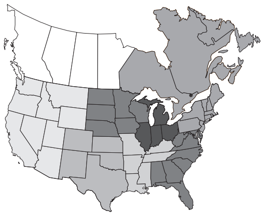
NEWS & VIEWS

A regional newsletter published by the
Potash & Phosphate Institute (PPI) and the
Potash & Phosphate Institute of Canada (PPIC)



Multi-region
October 1999

Hypoxia in the Gulf of Mexico and Fertilization Facts

What is hypoxia?

In the Gulf of Mexico, hypoxia has been operationally defined as that condition in which dissolved oxygen (O_2) concentrations are less than 2 parts per million (ppm or mg/L) of water. Marine scientists have chosen this definition because it is the level of O_2 at which there are anecdotal reports of reduced captures of shrimp in trawler nets. ***It should be pointed out, however, that there has been no measured economic effect of hypoxia on the Gulf of Mexico fisheries to date.***

According to scientists at the University of Alabama Environmental Institute, there are at least three processes, operating independently or in concert, which contribute to the potential for hypoxia development in the Gulf of Mexico:

1. **Eutrophication**—The process of being enriched in dissolved nutrients, especially nitrate (NO_3) and phosphate. Eutrophication can enhance phytoplankton (microscopic, passively floating plants) growth. This increased growth can cause an increase in organic matter deposition. As the organic matter from dead phytoplankton and fecal residues from zooplankton (which feed on the phytoplankton) drops to the bottom waters, microorganisms decompose it and deplete dissolved O_2 from the water.
2. **Organic matter deposition**—When organic matter from land surfaces is deposited in a water body, the activity of organisms in the bottom waters increases and causes consumption of dissolved O_2. However, a large percentage of the organic matter derived from land surfaces is usually not “available” for rapid microbial decomposition because it often has a high concentration of lignin and cellulose.
3. **Physical stratification** of fresh waters over heavier salt water—In the absence of significant winds or tidal mixing, the stratification may become stable. Continued deposition of organic matter from the surface to bottom waters can occur without the re-supplying of O_2 from surface waters to bottom waters.

For centuries, these same processes of sediment and nutrient delivery and stratification have resulted in the Gulf of Mexico being one of the most productive fisheries in the world.

Some important facts about the Mississippi River and the Gulf of Mexico

The Mississippi River

- contributes over 90 percent of the fresh water to the Gulf
- ranks among the world’s top 10 rivers in fresh water and sediment inputs to the coastal ocean
- has been shortened by 88 miles and is navigable from Minneapolis, MN to the Gulf of Mexico
- has constructed levees along much of its length to protect adjacent lands from flooding
- deposits over 3.3 million gallons of water per second into the Gulf of Mexico
- is the drinking water source for over 70 cities and towns

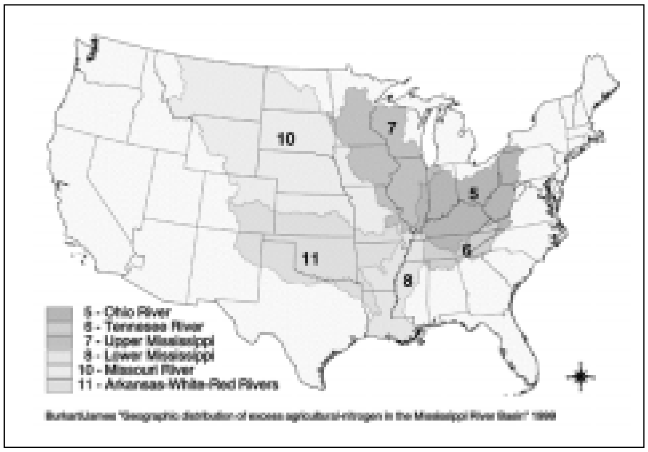
The Mississippi River Basin (see Figure 1)

- drains 41 percent of the contiguous U.S.
- covers 55 percent of U.S. agricultural lands
- includes 33 major river systems and 207 estuaries
- includes 27 percent of U.S. population
- includes about 80 percent of U.S. corn and soybean acreages, and much of the cotton, rice, sorghum, wheat, and forage lands
- has an estimated value of agricultural production close to $100 billion annually

The Gulf of Mexico

- is the source of 72 percent of U.S. harvested shrimp, 66 percent of the harvested oysters, and 16 percent of the U.S. commercial fish harvest
- has fisheries valued annually at over $700 million at dockside. Its commercial and recreational fisheries have a combined value of $2.4 billion per year

- currently receives an average of about 1.7 million tons of N annually from the Mississippi River, with about 60 percent of the N in the NO_3 form
- has had no change in phosphorus (P) loading from the Mississippi River since the early 1970s when record-keeping began
- has experienced no change in the loading of silica (Si) via the Mississippi River since the 1950s when records began



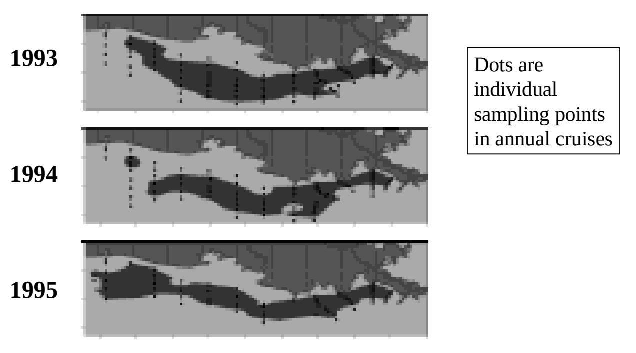
Burkart/James "Geographic distribution of excess agricultural-nitrogen in the Mississippi River Basin" 1999

Figure 1. Hydrologic regions of the Mississippi River Basin.

Where is the hypoxic zone, how big is it now, and how long has the zone been present?

Large areas in shallow coastal waters around North America and other continents, have often been hypoxic in the geologic past. An hypoxic zone has been known to occur regularly in waters from about 15 to 90 feet deep off the Louisiana-Texas shelf in the northern Gulf of Mexico since the 1970s (**Figure 2**). During high-flow years of the Mississippi River, the area can extend from the Mississippi River discharge off southeast Louisiana to just east of Galveston Bay, Texas. In low-flow years, the area is primarily confined to the vicinity of the Mississippi River discharge, referred to as the Mississippi River Bight. The size, location and duration of the hypoxic zone vary within a year and among years (**Figure 3**). In 1988 and 1989, there was hardly any hypoxic area measured, presumably because of low flow from the Mississippi River. In contrast, following the "Great Flood of 1993", the hypoxic zone was measured at a little over 7,000 square miles. In midsummer 1998, the hypoxic zone decreased to about 4,800 square miles, but increased again to 7,728 square miles in midsummer 1999. This represents a little more than one percent of the Gulf of Mexico.

Low subsurface O_2 was documented in locations further offshore in the 1930s. Based on sediment records and historical reports of red and brown (algae/phytoplankton) tides, hypoxia may have been present in the Gulf much longer. The hypoxic zone has been annually monitored off the coast of Louisiana since 1985. A once-per-year, systematic sampling of bottom waters has been conducted in mid to late July because it is thought to be the time of the maximum size of the hypoxic zone and easiest detection.



Dots are individual sampling points in annual cruises

Figure 2. Hypoxic zone off the coast of Louisiana.
Source: Rabalais, Turner and Wiseman. Louisiana Universities Marine Consortium (LUMCON)

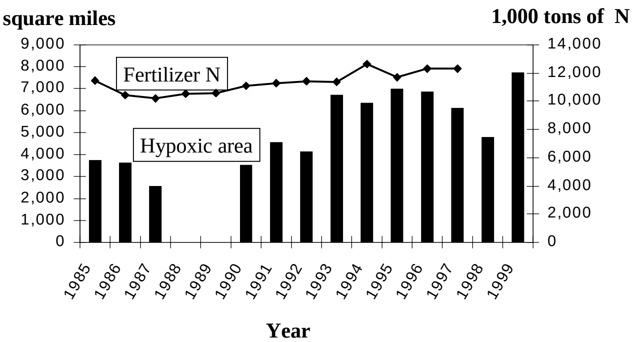


Figure 3. Hypoxic area in the Gulf of Mexico vs. fertilizer N use in the U.S.

Is N discharge from the Mississippi River to the Gulf the cause of hypoxia?

Some marine scientists have suggested that the principal cause of the hypoxic zone in the Gulf of Mexico is NO_3-N discharge from the Mississippi River. One hypothesis promoted is that increased NO_3-N concentration in the lower Mississippi River contributes to an increased biological productivity in the Gulf. The consequence of the increased biological productivity is an increase in organic matter, which falls to the bottom and consumes O_2 during microbial decomposition. These scientists have reported a strong correlation between long-term (1930s to 1988) annual fertilizer N consumption and NO_3-N concentration in the lower Mississippi River. Contrary to the position advanced by some of the more outspoken marine scientists, this strong relationship does **not** mean there is a cause and effect relationship between U.S. fertilizer N consumption and the total quantity of NO_3-N delivered to the Gulf (**Figure 4**). Neither is there a significant relationship between N fertilizer consumption and the size of the hypoxic zone measured since 1985, especially when the 1993 flood year is considered an aberration from the recent trends (**Figure 3**). These data imply that other factors may be more important in affecting the development of Gulf hypoxia than is the N discharge via the Mississippi River. Some of these other factors include:

- changes in precipitation patterns and quantities within the Mississippi River Basin
- increased Mississippi River flow and fresh water stratification over salt water
- complex interactions among marine organisms
- increased or sustained large fisheries harvests
- gulf storms and hurricanes
- tidal currents and their characteristics (temperature, circulation, etc.)
- loss of coastal wetlands (25-35 square miles/year in Louisiana alone)
- nutrients from re-suspended N sediments and upwelling off the Yucatan Peninsula

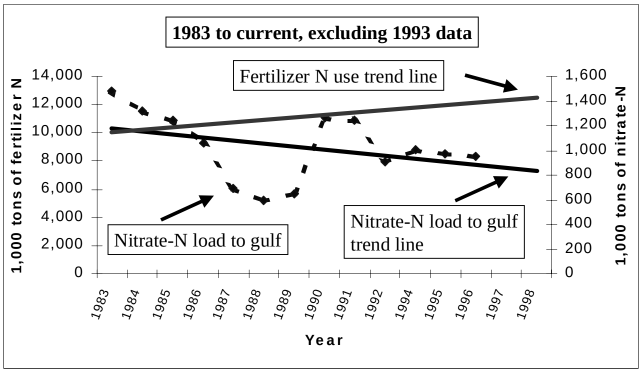


Figure 4. Fertilizer N use and nitrate-N load to the Gulf of Mexico.

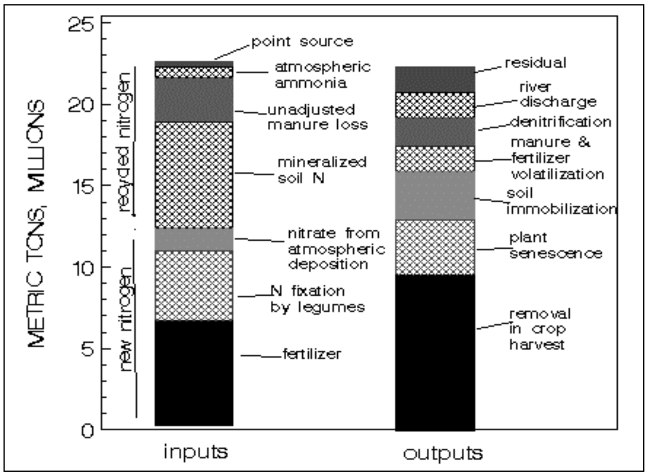


Figure 5. Nitrogen input/output balance in the Mississippi River basin, 1980-1996.

Source: D. Goolsby, USGS

According to the USGS, the discharge of N from the Mississippi River increased 2 to 5-fold between 1900 and the last decade. The annual total N discharge to the Gulf tripled in the last 30 years, with most of the increase occurring from 1970 to 1983. However, the average annual discharge of N has changed very little since the early 1980s. Large year-to-year variations in discharge of N are caused by large variations in precipitation within the Mississippi River Basin (e.g. 1993).

What are all the sources of N to the Mississippi River Basin?

U.S. Geological Survey (USGS) estimates of annual N inputs to the Mississippi River Basin are shown in **Table 1.**

Table 1. Nitrogen Inputs to the Mississippi River Basin.

N Source	Short Tons
Mineralized soil N	7,497,404
Fertilizer N	7,497,094
Legume N fixation	4,445,155
All manure N	3,582,911
Atmospheric wet and dry deposition of nitrate-N	1,461,656
Atmospheric deposition of ammonium-N	663,497
Municipal point sources of N	221,266
Industrial point sources of N	94,370

Based on the USGS model of balancing inputs and outputs of N, estimated annual average output from the Mississippi River Basin is about equal to the average annual inputs (**Figure 5**). The largest output (removal) of N from the Basin is in harvested crops and pastures. Nitrogen in crop harvests accounts for about 46 percent of the total outputs and is nearly 50 percent larger than the fertilizer N inputs.

There is some concern that USGS estimates may involve some “double-counting” for inputs such as soil mineralization and atmospheric deposition, as well as minimum estimates for point source discharges from municipalities and industries. Some evidence shows that agricultural soils are currently net carbon (C) accumulators. As the soil organic C (organic matter) increases, the storage of N must also increase because the C to N ratio of stable soil organic matter is about 10:1. These facts raise questions about the actual quantity of N released through organic matter mineralization.

Six scientific reports have been written for the National Science and Technology Council’s Committee on Environment and Natural Resources (CENR) on the causes and consequences of hypoxia in the Gulf of Mexico. According to one of the reports (*Report 3: Flux and Sources of Nutrients in the Mississippi-Atchafalaya River Basin*), the average Basin discharge of N is estimated at about 4.4 lb/A per year. The magnitude is about three times smaller than the N loss required to raise groundwater NO_3-N levels above current drinking water standards. Thus, the hypoxia concern potentially could demand more conservative use of N than required for protection of groundwater quality.

How much N and P are being lost from farm fields and possibly making their way to the Mississippi River and the Gulf of Mexico?

Surface runoff

Without best management practices (BMPs), the research literature indicates that an average of about 12 percent of the applied N and 8 percent of the applied P may be lost from fields in surface runoff. Stated another way, an average of 88 percent of the applied N and 92 percent of the applied P is not lost in surface runoff. Based on numerous studies, measured losses of N and P in surface runoff are often below 4 and 1 lb/A, respectively, whether applied as fertilizer or as animal wastes. With BMPs (e.g. soil testing, nutrient management planning, appropriate application timing and placement, conservation tillage, vegetative buffers, riparian zones, etc.), the potential for loss from fields can be minimized. Recent work by the USDA-ARS and the University of Missouri has shown that method of incorporation, runoff volume, and timing of runoff relative to date of application had a greater influence on loss of NO_3-N to surface runoff than did application rate (0 to 170 lb/A of N). On average, 6 percent of the applied N was lost in surface runoff. More than 75 percent of the loss occurred within 6 weeks after application on a claypan soil in north-central Missouri with field slopes ranging from 0 to 4 percent.

Placement of P below the zone where the surface soil and runoff water interface minimizes the potential for P loss. Scientists at Kansas State University recently demonstrated that surface runoff loss of P was affected more by placement than by rainfall, tillage system, or time. Among three tillage systems, surface broadcast application resulted in the greatest P runoff loss, while deep-banding resulted in average total P losses only slightly more than the control.

The amount of N in wet atmospheric deposition in the Mississippi River Basin (as reported by the National Atmospheric Deposition/National Trends Program) ranges from 0 to 6 lb/A per year. The amount of N deposited by all precipitation in the Mississippi River Basin varies, but often ranges from 10 to 16 lb/A per year, according to other published reports. Considering the average amount of N lost in surface runoff, it appears that agricultural lands are frequently absorbing/utilizing N deposited by precipitation. Otherwise, the discharge to surface waters would be greater than the amount delivered in precipitation. This has been observed in a 2,775-acre watershed devoted to crop production in the Texas Coastal Bend region. Total rainfall over a three-year period contained 5.5 times more total N than was measured in runoff over the same period.

Subsurface Drainage

The percentage of cropland which is drained in Indiana, Ohio, Illinois, Michigan, Iowa, Missouri, and Minnesota, ranges from 10 to 60 percent, according to a 1998 survey. Research in some of these states indicates significant losses of NO_3-N can occur through subsurface tile drainage. Nitrate-nitrogen losses on the order of 7 to 34 lb/A have been measured in research plots, depending on the N application rate and application timing (fall or spring). Research in Minnesota showed that if wet years follow dry years, the loss of NO_3-N in tile drainage can exceed 40 lb/A per year, when N rates of 150 lb/A were applied yearly. The amount of NO_3-N lost in drainage is directly affected by the amount of precipitation, and when it occurs, relative to the time of N application.

What can be done to maximize uptake of applied N to minimize potential losses to water resources?

If the N rate exceeds the crop uptake demand, the potential for loss increases. Nutrient management planning, based on site-specific yield goals and soil physical and chemical characteristics, can help minimize the potential for loss to surface and ground waters. Keeping P and K levels in the high range ensures optimum N use efficiency by the cropping system and helps to minimize the potential for surface and drainage losses of N.

Conservation tillage, nutrient placement, vegetative buffers, riparian zone establishment, and wetland restoration in strategic locations are other BMPs which complement the basics of site-specific soil testing and nutrient management planning. Nutrient applications can be timed to minimize the potential loss of the more soluble forms of N and P, by avoiding periods of intense rainfall which produce significant runoff. Nitrogen stabilizers may be added to fertilizers to slow soil microbial conversion of ammonium (NH_4) forms to NO_3, but should be evaluated based on local research experience and economics.

Recent soil testing summaries compiled for North America by PPI indicate that 46 percent and 44 percent of the samples submitted to participating private and public laboratories test medium or lower in P and K, respectively. Considerable variation exists among states and provinces, as well as among individual farms, fields, and portions of fields. Data from the National Agricultural Statistics Service show that N, P, and K use efficiency by corn in the U.S. has improved in the last 10 to 20 years (**Figure 6**). With greater attention to balanced plant nutrition and more skillful management, nutrient use efficiency will probably continue to improve.

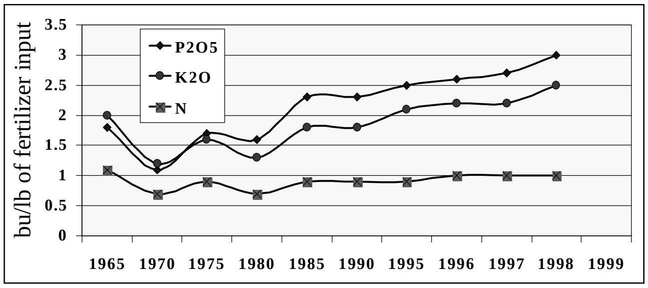


Figure 6. Corn nutrient use efficiency (calculated from National Agricultural Statistics Service data).

Summary

Hypoxia in the Gulf of Mexico is a result of complex interactions among chemical, physical, and biological factors. There are numerous sources of nutrients which may contribute to loading in the Mississippi River. Fertilizer N is an important input for crop production in the Mississippi River Basin, but it is no more likely to find its way to the Mississippi River in runoff and subsurface drainage than other N sources such as precipitation, crop residue and soil organic matter decomposition, animal wastes, sewage sludge and effluent, and composted materials containing N.

In general, farmers are doing a good job of minimizing nutrient losses, but may be able to improve nutrient use efficiencies. Some management changes, for water quality protection/improvement, will result in an increase in expenses and a loss in profits. The voluntary approach to minimizing loss of nutrients to surface waters and the Gulf of Mexico will likely be the most successful. Nutrient management education and research can identify opportunities for improvement. Site-specific nutrient management, considering all nutrient sources in conjunction with other BMPs, can significantly reduce the risk of nutrient loss from many fields. Certified Crop Advisers (CCAs) and other crop consultants can assist farmers in getting the greatest agronomic, economic, and environmental benefits from nutrient applications. These same principles can also be used to reduce nonpoint source nutrient losses in urban settings. ■

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RN 99176

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October 1999

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