



Nutrient farming: The business of environmental management

Donald L. Hey*, Laura S. Urban, Jill A. Kostel

Senior Vice President, The Wetlands Initiative, 53 W. Jackson Blvd., #1015, Chicago, IL 60604, USA

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Abstract

Restored wetlands could be used successfully to address our recurring problems of excess nutrients (and sediments) and flood damages along U.S. rivers. Credit markets for flood storage, nitrogen, phosphorous, carbon, atrazine, sediment, and many other constituents would economically motivate landowners to restore wetlands. The resulting high-quality open space would provide for recreation, wildlife habitat, and biodiversity. By instigating the market for nitrate-nitrogen, we can jumpstart the entire process of using markets to manage ecosystems. The nitrogen market will create a new land-economics paradigm and new opportunities for landowners, particularly farmers.

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1. Introduction

Our nation can address and ameliorate several major ecosystem problems (e.g., flooding, excess nutrients, habitat loss) by restoring wetlands. Restored wetlands can store floodwaters, remove excess nutrients, and provide wildlife habitat. Furthermore, we can finance this restoration by creating nutrient removal credits and selling or trading them to dischargers who need to meet water quality standards. These credits, bought or sold on an open market or through long-term contracts, could offset wetland losses due to agricultural, industrial, commercial, or residential development, while providing high-quality open space

for recreation, wildlife habitat and biodiversity. The Wetlands Initiative calls this strategy of creating a marketplace for nutrient credits “Nutrient Farming.” In comparison to other credit-based programs that focus on watershed trading opportunities between municipalities (Moore et al., 2000) or point and non-point sources (Johnson et al., 2001), nutrient farming centers on the use of wetlands to remove excess nutrients.

One of the easiest ecosystem commodities to generate, monitor, and manage is aqueous nitrate–nitrogen ($\text{NO}_3\text{-N}$). Wetlands do not sequester nitrate; they remove it largely through denitrification (Mitsch and Gosselink, 2000). An anaerobic biological process, denitrification reduces inorganic nitrate (NO_3^-) and nitrite (NO_2^-) to nitrogen gas (N_2). The biological process is dependent on the microbial communities present in the wetlands. Gaseous nitrogen volatilizes, thus ni-

* Corresponding author.

E-mail address: dhey@wetlands-initiative.org (D.L. Hey).

trogen is eliminated as a water pollutant. Nitrogen gas is relatively inert, so its release to the atmosphere poses no danger; in fact, nitrogen comprises 78% of the atmosphere. To a lesser extent, nitrate is also removed from water by assimilative nitrate reduction, where nitrate is reduced to ammonia, which serves as a nitrogen source for growth by plants, fungi, and bacteria.

A viable nitrogen credit market will readily demonstrate the economic value of land for purposes other than corn production, housing, or commercial development. The nitrogen market will monetize ecosystem services for water quality management. This precedent will facilitate monetizing phosphorous control, flood storage, wildlife management, and many other ecosystem services. The nitrogen market will create a new land-economics paradigm. It will create new financial opportunities for landowners, particularly farmers, and lessen the agricultural community's dependence on government subsidies, while bringing an equitable resolution to the problem of non-point source pollution.

2. Excess nutrients

The modern landscape (e.g., the Upper Mississippi River Basin) suffers from degraded water quality, excessive flood damage, decimated wildlife populations, and declining biodiversity. The impact of landscape modifications in this basin also directly affects other regions. For example, the hypoxic zone in the northern Gulf of Mexico has nearly doubled in size in the past two decades. The hypoxic area averaged 8300 km² in 1985–1992 and increased to approximately 16,000 km² in 1993–2001 (Rabalais et al., 2002). Explanations for the increased size of the hypoxic zone have varied, but the increase is principally attributed to an almost three-fold increase in nitrogen load to the Upper Mississippi River Basin since 1950 (Goolsby et al., 1999). Hypoxia, or oxygen depletion, is the result of the overenrichment of nitrogen, mainly nitrate–nitrogen, which increases algal production within this aquatic ecosystem. The decomposition of the dead algae leads to the low dissolved oxygen concentrations (<2 mg/L O₂). During the late spring and early summer months, the low dissolved oxygen concentrations force fish and other mobile aquatic organisms to flee the regions of low oxygen, while less mobile organisms are killed. High nitrogen concentrations have been linked to

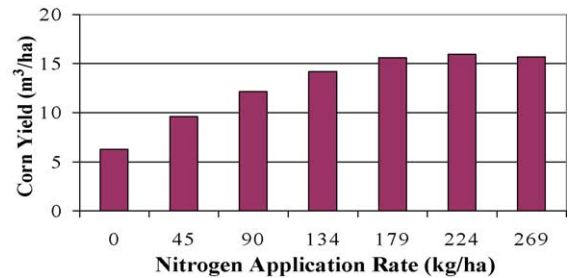


Fig. 1. Effect on corn yield of nitrogen application rate (Hoefl et al., 1999).

human and ecological health effects, including blue baby syndrome and increased risks of cancer (Weyer et al., 2001). In addition to the excess nitrogen loading, wetland loss and more efficient drainage practices have contributed to the hypoxia problem.

Agricultural practices are the principal sources of nitrogen to the basin as the use of commercial fertilizers, the application of manure, and the production of legumes (e.g., soybeans) contribute to the increased nutrient concentrations (Goolsby et al., 1999). In the Mississippi basin, 31% of the nitrogen load to the Gulf of Mexico comes from the fertilizer applied to agricultural lands. Corn yields have increased as nitrogen fertilizer application rates have increased (Fig. 1). Hoefl et al. (1999) found a 2.5 increase in corn yield with application of 224 kg/ha (200 lbs/acre) of nitrogen fertilizer compared to crops with no fertilizer. This increase in yield is not merely theoretical; annual use of nitrogen fertilizer has increased six-fold since 1950 in the Mississippi–Atchafalaya River Basin (Fig. 2).

While use of nitrogen-based fertilizers in the basin has increased, so has hydraulic efficiency of the

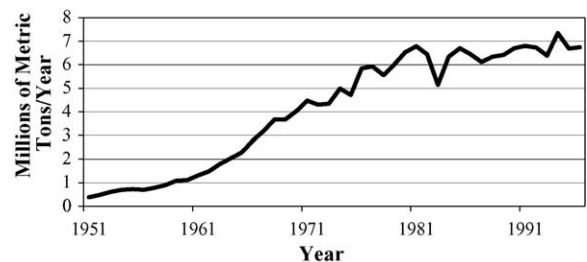


Fig. 2. Annual nitrogen input from fertilizer, Mississippi–Atchafalaya River Basin (Goolsby et al., 1999).

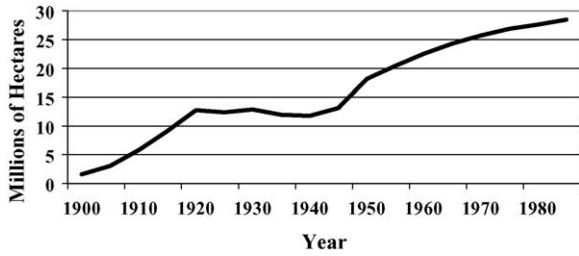


Fig. 3. Land area drained in the Mississippi–Atchafalaya River Basin (Mitsch et al., 1999).

watershed. By the 1980s, more than 28 million ha (70 million acre) in the Mississippi Basin had been drained by extensive systems of drain tiles and outlet ditches (Fig. 3). These systems were constructed to move surface and groundwater out of agricultural fields efficiently. Field drainage directly impacts corn yield (Fig. 4). A hectare (acre) without drainage might yield 2.1 m³ (60 bushels) of corn, whereas the same hectare

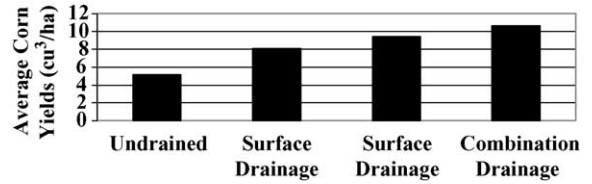


Fig. 4. Effect of drainage intensity on corn yield (Zucker and Brown, 1998).

with a properly designed surface drainage system could yield 3.2 m³ (90 bushels) of corn (Zucker and Brown, 1998).

Many, but not all, of the drained areas had once been wetlands. Not surprisingly, as drainage has increased, total wetland area in the basin has decreased. Dahl (1990) estimated that six Upper Mississippi River Basin states—Iowa, Missouri, Illinois, Indiana, Ohio, and Kentucky—lost 80–90% of their wetlands from 1780 to 1980 (Fig. 5). This is approximately the same region with the highest fertilizer usage (Fig. 6). Conse-

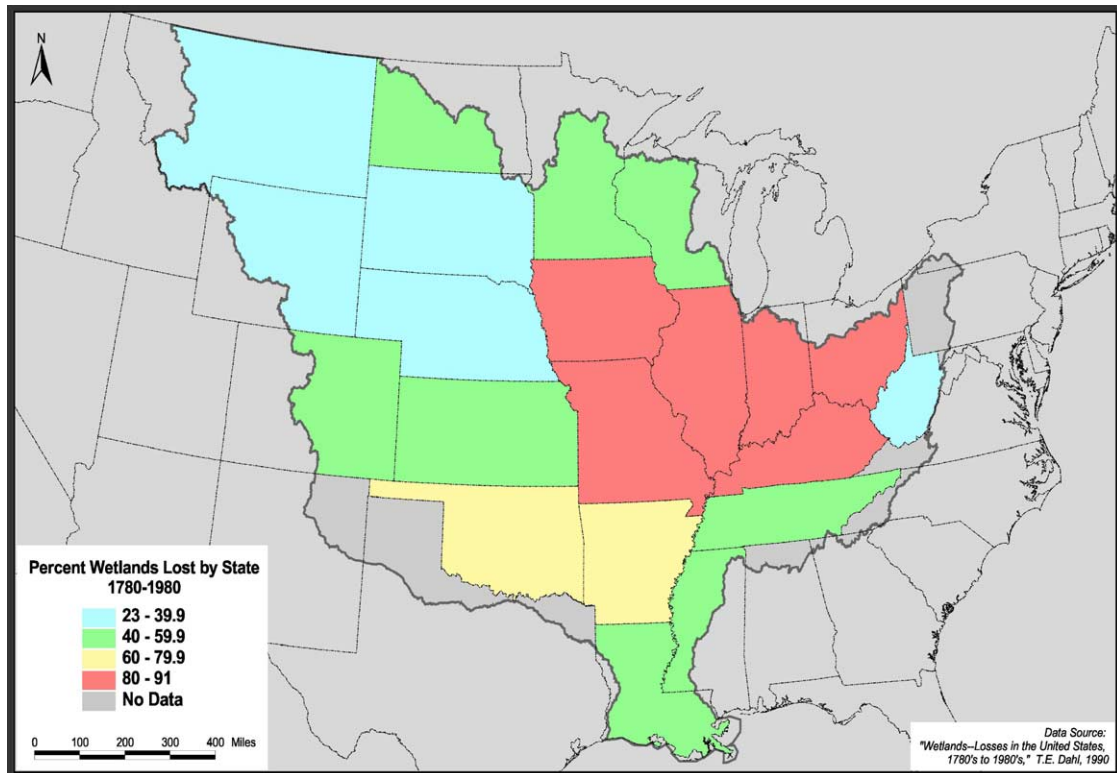


Fig. 5. Percentage of wetlands lost, 1780–1980 (Dahl, 1990).

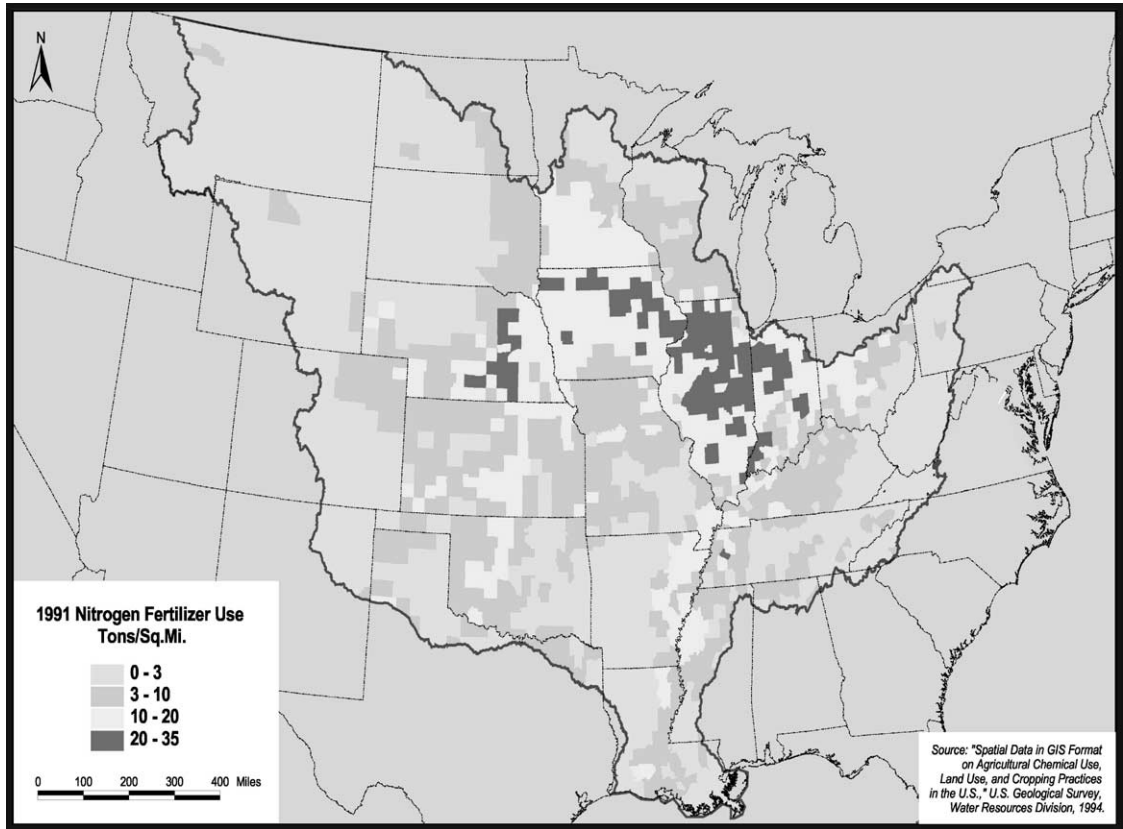


Fig. 6. Nitrogen fertilizer use, 1991 (USGS, 1994).

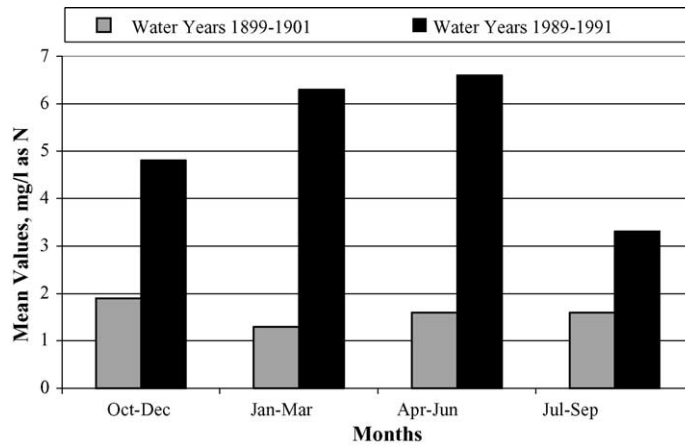


Fig. 7. Nitrite–nitrate concentrations in the Illinois River near Peoria (Palmer, 1902; USGS, 1989–1991).

quently, these regions typically have streams and rivers with highly elevated nitrite–nitrate concentrations due to both non-point and point discharges. For example, the nitrite–nitrate concentrations in the Illinois River near Peoria have changed in magnitude and distribution. Mean concentrations have increased from 1.9 to 6.5 mg/l over the past 100 years. At the same time, the highest seasonal concentrations shifted from fall to spring (Fig. 7).

Past efforts have failed to persuade farmers to reduce fertilizer usage and limit runoff from their fields. The reason for these failures is simple: the farmer was not been adequately compensated. For example, crop yield reduction would not be offset by an increase in price. The farmer clearly understands that fertilizers and drainage affect income, but designers of past regulatory programs have not realized this economic reality.

3. Flooding

Mean annual national flood damages have been steadily increasing; now approximating US\$ 3.4 billion (Fig. 8). This rise has occurred despite a similar rise in control costs (Fig. 9). The need for flood storage was never more apparent than during the 1993 floods on the Mississippi River and its tributaries when flood losses were US\$ 16 billion (Richards, 1994). Floodwalls at St. Louis would have been overtopped if numerous levees upstream had not failed, allowing the accumulated floodwaters to inundate former floodplain areas. At the time, owners of failed levees likely gave little

thought to the economic value of their flooded property as a place to store floodwaters. Had upstream levee districts been organized and downstream owners well informed, a market for floodwater storage certainly would have flourished in the late spring and summer of 1993.

Avoiding these losses would have necessitated an additional 49 billion m³ (40 million acre-ft) of flood storage. Based on resulting damages from the 1993 flood, a cubic meter of storage would have been worth US\$ 0.33. Assuming that the floodwaters had been stored in shallow (less than 1 m deep) wetlands located behind the levees, 5.3 million ha would have been required. The rental rate for the 1993 event would have yielded US\$ 486/ha, a handsome sum, since most agricultural land in the Midwest rents for US\$ 40–60/ha. If floodwaters were stored in deeper pools behind levees, the unit-area rental rate would be even higher. The probability of a flood equaling the magnitude of the 1993 occurrence is 0.01 (1%) in any given year, so the projected value of damages would be approximately US\$ 160 million (US\$ 16 billion \times 0.01). This would result in an annual value of only US\$ 5/ha for a wetland flood-storage credit. If floodwater could be stored to a depth of 4.5 m, however, the value would be US\$ 24/ha/year. This income would be in addition to the normal income from farming or other activities that would only rarely be interrupted.

4. Solution

The scale of wetland restoration needed to solve current nutrient, sediment, and flood control problems is

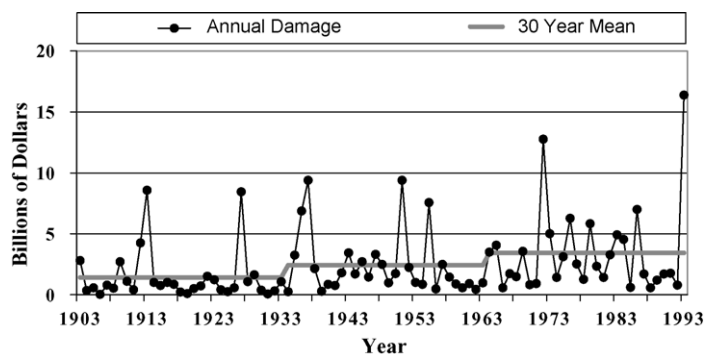


Fig. 8. National Annual Flood damages, 1993 dollars (Richards, 1994).

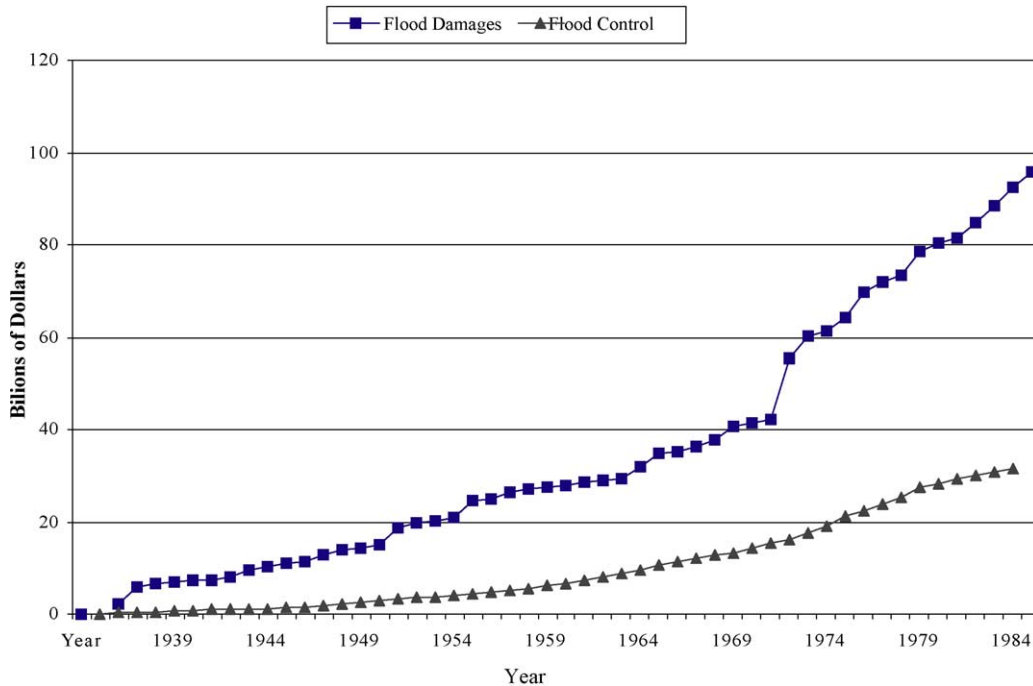


Fig. 9. Cumulative Flood Damage and Control Costs (1985 Dollars) (U.S. Weather Bureau and U.S. Army Corps of Engineers).

enormous. In the Mississippi River basin, for example, an estimated 2–5.3 million ha of restored wetlands would be required to stem the flow of nitrogen to the Gulf of Mexico, which, in turn, would diminish the hypoxic zone (Mitsch et al., 2001). The job is too enormous to be completed solely by government grants; market-based solutions are needed.

Our proposed strategy, called “nutrient farming,” could overcome the lack of economic incentive. This strategy involves converting lowlands from corn production to that derived from wetlands. The wetland accepts the inflow of nitrogen-laden water from upstream and discharges low-nitrogen water downstream. Through the inherent biogeochemical and physical processes in the wetland, a high percentage of nitrogen and phosphorus would be removed, depending on the location and size of the wetland. The farmer would record the amount removed, which would then be certified by the state. This is similar to the current self-monitoring practice used by operators of water reclamation plants who must provide daily monitoring reports to federal and state regulatory agencies. Once the

farmer received state certification, he/she would be free to sell certified nitrogen credits on the open market or through long-term contracts. Buyers of nitrogen credits might be other farmers, municipal and industrial dischargers, or other industries that release nitrogen and phosphorus to the atmosphere or aquatic ecosystems through point or non-point emissions (agriculture, automobile, manufacturing, etc.). Nutrient farming could create a market where the services of nutrient farming could be bought and sold, thereby creating a whole new economic structure for farming that focuses on optimal resource allocation and economic efficiency. Nutrient farming provides an alternative income for farmers.

Based on a preliminary investigation, the cost of producing a metric ton of nitrogen credit at a wetland nutrient farm would be approximately US\$ 2500 (Hey et al., in press). This covers the costs of the land and wetland restoration, as well as the labor and materials needed to operate the nitrogen farm. The true cost of corn production should include a per metric ton surcharge on applied fertilizer because the drainage re-

Table 1
Total annual cost comparison between wetlands and water reclamation plant (WRP) treatment (Hey et al., in press)

Criteria Limit	Wetland Area (ha)	Total annual cost (US\$)				Total annual cost with sale of excess credits (US\$)			
		Wetland total	WRP total	Savings	% ^a	Wetland total	WRP total	Savings	% ^a
3.0 mg/l TN	76,500	63,900,000	174,000,000	110,000,000	63	40,900,000	174,000,000	133,000,000	76
1.0 mg/l TP									
2.18 mg/l TN	130,000	103,000,000	211,000,000	108,000,000	51	46,000,000	211,000,000	164,000,000	78
0.5 mg/l TP									

^a Percent savings compared to WRP total annual costs.

moves approximately one-third of every metric ton of fertilizer applied to a crop. Therefore, a farmer should be required to purchase nitrogen credits for that third of a metric ton sent downstream. This could add US\$ 830 (one-third of the US\$ 2500 cost to remove nitrogen) to the farmer's per metric ton cost of fertilizer (currently US\$ 181).

Considering just the potential market available from farmers buying credits for their fertilizer usage, the market size is considerable. In 1998, for example, United States farmers purchased an estimated 11.3 million Mt of nitrogen fertilizer (FAO, 2002) at US\$ 181/Mt (TFI, 1960–2000) for a total cost of US\$ 2 billion. Assuming that one-third of the fertilizer entered the drainage system, then almost 4 million metric tons of nitrogen credit would have been required to offset the load on a 1:1 basis. The value of these credits would total US\$ 10 billion annually (4 million metric tons of credit × US\$ 2500/Mt removal).

Another, more immediate nitrogen credit market exists for industrial or municipal point source dischargers. To meet USEPA criteria for nitrogen and phosphorous, U.S. wastewater treatment plants must be upgraded. The cost of conventional treatment technology to remove nutrients to near-criteria levels was estimated for the Illinois Association of Wastewater Agencies (IAWA) (Zenz, 2003). The capital cost was estimated at US\$ 5.3 billion for the 814 publicly owned treatment works (POTWs) in Illinois. Annual operation and maintenance costs were estimated at nearly US\$ 500 million. Based on these numbers, capital costs nationwide would reach about US\$ 26 billion with annual operations and maintenance costs at US\$ 4.8 billion. If wastewater agencies would be willing to spend up to the estimated operations and maintenance costs to avoid the capital costs, the market in nitrogen and phosphorous credits could reach US\$ 4.8 billion/year.

Based on a cost comparison analysis performed between conventional biological nutrient removal at wastewater treatment facilities and treatment wetlands, nutrient farms can cost effectively remove nitrogen to proposed nutrient criteria (Hey et al., in press). For example, the annual cost for a sanitary district located in the upper Illinois River watershed to construct and implement biological nutrient removal control to meet nutrient criteria of 2.18 mg/l TN and 0.5 mg/l TP would be US\$ 211 million (Table 1). The annual cost of restoring and operating 130,000 ha (322,000 acres) of nutrient farm wetlands, which is the area required to remove the sanitary district's monthly demand, is US\$ 103 million or 51% less than advanced wastewater treatment costs. Since the performance of treatment wetlands is seasonally dependent, the nutrient farms have to be designed to meet the monthly demand of industrial and/or municipal dischargers. Therefore, during certain times of the year, such as the summer or fall, there is an excess capacity to remove nutrients in the wetlands and the nutrient farms could generate surplus credits. Thus, the 130,000 ha (322,000 acres) of treatment wetlands would remove a surplus of 26,100 Mt (28,800 t) of nitrogen and 2000 Mt (2200 t) of phosphorus with a total value of approximately US\$ 56.3 million. If secondary markets for these excess nutrient credits could be developed, then the savings could reach as high as 60–70% of the cost of conventional biological nutrient removal.

The market area for nitrogen farming would be restricted to the more humid, eastern portion of the United States and along the Pacific coast where row crops are intensely grown. The western portions of the Missouri River basin produce little nitrogen-laden runoff due to low precipitation and the particular crops grown in the region. On the other hand, rivers along coastal California and rivers draining southern Minnesota, Iowa,

Missouri, and Arkansas and all states eastward would present fertile areas for nitrogen farming. The magnitude of each market could be estimated from fertilizer sales, emissions of power plants and automobiles, and the discharge of municipal and industrial point sources.

The cornerstone for the nitrogen market has been laid. In January 2001, the United States Environmental Protection Agency promulgated nutrient criteria, including nitrogen, for the streams and rivers of the nation. In the “Cornbelt Eco-region,” where most of the nitrogen fertilizer is used, the total nitrogen criterion was set at 2.18 mg/l. Of this concentration, about 1.6 mg/l is nitrate–nitrogen. This is substantially lower than the nitrogen concentrations of now conveyed by Midwestern rivers: Peak concentrations of nitrate–nitrogen in the Sangamon River in central Illinois have reached 12–16 mg/l over the past decade. For the Illinois River, approximately 90,700 Mt/year will need to be removed. At the estimated cost for credit production of US\$ 2500/Mt, the annual market for nitrogen credits would be approximately US\$ 227 million.

The nitrogen market would need to be locally based. Dischargers of nitrogen would likely have to buy credits from sellers upstream of their discharge point. In this way, elevated concentrations of nitrogen in the river system would be minimized. In cases where the nutrient farm is located at a distance from the point of nutrient discharge, regulatory agencies will need to identify stream reaches where nutrient transport will be allowed as a designated use. These reaches will likely be in highly modified channels (e.g., the Illinois Waterway) and removed from primary contact and drinking water uses. This reclassification, however, would require a change in the way water quality standards are currently administered. In many cases, nutrient farms will be able to be sited near the point of discharge; therefore, transport issues will not be of concern.

The nitrogen credit market would remain viable as long as crops need to be grown on well-drained and fertilized land. A shift to crop species more tolerant of saturated soils or a change in the chemical nature and application of fertilizer could reduce the need for such credits. Currently, crops requiring less drainage and nitrogen are being actively considered. New forms of nitrogen fertilizer that attach to soil and dissolve more slowly are being developed. Nonetheless, current market opportunities are enormous.

To expand the nutrient market, both phosphorus and carbon should be considered. The very wetlands that act as nitrogen farms also would act as phosphorus and carbon sinks. Credits could be sold to emitters of carbon to water and air. Consequently, nitrogen farms could be used to reduce greenhouse gases. Finally, a sediment market could be structured in the same way as the other credits. Sequestering sediments in wetlands would protect downstream aquatic habitats and reduce the dredging costs incurred by the U.S. Army Corps of Engineers that are related to maintaining river navigation.

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Corrigenda

Please note the following corrections on page 283, 2nd column, 1st paragraph:

\$486/ha should appear as \$2960/ha

\$40-60/ha should appear as \$247-\$371/ha

\$5/ha should appear as \$30/ha

\$24/ha/year should appear as \$148/ha/year