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NITROGEN FARMING: HARVESTING A DIFFERENT CROP

BY DONALD L. HEY, PH.D.

There is simply too much nitrogen in the waters of the Mississippi River. The most prevalent form of nitrogen, nitrate-nitrogen (NO_3^-), can cause considerable environmental damage and threaten human health (Martin et al., 1999). Reducing the amount of nitrogen in our rivers and streams has become a pressing environmental problem. While debate exists on how to achieve that reduction, this paper proposes that using restored wetlands as “nitrogen farms” could be a low-tech, viable means to remove nitrates.

Properly managed, wetlands are efficient chemical reactors, dispelling nitrate-nitrogen to the atmosphere as nitrogen gas (a process called “denitrification”). Nitrogen farming would restore land to wetlands and then rely on the natural functions of wetlands to reduce nitrates far more economically than conventional treatment methods. Further, nitrogen farms would prosper where conventional farms falter—on flood prone bottomlands.

EFFECTS OF EXCESS NITROGEN

When babies consume water containing nitrate in excess of 10 mg/l, they risk devel-

oping blue-baby syndrome (methemoglobinemia), which can be lethal in some cases. Nitrate concentrations exceed this threshold at various times throughout the year in streams across the Midwest. Communities with public water supplies affected by nitrate must pay for expensive treatment or, at a minimum, publish alerts in newspapers and post warnings in restaurants and public places informing parents about the risk to their babies.

Excess nitrate also can lead to luxuriant algal growths, or algal blooms, which have a number of adverse effects. Algal blooms can color streams and lakes brilliant green, which detracts from the aesthetic quality of the water. More importantly, the blooms cloud the water, or make it turbid, so sight-feeding fish such as pike and bass have difficulty finding their prey. Turbidity limits the propagation of submerged and emergent aquatic plants. This, in turn, limits the habitat for a wide variety of fauna, from microbes to mammals. When the bloom subsides, the algal cells sink to the bottom and decay. Decomposition of this organic material consumes oxygen in the water, reducing its concentration to near zero in many cases. When this happens, many of the more desirable fauna are driven from the affected body of water or die.

Excessive nitrate also may lead to the propagation of unwanted microbial populations. Scientists believe that these microbes excrete organic polymers that bind suspended silt and clay particles into a flocculent mass, or “floc.” Since the density of the floc is

approximately that of water, it does not readily settle and, when it does settle, does not compress because of the strength and structure of the binding polymers. The first condition exacerbates the problems of turbidity; the second results in a soft, unconsolidated river bottom. Without light penetration and a firm substrate, plant and macroinvertebrate populations do not prosper. This limits the available food and shelter required of higher organisms.

Substantial evidence exists that the higher concentrations of nitrate found in rivers across North America are detrimental to frogs and other aquatic organisms. Concentrations exceeding 1 mg/l have been found to be toxic to frogs, other amphibians, and insects (Rouse, Bishop, and Struger, 1999). The Illinois River, on average, exceeds this threshold three or fourfold.

Unfortunately, the excess nitrogen load is only partially neutralized as it travels through the waters of the Mississippi River. The nitrogen load disperses in the shallow, coastal waters of the Gulf of Mexico, imposing the

same adverse biological and chemical effects as it did in the tributary rivers and streams. Varying in extent from season to season and year to year, dissolved oxygen can be depleted (a condition known as hypoxia) over an area as large as 7,000 square miles (Rabalais et al., 1996, 1998). Hypoxia disrupts the ecological balance and reduces biodiversity of this huge area. It threatens sport and commercial fisheries and the economies of coastal communities.

The problem is enormous and, as might be imagined, the solution could be quite costly. Yet, there is an efficient, self-sustaining solution that could significantly reduce aqueous nitrogen with only minimal governmental intervention and cost: nitrogen farming. This solution involves using wetlands to remove nitrogen and then selling the resulting nitrogen removal credits to those individuals or organizations who are seeking an economical means to compensate for their release of nitrogen. In the following discussion, the sources and transport of nitrogen are explored. The history of agricultural drainage and the loss of wetlands are also discussed, as it is important to understand how this has affected the nitrogen cycle. Alternative means of nitrogen control also are mentioned. Finally, the structure, scope, and benefits of nitrogen farming are presented.

NITROGEN SOURCES

The term “total nitrogen” refers to all the various forms of nitrogen found in water: nitrite-nitrate (NO_2^- - NO_3^-), ammonium (NH_4^+), and organic nitrogen. The focus of this paper is the nitrate ion. In the nitrate-nitrite species, the nitrate ion is of greater importance, since the nitrite ion is relatively unstable and quickly accepts another atom of oxygen to form nitrate. Nitrate is an important nutrient and is readily available to plants—both single cell (e.g., algae) and vascular (e.g., bulrush and corn).

The sources of nitrogen are both natural

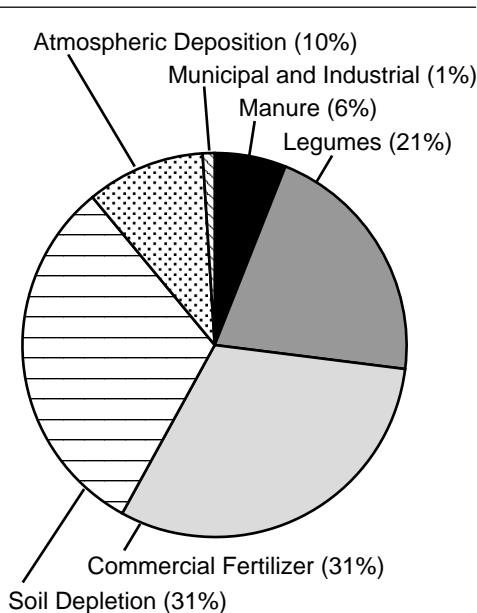


Figure 1. Sources of nitrogen in the Mississippi River basin. (Source: Goolsby et al., 1999)

and cultural. Nitrogen naturally occurs in the soil and air and is leached into the water from both sources (see “atmospheric deposition” and “soil depletion,” Figure 1). Cultural sources include agricultural, industrial, automotive, and municipal activities.

Agricultural sources—including commercial fertilizer, manure, and legumes (e.g., soybeans)—account for 58 percent of the nitrogen present in the Mississippi River basin (Figure 1). Commercial fertilizer makes up the largest component of the agricultural sources, approximately 31 percent. Not surprisingly, the highest use of nitrogen fertilizer occurs in the Corn Belt—Indiana, Illinois, and Iowa (USGS, 1994). The crop production and economic benefits of nitrogen fertilizer are well established. Crop yield increases with increasing rates of application (Hoelt et al., 1999). As yield increases so does gross income. Without fertilizer, typical yield of an acre of corn might be 72 to 75 bushels. With application of 200 pounds per acre of nitrogen fertilizer, the yield could be boosted to over 180 bushels per acre—almost a threefold increase (Figure 2).

The economic importance of nitrogen fertilizer debuted after World War II. From the early 1950s to the end of the 1970s, the use of nitrogen fertilizer increased sixfold (Figure 3). In the early 1950s, annual use of fertilizer was less than 0.5 million metric tons. Thirty years later, the use was close to 7 million metric tons per year.

How does this nutrient get to our streams and surface waters? The modern landscape makes it quite easy. Hundreds of thousands of miles of tile lines underlie agricultural fields, efficiently draining soil and ground water. The tile networks connect to a labyrinth of outlet ditches—canalized replacements of the shallow, plant-clogged swales that once dominated surface drainage in North America. The modern agricultural drainage system moves water from the field to the stream in a matter of hours. In the presettlement landscape, the same quantity

of water required days to move through sluggish swales and debris-clogged, meandering streams. Improved drainage, like nitrogen fertilizer, has increased the productivity of the land. Where wetlands once stood corn now grows prodigiously.

The economic value of agricultural drainage is well understood (Zucker and Brown, 1998). An acre without drainage might yield 60 bushels of corn (Figure 4) while that same acre, with a properly designed surface drain,

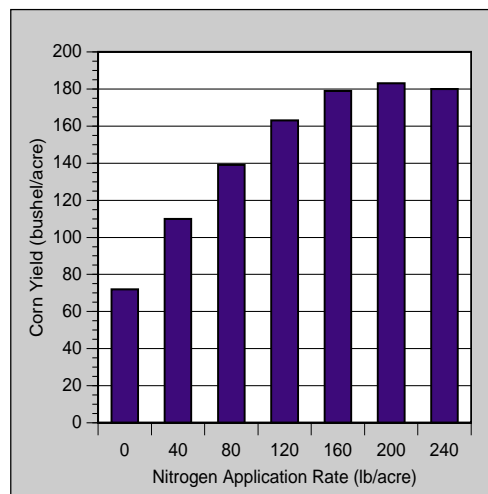


Figure 2. Effect of nitrogen application rate on corn yield. (Source: Hoelt et al., 1999)

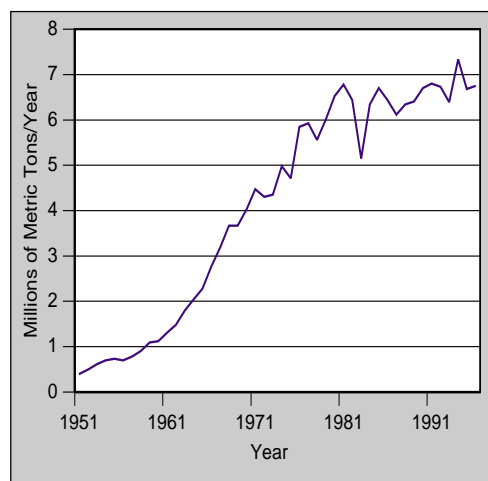


Figure 3. Annual nitrogen input from fertilizer, Mississippi-Atchafalaya River Basin. (Source: Goolsby et al., 1999)

could yield 90 bushels of corn. If the field were under-drained with tiles, the yield might exceed 100 bushels per acre. Combining surface and subsurface drainage, the yield could be boosted to more than 120 bushels per acre. The bottom line is that drainage

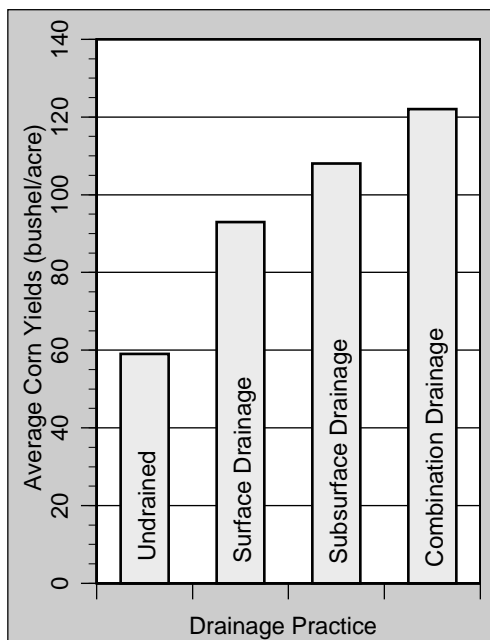


Figure 4. Effect of drainage intensity on corn yield. (Source: Zucker and Brown, 1998)

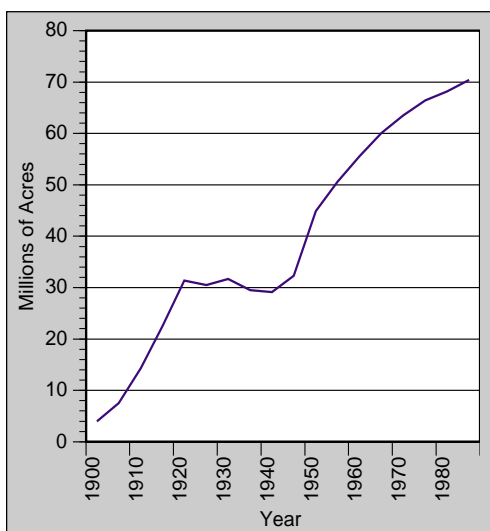


Figure 5. Land area drained in the Mississippi-Atchafalaya River Basin. (Source: Mitsch et al., 1999)

doubles the yield—an economic reality that has not been lost on the American farmer.

While the importance of drainage was recognized by the middle of the 19th century, land drainage did not start in earnest in the Midwest until the turn of the 20th century. Only 30 million acres of land had been drained in the Mississippi basin by the 1920s (Figure 5). During the Depression and World War II, drainage activity all but stopped. Following the war, agricultural drainage expanded dramatically. By the 1980s, the area drained in the Mississippi basin increased by 2.5 times, to more than 70 million acres.

WETLANDS AND NITROGEN

The expansion of agriculture and drainage produced a dramatic loss of wetlands. According to Dahl (1990), more than 66 million acres of wetlands in the Mississippi basin were lost from the 1780s to the 1980s (Table 1). [This figure differs from the more than 70 million acres figure given above for land drained, which included upland areas as well as wetlands.] The loss of wetlands (Figure 6), in itself, had a profound effect on the nitrogen load emanating from the Mississippi basin. The vast expanse of these drained wetlands—covering an area larger than Illinois and Indiana combined—no longer trapped organic material nor reduced aqueous nitrogen. Rather, these lands now produced nitrogen through oxidation of soil organic matter, surface erosion, and soil leaching.

The geographical relationship among drained wetlands (Figure 6), nitrate-nitrogen yield (Figure 7), and fertilizer usage (Figure 8) is striking, but not surprising. The nitrate yield is the highest where the most wetlands have been lost and nitrogen fertilizer is heavily used. For example, the Illinois River yields 126,000 tons per year of nitrogen or 12 percent of the load reaching the Gulf of Mexico. The Illinois River watershed, however, accounts for only 2.3 per-

cent of the Mississippi River basin's total area. More than 90 percent of the wetlands in the Illinois River basin have been drained. Fertilizer use is enormous: 45 million tons in 1995. As fertilizer use and drainage increased, the nitrite-nitrate concentrations in the Illinois River changed in magnitude and distribution. At the end of the 19th century, concentrations of nitrate and nitrite in the Illinois River averaged less than 1.5 mg/l, with the January through March period having the lowest concentrations and the October through December period having the highest (Figure 9; Palmer, 1902). By the late 1980s, the concentrations averaged more than 5 mg/l, ranging from 3 to 6.5 mg/l with the highest concentrations occurring in the April through June period and lowest concentrations in the July through September period (Figure 9; USGS, 1989, 1990, 1991). Both the concentration and seasonal distribution of nitrate has been changed.

Historical trends are not the only evidence of the critical role that wetlands play in nitrogen removal. Recent research has documented that anaerobic bacteria in wetlands can remove approximately 80 percent of the nitrate in wetlands (Hey, Barrett, and Biegen, 1994).

NITROGEN CONTROL

There is little argument about the need to reduce nitrogen in our surface waters. The debate focuses on how best to accomplish the task. Some argue that less nitrogen fertilizer should be used, while others propose on-farm controls (such as reducing surface runoff and tile drainage) during the non-growing season. These controls would also reduce soil erosion, which is also of concern.

For obvious economic reasons, the potential for reducing fertilizer usage and farm drainage is limited, since such reductions would adversely affect farm income. Currently, the farmer faces no legal requirement or economic incentive which might guide his/her behavior in this regard. The water quality problems of

the Mississippi River basin are not of immediate enough concern to persuade the farmer to voluntarily reduce fertilizer usage. Even if possible to implement, reducing the use of fertilizer and other on-farm practices would lead to only a 20 percent reduction in the nitrogen

Table 1. Wetland losses (x10³) in Mississippi River basin states. (Source: Dahl, 1990)

State	Area in 1780 (acres)	Area in 1980 (acres)	Loss (acres)
Louisiana	16, 195	8,784	7,410
Arkansas	9,849	2,764	7,085
Illinois	8,212	1,255	6,958
Minnesota	15,070	8,700	6,370
Mississippi	9,872	4,067	5,805
Indiana	5,600	751	4,849
Ohio	5,000	482	4,517
Wisconsin	9,800	5,331	4,469
Missouri	4,844	643	4,201
Iowa	4,000	422	3,578
North Dakota	4,928	2,499	2,429
Oklahoma	2,843	950	1,893
Kentucky	1,566	300	1,266
Tennessee	1,937	787	1,150
Nebraska	2,911	1,906	1,005
Colorado	2,000	1,000	1,000
South Dakota	2,735	1,780	255
Wyoming	2,000	1,250	750
Kansas	841	435	406
West Virginia	134	102	32
Total	110,335	44,208	66,127

Note: Small parts of other states are in the watershed, but their wetland losses, relative to the 20 listed, are insignificant, and some parts of the listed states are outside the watershed.

load (Mitsch et al., 1999). However, a 70 percent reduction in the nitrogen load is needed to reduce the extent of hypoxia and other nitrogen-related problems.

An alternative method for controlling

nitrogen is the restoration of wetlands. Recently, this idea was promoted by a group of scientists as a result of a study, sponsored by the National Oceanic and Atmospheric Administration, on hypoxia in the Gulf of



Figure 6. Percentage of wetlands lost, 1780-1980.

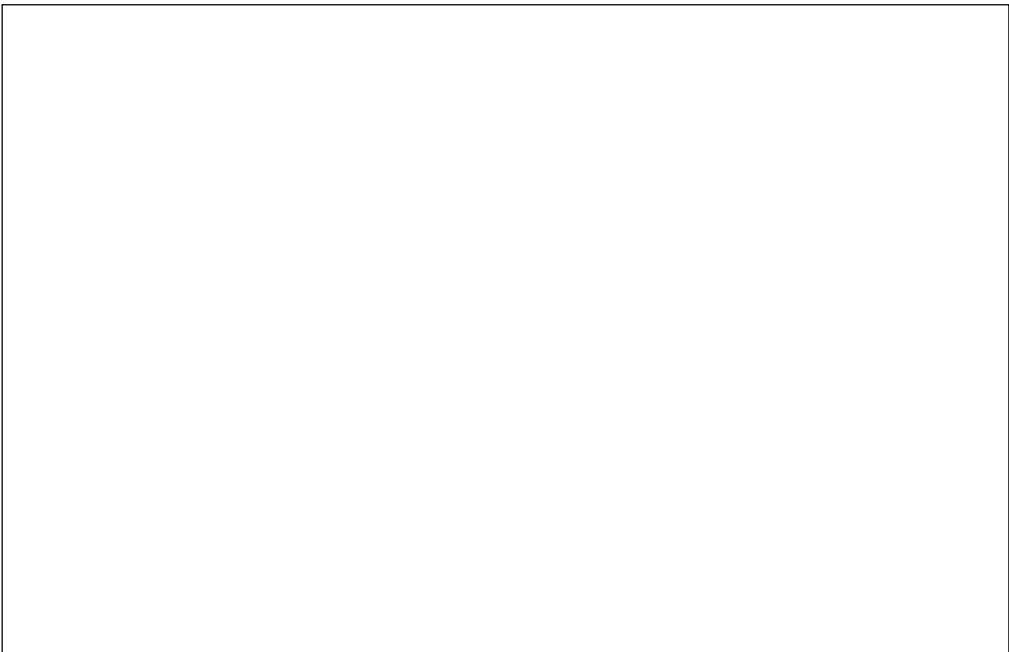


Figure 7. Estimated nitrate-nitrogen yields in the Mississippi River basin, 1980-96.

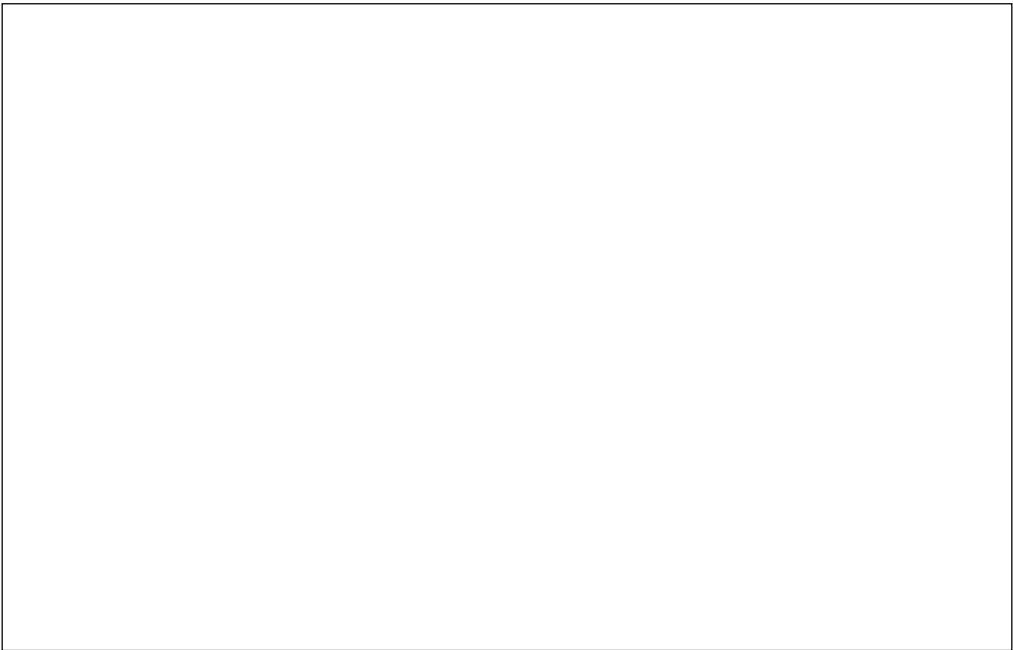


Figure 8. Nitrogen fertilizer use in the Mississippi River water-

Mexico (Mitsch et al., 1999). The scientists estimated that 24 million acres of restored wetlands and riparian buffers are needed to control the nitrogen problem. Where appropriate, other control techniques were also recommended, including reduction of fertilizer application, on-farm drainage controls, and buffer strips to intercept surface drainage.

If restored wetlands were to be the major means of controlling nitrogen, how would restoration be financed? Seemingly, the cost would be enormous. To acquire, restore, operate, and maintain 24 million acres of wetlands, the cost could exceed \$40 billion. This would yield an annual cost of approximately \$2.7 billion.

One approach to financing wetland restoration could be nitrogen farming, a simple, low-tech solution to nitrogen removal. Nitrogen farming involves flooding land with nutrient-rich water for a period of time sufficient to achieve denitrification—about six to eight days. A nitrogen farm can be established wherever there is sufficient water, adequate soils (i.e., hydric soils, which

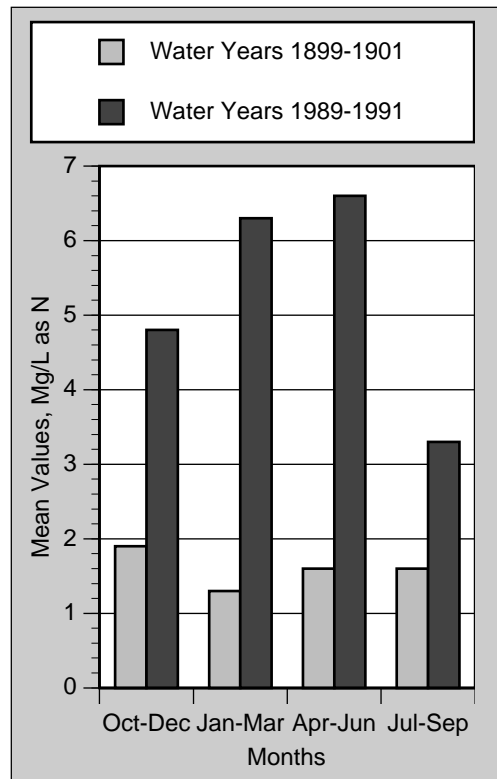


Figure 9. NO₂⁻-NO₃⁻ concentrations in the Illinois River near Peoria. (Source: Palmer, 1902; USGS, 1989, 1990, 1991)

naturally form under wetlands), and energy (i.e., gravitational or electrical) to achieve and maintain inundation. Wetland microbes would strip and consume the oxygen atoms from the nitrate molecule, releasing nitrogen gas (N_2) to the atmosphere. The farmer's "harvest" of this gas would be recorded as credits, quantified by the tons of nitrogen removed from the water. The credits, in turn, would be sold to industries, municipalities and farmers discharging excessive amounts of nitrogen, and, presumably, to the highest bidder among these groups.

For example, some farmers may choose to continue high yield corn production, releasing large quantities of nitrogen to surface waters. To mitigate the environmental harm and to pay the external costs of production, these farmers would purchase credits from a nitrogen farmer in the affected watershed. Municipalities and industries discharging nitrogen could make similar purchases, thereby establishing a nitrogen trading market.

Such a market would direct financial resources to the most efficient farms, or producers of the lowest priced credits. It would support the continued private ownership of small farms, given that a nitrogen farm could be economically established, and that the economies of scale would not be too great. Accepting the idea that nitrogen farms are the most efficient means of nitrogen control and that a modicum of government regulation is necessary, market forces would define the methods, location, and scale of nitrogen farming.

The government (federal and state) will need to set nitrate standards that will serve to guide improvement and protection of water quality. Further, government control would be needed to define market areas within which credits could be produced and purchased. For example, unacceptable environmental harm could result if a buyer acquired credits from a farmer a long distance (up or downstream) from the buyer's point of discharge or from a farmer outside the affected watershed. The buyers of credit would not

have to raise the capital to build nitrogen controls, nor would they have to meet the operating costs or lose productive land for on-site controls. Past and future credit sales would fund the development and operation of nitrogen farms.

Before credits can be produced and sold, the nitrogen market needs to be established. The U. S. Environmental Protection Agency (USEPA) is about to create the necessary conditions for this. The agency is currently studying criteria that will be used to strengthen nutrient standards for surface and ground waters by all states. Once established, all states, Indian tribes, and territories will be required to enact the standards and develop implementation procedures that will result, with reasonable assurance, in the standards being met. The term "reasonable assurance" implies that the control of both point sources (e.g., municipal) and nonpoint sources (e.g., agricultural runoff) will contribute to meeting the standards. The inclusion of nonpoint sources is a significant change to the existing regulatory procedures.

Another necessary change for nitrogen farming to work is the explicit recognition that the nutrient standards need not be met in all stream reaches. This recognition would enable a nitrogen farmer to transport—via a farm ditch or stream—nutrient-rich water from its source to the nitrogen farm. Similarly, some cities, such as Chicago, are located in the headwaters of their drainage basins where there is little opportunity for nitrogen farming. Thus, if their effluent requires denitrification, it would be necessary to transport their nitrogen-rich water to nitrogen farms downstream, rather than treat the water locally.

Although 24 million acres dedicated to wetland restoration sounds like a prohibitively large amount of land, consider that in 1999 more than 22 million acres of the Mississippi River basin, which were formerly crop lands, were idle. These lands were enrolled in the U. S. Department of Agriculture's price control

program, the Conservation Reserve Program (CRP). The USDA spends \$1 billion per year on CRP to keep these lands fallow. If these CRP funds could be used to establish nitrogen farms, then commodity price control and nitrate reduction would be advanced simultaneously.

ILLINOIS RIVER SOLUTION

The solution to the Gulf of Mexico hypoxia problem starts in the small tributaries of the Illinois River. From 1980 to 1996, the average nitrate load reaching the Gulf of Mexico was 1.05 million tons per year (Goolsby et al., 1999). Of this, the Illinois River contributed 126,000 tons, or 12 percent (Meade, 1995). Relative to its land area, the Illinois River contributed a disproportionately large share; the Illinois watershed comprises only 2 percent of the Mississippi River watershed. Similarly, the Illinois River accounts for only 3 percent of the water discharged into the Gulf of Mexico from the Mississippi River (Table 2).

To accomplish a significant reduction in the nitrate load reaching the Gulf of Mexico, only a small portion of the Illinois watershed would need to be converted

to nitrogen farms. These could be operated on less productive, flood prone bottomland throughout the watershed. This solution would cost far less than conventional means of treat-

ment and those contributing to the problem would pay for its solution.

How much nitrate need be removed? The answer to this question has not been deter-

Table 2. How the nitrate load of the Illinois River impacts the Mississippi River and how wetland restoration in the Illinois River offers solutions

	Mississippi River	Illinois River	% from Illinois River
Load of NO ₃ ^D as N to Gulf of Mexico (tons/yr)	1,050,000	126,000	12%
Drainage area (acres)	805,000,000	18,500,000	2%
Mean daily discharge (cfs)	898,000	31,400	3%
Mean NO ₃ ^D concentration (mg/l)	1.19	4.09	
Pre-1970s load to the Gulf (tons/yr)	350,000		
Required load reduction (tons/yr)	700,000	100,000	14%
Resulting mean concentration of NO ₃ ^D (mg/l)	0.40		
Proposed solution for the Illinois River			
Target load (Pre-1900 NO ₃ ^D concentrations, mg/l)		0.80	
Acceptable load (tons/yr)		24,600	
Load to be removed (tons/yr)		101,000	80%
Percent of load reduction to Gulf of Mexico			14%
Flow to be processed (cfs)		31,400	
Flow to be processed (mgd)		6,760	
Wetland area required (acres); % of watershed		407,000	2%
Flood prone area (acres)		1,280,000	
Required wetlands as percent of flood prone area			32%
Wetlands drained (acres)		4,170,000	
Required wetlands as percent of wetlands drained			10%

mined, and may never be, but a general idea of the magnitude can be obtained by considering the nitrate load prior to the 1970s when hypoxia was not so acute. Since then, nitrate loads

to the Gulf of Mexico have increased by three-fold (Goolsby et al., 1999); thus, the nitrate load 30 years ago would have been approximately 350,000 tons per year (Table 2). To achieve this load today, 700,000 tons per year would need to be removed. This, then, leads to the question: how much of the load can be reduced by actions taken in the Illinois River watershed?

Assuming the concentration of nitrate in the Illinois River could be reduced to the level observed at the turn of the century (<1.0 mg/l; Palmer, 1902), then the reduction in the load from the Illinois River would be approximately 100,000 tons per year. This would represent 14 percent of the needed load reduction or 10 percent of the total nitrate load reaching the Gulf. Based on research results (Hey, Barrett, and Biegen, 1994), approximately 400,000 acres of restored wetlands could accomplish this task.

This is a large area, yet, viewed from several different perspectives, it is not an unrealistic use of the land resources of the watershed. For example, this acreage is less than 2 percent of the total watershed area and only 32 percent of the watershed's flood prone area. In addition, the restored wetlands would account for only 10 percent of the wetlands that were drained over the past 200 years, mostly for agricultural production.

The land and restoration costs for 400,000 acres of nitrogen farms would amount to approximately \$770 million. Annualizing this cost and adding the annual cost of operation and maintenance results in a total annual cost of \$55 million. This cost is considerably less than if conventional biological or chemical treatment were used. To do the same job, the conventional method of treatment, involving concrete tanks, pumps and chemical and electrical energy, could cost over \$110 million per year—not including the cost of land and sludge disposal (Dahab, 1987; USEPA Office of Water, 1999). The cost of conventional treatment is at least twice that of wetland treatment

and conventional treatment does not provide flood damage reduction, wildlife habitat, and the many other benefits of wetlands.

The cost of nitrogen control need not be borne by the farm community alone. Industries and municipalities should pay their fair share, covering their contributions of nitrate from point and nonpoint sources. The CRP, properly focused, would cover a large share of the capital cost (i.e., land purchase or lease). Fertilizer manufacturers also might be expected to pay a share. As the nitrogen trading market develops, the price of nitrogen credits should fall. Contributing to this fall could be other sources of revenue generated simultaneously with nitrogen removal: phosphorous removal, carbon sequestration, sediment trapping, and flood storage.

CONCLUSION

Because of the public health and environmental concerns about nitrates, restored wetlands will have a greater economic value when the USEPA establishes nutrient standards and the states adopt related regulations. The economic worth of restored wetlands should increase then, and, at the same time, wetland restoration should expand. Nitrogen trading would establish a market-based solution to the nitrogen problem and, at the same time, create an economic structure to solve other problems including erosion, flood control, declining habitat and wildlife diversity, and limited, high quality open space (Table 2).

For example, the flood of 1993, which caused, by some estimates, \$16 billion of damage, could have been contained within 13 million acres of restored wetlands in the upper Mississippi basin (Hey and Philippi, 1995). If these additional wetlands had existed, the flood damages and adverse water quality impacts could have been greatly reduced, and wildlife habitat and recreational opportunities greatly enhanced. The 13 million acres of restored wetlands would represent about half the esti-

mated wetlands and riparian corridors needed to reduce hypoxia in the Gulf of Mexico.

Nitrogen farming is a viable means of meeting the Federal Clean Water Action Plan for restoring and protecting America's waters. The cost and efficiency of nitrogen farming needs to be assessed through pilot projects. TWI is exploring several such projects in the Illinois River watershed.

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53 WEST JACKSON BOULEVARD, SUITE 1015

CHICAGO, ILLINOIS 60604-3703


PHONE (312) 922-0777

Fax (312) 922-1823

email: twi@wetlands-initiative.org

The Wetlands Initiative is a non-profit corporation dedicated to restoring the wetland resources of the Midwest to reduce flood damages, improve water quality, and increase wildlife habitat and biodiversity. Our mission is to promote restoration in ways that provide environmental and economic benefits to society and the landowner. Through research, education, public policy analysis, and large-scale demonstration projects, TWI aims to restore one million acres by the year 2010. While this number may seem large, it represents only 2 percent of the wetlands lost in the Midwest.

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THE WETLANDS INITIATIVE

53 WEST JACKSON BOULEVARD, SUITE 1015

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