Scientific Comments

by

The Potash & Phosphate Institute

on

the EPA Region 4 August 2004 paper:

Evaluation of the Role of Nitrogen and Phosphorus in Causing or Contributing to Hypoxia in the Gulf of Mexico

The Action Plan for reducing, mitigating, and controlling hypoxia in the Gulf of Mexico was based on the "best current science" to achieve a 30% reduction in nitrogen discharges to the Gulf of Mexico aimed at achieving the Coastal goal of reducing the areal extent of hypoxia in the Gulf (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, 2001) The Action Plan is based on an adaptive approach with a strategy to include periodic data analysis, interpretation and reporting to all stakeholders involved in the design and implementation of management, remediation, and restoration actions. The Action Plan, also states that by December 2005, and every five years thereafter, the Task Force is to assess nutrient load reductions achieved and the response of the hypoxic zone, water quality throughout the Mississippi River Basin, and economic and social effects. The AUG4R4E is consistent with the Action Plan goals and implementation strategy.

The following scientific views offered by the Potash & Phosphate Institute address the August 2004 Region 4 Report (AUGR4E), and also the overarching science supporting the Action Plan.

River flow, nitrogen, and fertilizer

Excessive nitrogen (N) loading to the Gulf of Mexico, principally as nitrate-N, has previously been viewed as the dominant cause of hypoxia development and persistence. Assertions and speculations of fertilizer N as "the cause " of hypoxia have abounded, not only in the popular press, but also in scientific publications.

One example of such continued speculation is a recent journal article by Osterman et al. (2005). Osterman et al. (2005) used four sediment cores from the Louisiana shelf area adjacent to the recurrent hypoxic zone and an isotopic lead dating technique to evaluate the sediment foraminiferal records as an indication of historic bottom water hypoxia conditions. They reported:

> "… low oxygen was occasionally present in the bottom water of the Louisiana shelf prior to the extensive use of fertilizer in the Mississippi Basin", and ".. the

> concentration of oxygen in the water may have dipped low enough to be defined as hypoxic".
>
> "The most interesting result of this research is the relatively high PEB (index of the presence of *Pseudomonion atlanticum*, *Epistominella vitrea*, and *Buliminella morgani, which are proxies of bottom water hypoxic conditions*) excursions in three cores prior to ca. 1901."

Although they stated, "there are a number of possible sources of nitrogen to the Mississippi river", they also reported, "The increased use of commercial fertilizer has amplified an otherwise naturally occurring process." This statement was made even though no clear statistically significant relationship between fertilizer N use in the Mississippi Basin and hypoxia development has been published.

Borsuk et al. (2004) studied the Neuse River Estuary in North Carolina and reported, .. "a consistent predictive relationship between nitrogen inputs and algal biomass has not been demonstrated". Their regression analyses, involving a compartmental subdivision of the estuary, showed that algal growth in that system could be sustained even with low river N inputs, under typical flow and temperature conditions. Their work addressed the issue of high N loading versus high N concentration and it also considered water residence time. They reported that the confounding influence of river flow and N concentration on phytoplankton density observed in the Neuse River estuary can be expected to occur in other systems as well.

Stow et al. (2005) reported, "While the areal extent of hypoxia (i.e. in the Gulf of Mexico) has been shown to increase with Mississippi River flow, it is unclear whether this increase results from enhanced vertical water-column stratification or from eutrophication caused by river-borne nutrients. They found that the top:bottom salinity difference is an important predictor of hypoxia, exhibiting a threshold, where the probability of hypoxia increases rapidly, at approximately 4.1 ppt. It was found that the stratification threshold decreased from 1982 to 2002, which indicates the degree of stratification necessary to induce hypoxia has gone down. According to Stow et al. (2005), "Although this declining threshold does not link hypoxia and nitrogen, it does implicate a long-term factor transcending yearly flow-induced stratification differences. Surface temperature increased, while surface dissolved oxygen decreased, which indicated that factors in addition to nitrogen may be influencing the incidence of hypoxia in the bottom water."

In Chesapeake Bay, midsummer hypoxic volume was positively correlated with winter–spring nitrate-N loading from the Susquehanna River (Hagy et al., 2004). Upon closer inspection of their data, unexpected complexity was revealed. They found that Susquehanna River nitrate-N loading did not explain as much variability in hypoxic volumes as river flow and a long-term second-order (i.e., quadratic) trend over time. Even though nitrate-N loading began to decline in 1990, hypoxic volumes continued to increase, such that reliance on nitrate-N loading prediction resulted in an underestimation of hypoxic volume.

We have found that annual Mississippi River flow clearly explains a greater portion of the variation in the annual size of the hypoxic zone than does nitrate-N discharge (**Figures 1** and **2**). A two-year lag effect between fertilizer N consumption and annual nitrate-N discharge was used in the correlation shown in **Figure 2**, similar to the approach used by Goolsby and Battaglin (2000).

The magnitude of the R-square value shown for the correlation in **Figure 1** is consistent with work cited by Borsuk et al. (2004), which demonstrated that a large percentage (78%) of the interannual variability in algal biomass in Chesapeake Bay could be explained by river flow alone.

Figure 1 - Annual Mississippi River flow to the Gulf of Mexico explains the majority of the annual variation in nitrate-N discharge.

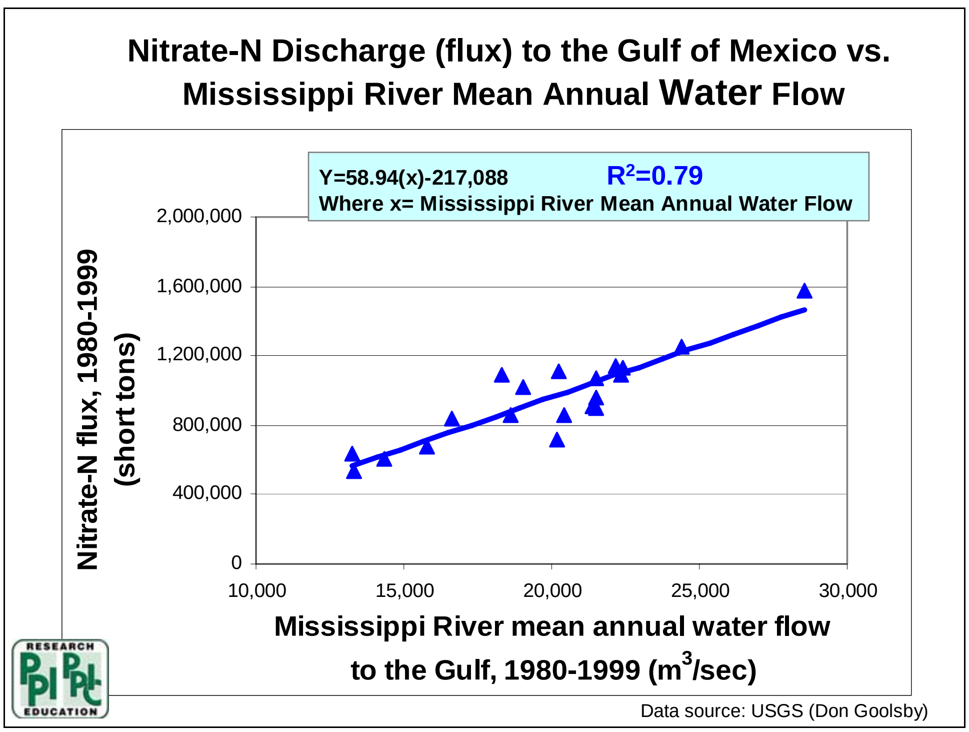
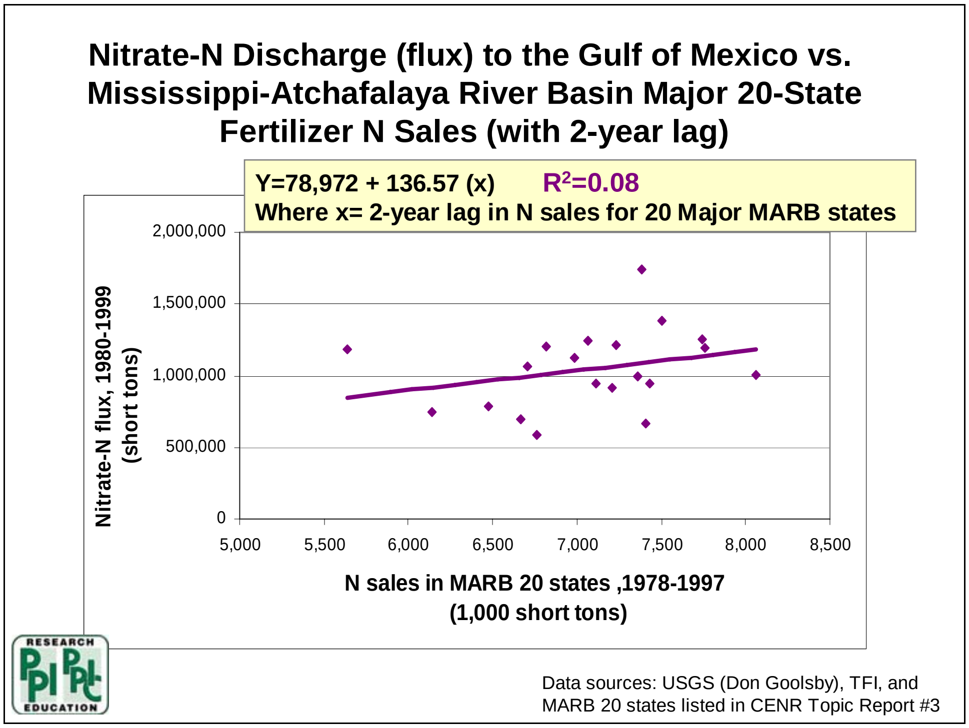


Figure 2 – Fertilizer N consumption in the 20 states with the majority of land area in the Mississippi-Atchafalaya River Basin (MARB) explains only a small proportion of the variation in annual discharge of nitrate-N to the Gulf of Mexico.



Although several studies of the Neuse River Estuary have reported the potential for nitrogen reduction to control phytoplankton growth, Borsuk et al. (2004) stated, .."a consistent predictive relationship between nitrogen inputs and algal biomass has not been demonstrated". They further stated, .."riverine total nitrogen concentration alone has only a minor role in determining estuarine chlorophyll a concentration. River flow has a stronger influence, likely through its effects on down-estuary nitrogen delivery, residence time, salinity, and turbidity. These results imply that using riverine nitrogen load as the metric to evaluate watershed nutrient management may not be appropriate".

Crop nitrogen use efficiency is improving

Burkart and James (2002) evaluated nitrogen applications and crop harvest removals for 1949 to 1997 in the Mississippi River Basin and reported the following:

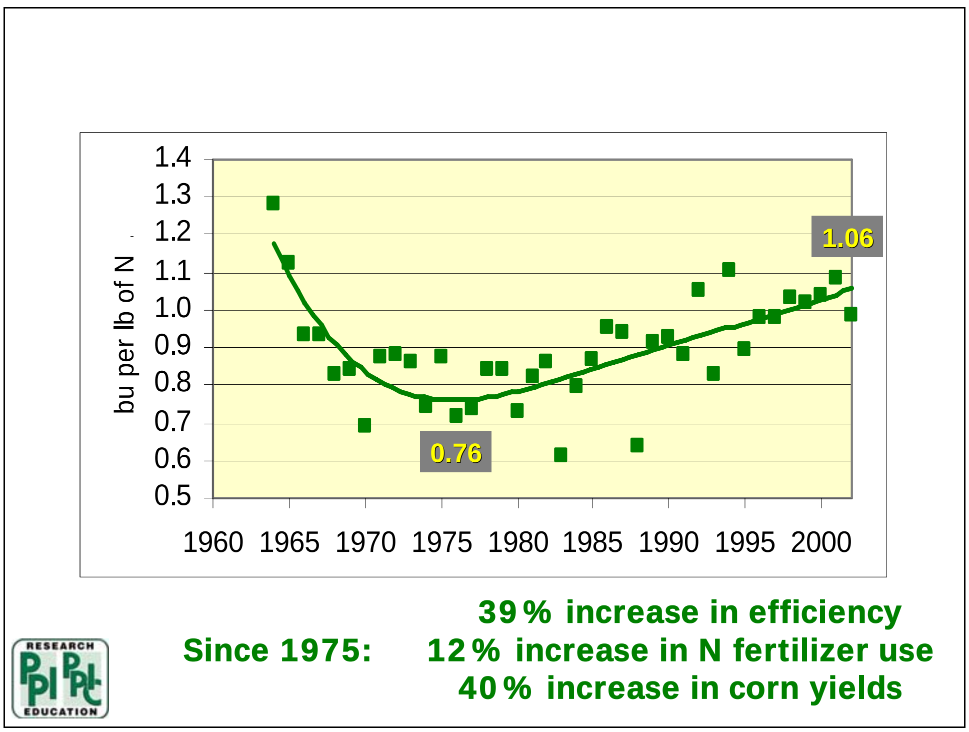
"Nitrogen removed with harvested crops increased throughout the Mississippi basin in quantities that exceed the increases in any individual nitrogen source. These trends are particularly conspicuous in the Upper and Lower Mississippi, Ohio, and Missouri hydrologic regions where increases in the rate of harvested nitrogen are as much as double those of inorganic fertilizer inputs. Only the Tennessee and Arkansas/Red regions experienced a larger increase in fertilizer use than an increase in harvested nitrogen. It is clear that agricultural systems in much of the basin have been increasingly successful in utilizing nitrogen sources.

Excess agricultural nitrogen has declined or remained stable in all regions except the Lower Mississippi. Here, the excess almost tripled between 1949 and 1978 but has subsequently declined so that in 1997 it was only 50% larger than the excess in 1949. Excess nitrogen in the Upper Mississippi region declined 20% mostly from 1978 to 1997.

The efficiency of nitrogen use for crop production increased in all regions since 1949. The Ohio and Upper Mississippi regions were initially the most efficient in using nitrogen and showed the greatest improvement in efficiency up to 1997. The Tennessee River and Lower Mississippi regions underwent the smallest improvement in efficiency."

These results by Burkart and James (2002) are consistent with results reported by Fixen and West (2002) for corn nitrogen use efficiency in the U.S. (**Figure 3**).

Figure 3. Corn grain produced in the U.S. per unit of fertilizer N used.



Historic changes in P concentrations in the lower Mississippi River and the northern Gulf of Mexico and scientific uncertainty in "reconstructed" P concentration data

Turner and Rabalais (1991) identified the lack of long-term data for total P and inorganic P (phosphate) concentrations in the lower Mississippi-Atchafalaya rivers and the northern Gulf of Mexico as limitations to statistical evaluation of P concentration trends over time. Turner and Rabalais, (1991) is cited in Table 4 on page 12 of the AUGR4E as the source of the "reconstructed "P data for total P (TP) in the Mississippi River and reactive P in the northern Gulf of Mexico. The Turner and Rabalais (1991) paper states the following:

> "We found no substantial records of total phosphorus concentrations in the lower Mississippi River before 1972. Although the concentration of total phosphorus appears to have increased since 1972, the variations between years are large, and trends, if they exist are not clear."

In a subsequent paper (Rabalais et al., 1996) the same qualifying statements about the lack of substantial records of P concentrations are repeated. Yet, the AUGR4E paper, Table 1 in Rabalais et al. (1996), and Table 1 in Rabalais et al., (1999) all show the same "reconstructed" P data for the 1960-1962 period in an attempt to contrast the "reconstructed" P numbers with total P concentration data collected for the Mississippi River during 1981-1987 and reactive P concentration data for the northern Gulf of Mexico collected during 1985-1991.

Such "reconstruction" of P concentrations for the 1960s in the lower Mississippi River, using a regression relationship developed from 1973 to 1987 data, represents a scientifically-unacceptable backward extrapolation. Such backward extrapolation to "reconstruct" data, and the inclusion of "reconstructed" values in Table 4 on page 12 in the AUG R4E report should be rejected. It is surprising that such conjecture has persisted in the published literature. Only measured P data should be reported in the AUG4RE and not "reconstructed" data that have been extrapolated beyond the bounds of the data set to 20 years in the past.

An additional point of concern in the AUG4RE paper is the lack of P data representing measurements from more recent years (e.g. 1987 to 1993 or from 1993-2003) for the Mississippi River and the northern Gulf of Mexico. To provide the most current science assessment, it is just as important to show annual average P concentrations (total and dissolved P) in the last ten to twenty years as it is to cite data from 30 to 40 years ago.

DIN:DIP and DIN:TP ratios

On page 1 under the *Introduction* in the AUGR4E - it is stated that water quality model results by Brezonik et al. (1999) "were not significantly different in predicted responses to reductions in nitrogen and phosphorus". Brezonik et al. (1999) reported, "It is important that we encourage the further development of regression-based models that relate nutrient related water quality variables to stream trophic state and nutrient loading from the watershed." In their CENR report, it appeared that the major focus was on total P and total N load reduction to the Gulf. It is uncertain if any attempt was made by Brezonik et al. (1999) to evaluate the impacts on hypoxia development form varying DIN:DIP ratios in waters delivered to the northern Gulf from the Mississippi Basin.

The AUGR4E report clearly shows similar trends in the DIN:DIP average monthly ratios for the Belle Chasse and the Morgan City sampling stations; higher DIN:DIP ratios in the spring followed by lower ratios in the late summer and fall. The AUGR4E report also illustrates the lack of monthly sensitivity in the DIN:TP ratio at the Belle Chasse sampling station.

The magnitude of the monthly average DIN:DIP ratios at Morgan City and Belle Chasse from 1980 to 1999 are reported as indicative of nutrient imbalance, based on the Redfield ratio. However, there was no apparent attempt in the AUGR4E paper to conduct regression analyses to evaluate the effects of yearly variations in selected monthly DIN:DIP ratios (e.g. March-May) on the size of the hypoxic area in the northern Gulf. Such regression analyses need to be performed to determine if indeed there is a predictable cause and effect relationship between spring river DIN:DIP ratios and hypoxia. Further, there is a need to include DIN:DIP ratios for the time since 1999 in evaluating cause and effect relationships with the development of hypoxia, its size, and persistence in the northern Gulf of Mexico.

The previous assertions that the DIN:TP ratios in the lower Mississippi River and the northern Gulf of Mexico were out of balance, and that they were driving hypoxia development, appear unfounded. We can find no published report of a relationship between DIN:TP in the Mississippi River or the northern Gulf of Mexico and waters the Gulf of Mexico and the annual size of the hypoxic area, based on statistically significant regression analyses.

The validity of a uniform Redfield ratio was called into question when Klausmeir (2004) reported; " results show that the canonical Redfield N:P ratio of 16 is not a universal biochemical optimum, but instead represents an average of species-specific N:P ratios." They developed a model that predicted "optimal N:P ratios will vary from 8.2 to 45.0, depending on the ecological conditions." This new information may warrant alternative evaluations of nutrient sufficiency/excess and DIN:DIP ratios in the northern Gulf of Mexico, which may be dependent on the majority of species present, especially during the peak hypoxia development period.

<u>Lack of P Concentration data at Morgan City and Belle Chasse for 1999 to current</u>

As mentioned above, there is an important need to include more recent data for 1999 to current in the scientific assessment of DIN;DIP ratios and their influence on hypoxia development.

DIP Concentration trends and possible need for flow-weighting

Based on the results shown on pages 4-9 in the AUG4RE, it appears that the DIP concentration in the Mississippi River water decreases considerably after it merges with drainage from the Red and Ouachita Rivers (Goolsby et al. (1999); see Figures 3.5a and 3.5b) before reaching Morgan City. Yet, it does not appear that the volume of water discharged from the Red and the Ouachita Rivers is sufficient in itself to result in such a striking dilution in river water P concentration. These contrasting river P concentrations (Belle Chasse at 0.09 mg DIP/L versus 0.05 mg/L at Morgan City) indicate the Morgan City DIP concentration is about 70% of the DIP concentration at Belle Chasse. Comparisons of the DIN values shown on page 4 of the AEG4RE indicate that Morgan City has DIN concentrations that are about 56% of those at Belle Chasse.

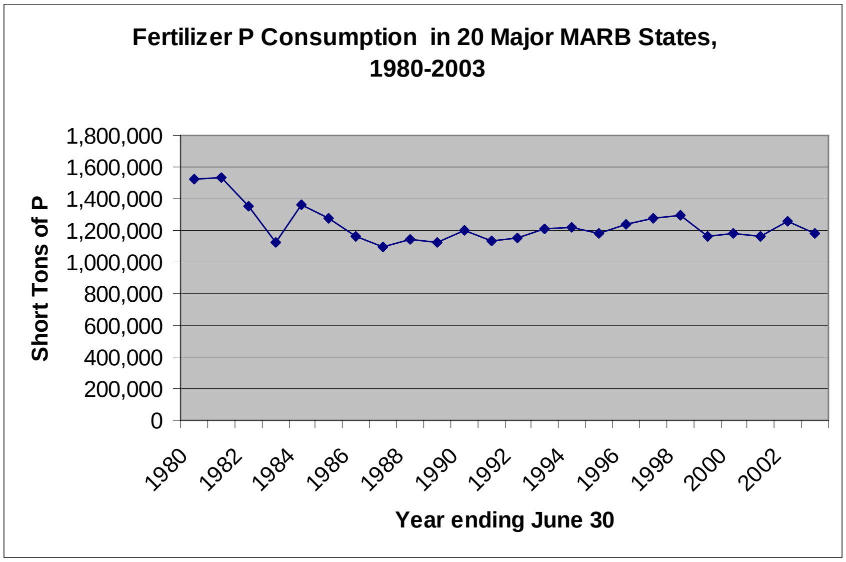
These differences in DIP and DIN values between the Morgan City and the Belle Chasse stations indicate the need to consider flow-weighting of DIP concentrations in subsequent regression analyses. Stow et al (2005) stated, "River flow (volume/time), which is directly related to nutrient loading (mass/time), also affects salinity, temperature, stratification, turbidity, and residence time, factors that all influence primary productivity. "

Level or declining DIP concentrations and fertilizer P use in the Mississippi Basin

Even though P concentration data are not reported for 1999-to- current at Morgan City in the AUG4RE, there has been no apparent net increase or decrease in DIP concentrations since the mid 1980s at Morgan City. Goolsby et al. (1999) reported, "There has been no significant change in the flux of phosphorus since the early 1970s, when records began."

These observations, and evidence in Figure 3 on page 6 of the AUG4RE showing a decline in ortho-P at Belle Chasse from 1980-1999, are particularly noteworthy since fertilizer P consumption in the major 20 states of the Mississippi-Atchafalaya River Basin (MARB) declined 23% since 1980 (see **Figure 4** below). During this same period, crop yields and the associated P removal from soils in the Basin increased substantially. Average P removal in harvested crops from 1998 to 2000 was 1.7 million short tons, exceeding fertilizer P applied in the 20 Basin states by 42% and the sum of fertilizer P and recoverable manure P by 8% (PPI, 2002). These facts should receive strong consideration in any policy decisions or strategies to reduce P concentrations and loads discharged by the Mississippi River system.

Figure 4 – Fertilizer P consumption in the 20 major states in the Mississippi-Atchafalaya Basin (MARB) has declined by 23% since 1980.



Goolsby et al. (1999) stated, "The highest yields of ortho-phosphate, 35 and 36 kg/km^2/yr (*0.31 to 0.32 lb of P/acre/year, respectively*), are in the Lower and Middle Mississippi Basin". According to Coupe (2002), who investigated N and P concentrations in part of the Lower Mississippi Basin and compared results with those in 42 streams in the entire Mississippi River Basin, "Yields of phosphorus in the Mississippi River Basin were highest in the MISE (Mississippi Embayment) study unit, although the use of phosphorus as a fertilizer is much less in the study unit and there are few significant point sources. The high phosphorus yields in the MISE Study Unit were attributed to the large amount of rainfall received in the Study Unit and to the soil texture of the Study Unit. Additionally, it was suggested that the large amount of surface drainage in the Study Unit could be contributing to the high phosphorus yields."

Accounting for sediment P release

The following information is provided to underscore the complexity in developing a complete understanding of the biogeochemical P cycle in the Mississippi River Basin and the northern Gulf of Mexico, and to emphasize the importance of accounting for sediment P release in any strategy aimed at reductions in P concentrations in the northern Gulf of Mexico.

Conley (2000) reviewed nutrient cycling and nutrient management strategies in freshwaters, marine waters, and estuaries and suggested that attempts should be made to account for losses of N by denitrification, the make-up of any denitrified N by N_2 fixation, and the regeneration of P in the water column from sediments under anoxic/anaerobic conditions. His review identified the need to consider seasonal variations in P release from sediments in the overall nutrient cycles, especially in estuaries.

This sediment P release issue is of particular interest since the average annual DIP concentration at Belle Chasse from 1980 to 1999 was 0.09 mg P/L while it was 0.05 mg P/L at Morgan City. Turner and Rabalais (1991) reported that the TP concentration at Morgan City from 1973 to 1987 was 130% of the TP concentration at St. Francisville. Since St. Francisville is upstream of Belle Chasse, these P concentration contrasts with Morgan City contradict one another and require answers about the influence of water flow and sediment regeneration of P on DIP concentrations in the water column.

As pointed out on page 13 of the AUGR4E report, there is a possible P limitation on chlorophyll a concentrations (indicator of algae production) in the eastern portion of the yearly hypoxic area. The observation that DIP concentrations appear to be relatively constant downstream of the initial algal production zone, indicate there is a strong possibility of sediment P release in the western region of the hypoxic zone.

Conley (2000) reported "One of the greatest differences in nutrient biogeochemical cycles between freshwater and marine systems occur in P biogeochemistry with the ability of freshwater systems to retain P in sediments through interactions with Fe. By contrast, in marine systems nearly all the P deposited in sediments is remineralized on an annual basis and returned to the overlying water". He also stated, "The seasonal switching in nutrient limitation observed in estuaries can be explained by the seasonal pattern in P release from sediments. P concentrations in estuaries are often found to be highest during summer corresponding to a strong temperature dependent release of P".

Release of DIP from sediments is not a new phenomenon and has been reported by many scientists. For example:

> Moore et al. (1991) found that P flux from underlying sediments averaged 2.7 mg per meter square per day and observed that this could increase the lakewater soluble reactive P by 0.5 mg/L annually. Reddy et al. (1996) stated that nutrient release from sediments may continue for a number of years after load reductions have occurred in lakewaters.
>
> James and Barko (2004) estimated the daily P desorption flux from TSS loads in the Mississippi River as it moved through Lake Pepin at 2.0 mg per meter square/day. This P desorption accounted for 21% of the measured sediment flux

to this reach of the river system. The bottom water oxygen concentration in their summer investigations was greater than 2 mg/L, which indicates that sediment P diffusive flux may be higher under less oxygenated (i.e.anoxic) conditions

Smith et al. (2005) investigated P loss from tile-drained agricultural fields in northeast Indiana and the effects of field size on N and P concentrations in drainage ditches within different watersheds. They also investigated the effects of aluminum sulfate or calcium carbonate addition to collected sediments on P equilibrium in the sediments and drainage water. Addition of alum decreased the exchangeable P ($MgCl_2$ extraction) by 50 to 90%, and they concluded that "watershed managers could potentially use chemical treatments with alum and calcium carbonate to remove P from the water column, thereby delivering cleaner water downstream".

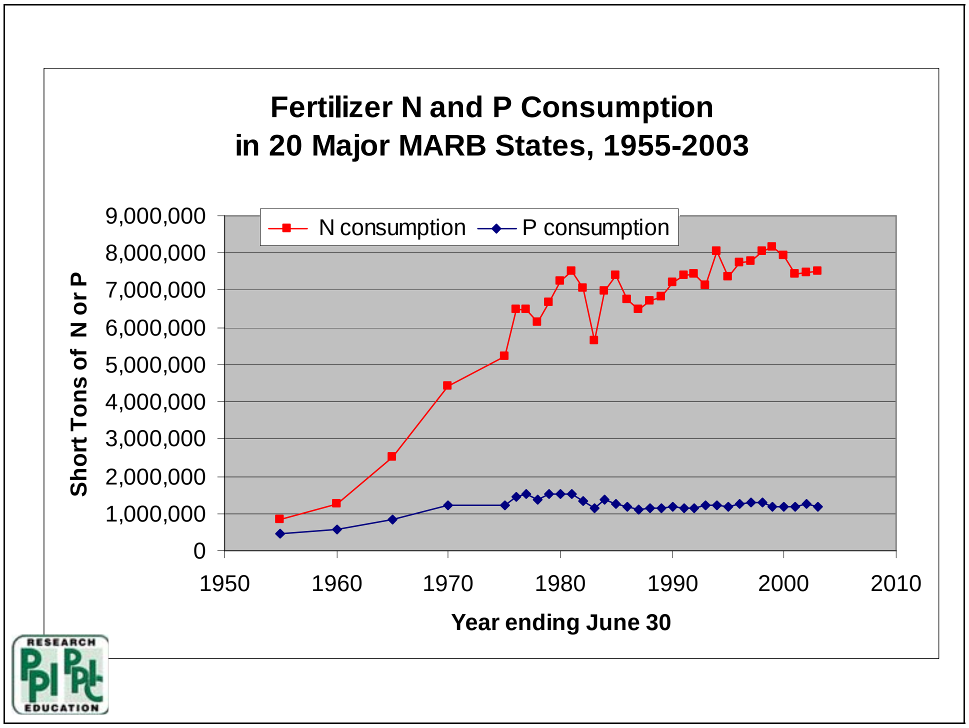
Conley et al. (2002) showed that annual changes in DIP pools were positively correlated to the area of bottom water hypoxia in the Baltic Sea, but not to changes in the total P load. They found that climatically driven variations in saltwater inflow from the North Sea, and bottom water oxygen concentrations have a profound effect on P biogeochemical cycles. A drastic reduction in the N load while the P concentration remained high, was considered as possibly ineffective in the Baltic Sea because it would enhance nitrogen fixation by cyanobacteria. The variations in the P pools measured in the Baltic Sea during the past decades do not reflect efforts to reduce P inputs. Their calculations demonstrated that an exchangeable pool of P is present in the sediments, which could account for yearly changes in water column P pool sizes.

Trends in fertilizer N and P use in the Mississippi Basin

Figure 8 on page 13 of AUG4RE is inappropriate and should be excluded because it shows fertilizer N and P use in the entire United States, and does not accurately represent the majority of the Mississippi River Basin.

Goolsby et al. (1999) used input and output data for the 20 states with the largest land area in the Mississippi Basin (see Section 5.2, page 70 (pdf version of CENR Topic 3 Report) in Goolsby et al.,(1999)). In keeping with the approach used by Goolsby et al. (1999) **Figure 5** (see below) was developed to show fertilizer N and P (P_2O_5 converted to P) use data for 1955 to 2003 for the 20 major Mississippi River Basin states. (*We would be happy to provide the fertilizer N and P data in this graph to EPA upon request*.)

Figure 5 – Fertilizer N and P consumption in the 20 major states in the Mississippi-Atchafalaya River Basin (MARB) since 1955.



Dissolved Silica and DIP

Note: There is considerable mixing of terms in the aquatic literature in addressing dissolved Si, including: dissolved silicate, dissolved silicon, and dissolved silica. The inconsistency in terminology contributes to interpretive confusion and restricts the ability to compare data among published reports.

Conley (2000) stated, "Diatom production can be seasonally limited by dissolved silicate concentrations in a number of estuarine systems". "An example is the Chesapeake Bay where dissolved silicate concentrations and loading determine the magnitude of the diatom bloom during the spring, causes the collapse of the spring diatom bloom and leads to changes in floristic composition of phytoplankton communities allowing for diatoms to be replaced by species not requiring dissolved silicate for growth."

Marine diatoms have an order of magnitude less silica per unit volume then freshwater diatom species (Conley and Kilham, 1989). These differences have an influence on the adaptation to low dissolved silica environments and sinking strategies. Considerably less is known about the production and transport of dissolved silicate compared to N and P. Conley et al. (2000) found that lakes and reservoirs along the continuum of rivers in Sweden and Finland resulted in increased retention of dissolved silicate and reduced delivery to the coastal ocean. Turner and Rabalais (1991) offered similar explanations for dissolved silicate concentrations in the Mississippi River and reduced concentrations reaching the northern Gulf of Mexico.

Turner et al. (1998) reported that the average annual dissolved silicate concentrations in the Mississippi River at New Orleans declined from the 1960s through the 1990s. They suggested that changes in the dissolved Si:DIN concentration atomic ratios 90 days before their sampling intervals affected the abundance of copepods that selectively graze diatoms. Their report indicated that the phytoplankton community can experience striking changes when the Si:DIN ratio in the river decreases to less than 1:1. Rabalais et al (1999) stated that dissolved silicate concentrations in the Mississippi river declined coincidentally with fertilizer P use from 1960 to 1985, presumably because of an antagonistic influence of DIP on dissolved Si. However, the mechanism for this DIP influence on Si concentrations is not clear, and there is confusion between dissolved Si:Total P and dissolved Si:DIP ratios in Rabalais et al. (1999).

The average monthly concentration of Si from January through July seems fairly stable, based on data form the Mississippi River at St. Francisville from 1975 to 1985 (see figure 39 in Rabalais et al., 1999). A decrease in silica availability relative to N or P has been correlated with an increase in harmful algal blooms (National Research Council, 2000). Since there is monthly variation in DIN:DIP ratios in the lower Mississippi River, it may also be important to investigate any importance of monthly variations in the DSi:DIP ratios on hypoxia development. Previously published work reported DSi:Total P ratios.

Strategies for reduction in P loads and concentrations in the lower Mississippi River

Studies of the Baltic Sea by Conley et al. (2002), studies of the Neuse River Estuary by Paerl et al. (2004) and other published reports point out the need to manage both N and P in reducing the risk of excessive phytoplankton growth and the potential for hypoxia development. Paerl et al. (2004) stated, “These findings underscore the need for watershed- and basin-scale, dual nutrient (N and P) reduction strategies that consider the entire freshwater-marine continuum as well as hydrologic variability (e.g., hurricanes, floods, droughts) when formulating long-term controls of estuarine eutrophication.”

Borsuk et al. (2004) concluded that nutrient load is not the proper metric for evaluating the success of nutrient management. They reported that “flow-adjusted concentration may be the more appropriate metric for measuring the effects of nitrogen management because the effect of flow can be held constant across time to assess long-term trends.”

Stow et al (2005) offered the following summary regarding reductions in the size of the hypoxic zone:

> "Large nitrogen fluxes to the Gulf and the concurrent eutrophication problems are only the more obvious symptoms of a suite of changes that have occurred in the Mississippi River watershed. The recently reported increase in exported alkalinity from the Mississippi River suggests that additional more subtle, long-term changes in water quality may be occurring. Some of these undocumented changes could also be directly or indirectly affecting DO concentrations. The recent suggestion that phosphorus may be a more important stimulant of algal production in the Gulf of Mexico than has been previously documented, further underscores the intrinsic uncertainty in most environmental decision-making and this situation in particular. Thus, estimating the nutrient load reductions required to reduce the severity of hypoxia and forecasting how quickly the system will respond to the implementation of management actions demand a thoughtful quantification of the inherent uncertainties so that decision-sensitive uncertainties can be identified and reduced, if possible, through directed study. Just as the perturbation of this system was a large uncontrolled experiment, so will be its recovery, with many opportunities for learning in an adaptive management framework ."

CONCLUSION

The EPA Region 4 August 2004 hypoxia evaluation report represents a significant advancement in the science from previous interpretations surrounding hypoxia in the Gulf of Mexico. However, the report should be modified with attention to the points made in this submission before it is completed and released to the public.

Any nutrient-related strategy aimed at reducing the potential for excessive phytoplankton growth and providing an acceptable dissolved oxygen status for water resources in the Mississippi River Basin and the northern Gulf of Mexico, probably needs to consider the role of both dissolved inorganic N and dissolved inorganic P and their ratios. Of the two nutrients (N and P), P management may initially appear more easily achieved because it does not involve a gaseous phase in its biogeochemical cycle. However, the complexity of P biogeochemistry, including potential long-term interactions of P in sediments and soil lost to surface waters by erosion, will require a thorough scientific understanding before adopting a strategy to improve water quality in the Mississippi River Basin and the northern Gulf of Mexico. The dynamics associated with all P sources, including human and other animal wastes in the Basin, must be considered in any revised or new adaptive strategy for the Mississippi River Basin and the northern Gulf of Mexico.

Rigorous multiple regression analyses and nutrient budget evaluations are needed to test multiple nutrient hypotheses and to develop statistical confidence in relationships that ultimately will be helpful in achieving water quality goals. To help ensure that any strategies developed will reflect the best science available and would be likely to result in successful restoration of acceptable water quality, scientific approaches similar to those used by Stow et al. (2005), Borsuk et al. (2004), Hagy et al. (2004), Paerl et al. (2004), Burkart and James (2002), and James and Barko (2002) should be considered.

REFERENCES CITED

Borsuk, M.E., C. A. Stow, and K. H. Recklow. 2004. Confounding effect of flow on estuarine response to nitrogen loading. J. Environ. Engineer.130(6):605-614.

Brezonik, Patrick L., Victor J. Bierman, Jr., Richard Alexander, James Anderson, John Barko, Mark Dortch, Lorin Hatch, Gary L. Hitchcock, Dennis Keeney, David Mulla, Val Smith, Clive Walker, Terry Whitledge, and William J. Wiseman, Jr. 1999. Effects of Reducing Nutrient Loads to Surface Waters within the Mississippi River Basin and the Gulf of Mexico: Topic 4 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series No. 18. NOAA Coastal Ocean Program, Silver Spring, MD. 130 pp.

Burkart, M.R. and D. E. James. 2002. Nitrogen trends in the Mississippi Basin, 1949-1997. 2002. U.S. Department of Agriculture. URL: http://www.nstl.gov/pubs/burkart/trends/index.html (verified April 17, 2005)

Conley, D. 2000. Biogeochemical nutrient cycles and nutrient management strategies. Hydrobiologia 410:87-96.

Conley, D.J., P, Stalnacke, H. Pitkanen, and A. Wilander. 2000. The transport and retention of dissolved silicate by rivers in Sweden and Finland. Limnol. Oceanogr. 45(8): 1850-1853.

Conley, D.J., C. Humborg, L. Rahm, O.P. Savchuk, and F. Wulff. 2002. Hypoxia in the Baltic Sea and basin-scale changes in phosphorus biogeochemistry. Environ. Sci. Technol. 36:5315-5320.

Conley, D.J. and S.S. Kilham. 1989. Differences in silica content between marine and freshwater diatoms. Limnol. Oceanogr. 34(1): 205-213.

Coupe, R.H. 2002. Nitrogen and phosphorus sources and fluxes of streams in the Mississippi Embayment study unit, 1996-98. U.S. Geological Survey Water-Resources Investigations Report 01-4024.

Fixen, P.E. and F.B. West. 2002. Nitrogen fertilizers: meeting contemporary challenges. Ambio 31(2): 169 - 176.

Goolsby, D.A., and W.A. Battaglin. 2000. Nitrogen in the Mississippi Basin--Estimating Sources and Predicting Flux to the Gulf of Mexico: U.S. Geological Survey Fact Sheet 135-00, 6 p.

Hagy, J.D., W. R. Boynton, C. W. Keefe, and K.V. Wood. 2004 . Hypoxia in Chesapeake Bay, 1950-2001: Long-term change in relation to nutrient loading and river flow. Estuaries 27(4):634-658.

James, W.F. and J.W. Barko. 2004. Diffusive fluxes and equilibrium processes in relation to phosphorus dynamics in the upper Mississippi River. River Res. Applic. 20:473-484.

Klausmeir, C. A. , E. Litchman, T. Daufresne, and S. A. Levin. 2004. Optimal nitrogen-to-phosphorus stoichiometry of phytoplankton. Nature 429:171-174.

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. 2001 Action Plan for Reducing , Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico.31 pp. U.S. environmental Protection Agency, Office of Wetlands Oceans and Watersheds. Washington, D.C.

Moore, P.A., Jr., K.R. Reddy, and D.A. Graetz. 1991. Phosphorus geochemistry in the sediment-water column of a hypereutrophic lake. J. Environ., Qual. 20:869-875.

National Research Council. 2002. Clean Coastal Waters. Understanding and reducing the Effects of Nutrient Pollution. 405 pp. National Academy Press. Washington, DC.

Osterman, L.E., R.Z. Pooer, P.W. Swarzenski, and R.E. Turner. 2005. Reconstructing a 180-yr. record of natural and anthropogenic induced low-oxygen conditions from Louisiana continental shelf sediments. Geology 33(4):329-332.

Paerl, H.W., L.M. Valdes, A.R. Joyner, M.F. Piehler, and M.E. Lebo. 2004. Solving problems resulting form solutions: evolution of a dual nutrient management strategy for the eutrophying Neuse River Estuary, North Carolina. Environ. Sci. Technol. 38:3068-3073.

PPI. 2002. Plant Nutrient Use in North American Agriculture. PPI/PPIC/FAR Technical Bulletin 2002-1. Potash & Phosphate Institute, Norcross, GA.

Rabalais, N.N., R.E. Turner, D. Justic´ , Q. Dortch, W.J. Wiseman, Jr., and B.K. Sen Gupta.1996. Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. *Estuaries* 19:386–407.

Rabalais, Nancy N., R. Eugene Turner, Dubravko Justic´ , Quay Dortch, and William J. Wiseman, Jr. 1999. Characterization of Hypoxia: Topic 1 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series No. 15. NOAA Coastal Ocean Program, Silver Spring, MD. 167 pp. (URL: http://www.nos.noaa.gov/products/hypox_t1final.pdf . Verified April 19, 2005).

Reddy, K.R., M.M. Fisher, and D. Ivanoff. 1996. Resuspension and diffusive flux of nitrogen and phosphorus in a hypereutrophic lake. J. Environ. Qual. 25:363-371.

Stow, C.A, S.S. Qian, and J.K. Craig. 2005. Declining threshold for hypoxia in the Gulf of Mexico. Environ. Sci. Technol. 39:716-723.

Turner, R.E. and N.N. Rabalais. 1991. Changes in the Mississippi River water quality this century. BioScience 41(3): 140-147.

Turner, R.E., N. Qureshi, N.N. Rabalais, Q. Dortsch, D. Justic, R.F. Shaw, and J. Cope. 1998. Fluctuating silicate:nitrate ratios and coastal plankton food webs. Proc. Natl. Acad. Sci. 95:13048-13051.