.html)

Fig. 8 - Hypoxic area in the Gulf of Mexico vs. annual ortho-P discharge by the Mississippi River, 1985-2004



Snyder – Lower Miss. Sub-Basin Nutrients Symposium (2006)
Source of discharge data: (http://co.water.usgs.gov/hypoxia/html/nutrients_new.html)

Fig. 9 - Hypoxic area in the Gulf of Mexico vs. ortho-P discharge in May by the Mississippi River, 1985-2004

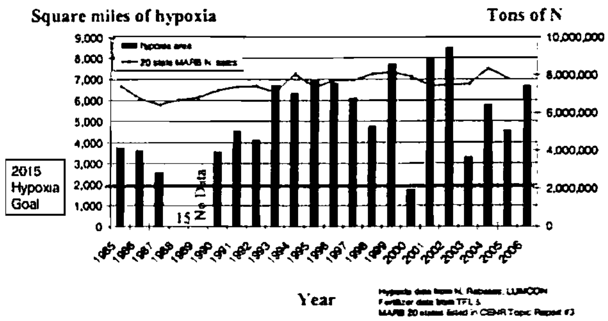


Snyder - Lower Miss. Sub-Basin Nutrients Symposium(2006)
Source of discharge data: (http://co.water.usgs.gov/hypoxia/html/nutrients_new.html)

Turner et al. (2006) recently reported a more detailed analysis of the seasonality of nutrient discharge and the annual size of the hypoxic zone. Unfortunately, they continued to focus on the nitrate-N paradigm and tended to ignore the possible importance of ortho-P discharge in the spring.

In spite of a drought in many parts of the MARB this spring and summer (2006), and reduced flow of the Mississippi River during much of the year, the size of the hypoxic zone was relatively large again (**Figure 10**). Those who measured the size of the hypoxic zone (Rabalais et al.) have suggested that Mississippi River flow was large enough in the spring of 2006 to deliver sufficient nutrients to sustain its size.

Fig. 10 - Gulf of Mexico Hypoxia and Fertilizer N Use in Miss.-Atchafalaya River Basin (MARB) 20 Major States



biogeochemists, wetlands ecologists, soil scientists and agronomists: Mark David-University of Illinois, Richard Lowrance - USDA ARS, Andrew Sharpley - USDA ARS, Tom Simpson-University of Maryland, and Cliff Snyder- PPI .

EPA has asked the SAB to "develop a report that addresses the state of the science of hypoxia as well as the scientific basis for mitigating hypoxia through management options. The SAB is asked to focus particular attention on scientific advances since 2000 that may have increased understanding and options in three general areas."

1. **Characterization of the Cause(s) of Hypoxia**. The physical, biological and chemical processes that affect the development, persistence and extent of hypoxia in the northern Gulf of Mexico.

2. **Characterization of Nutrient Fate, Transport and Sources**. Nutrient loadings, fate, transport and sources in the Mississippi River that impact Gulf Hypoxia.

3. **Scientific Basis for Goals and Management Options**. The scientific basis for, and recommended revisions to, the goals proposed in the Action Plan; and the scientific basis for the efficacy of recommended management actions to reduce nutrient flux from point and nonpoint sources.

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

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Program Chair:

Dale Leikam
Kansas State University
Manhattan, KS
(785) 532-6183
dleikam@ksu.edu

Published by:

Potash & Phosphate Institute
772 – 22nd Avenue South
Brookings, SD 57006
(605) 692-6280
Web page: www.ppi-ppic.org

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