2.2 Nitrogen Pollution: Problems, Sources, and Policy

Why is environmental nitrogen important? Nitrogen is an essential nutrient for organisms as an integral part of DNA, amino acids and chlorophyll. It naturally cycles through the biosphere in various organic and inorganic forms. Water-borne nitrogen is the form used by most plants. Stream gauge data, reporting the concentrations of various nitrogen compounds in the Illinois River, shows a marked increase in the amount of total nitrogen and especially nitrate-nitrogen (hereafter called nitrate) between the early 1900s and early 2000s.[1] This excess aqueous nitrogen is of increasing concern in the Illinois and Mississippi River Basins. However, the gauge data does not establish whether the increase represents a problem. Meaningful discussion of elevated nitrogen concentrations requires an examination of the consequences of the increase. First, does the increase in nitrogen and nitrate negatively affect the human and/or the natural environment in the Illinois River Basin and likewise in the Mississippi River Basin? Second, if excess nitrogen creates a problem, what are the sources of the excess nitrogen? Finally, what are the best methods for removing it? Before answering these questions, we begin with a discussion of the nitrogen cycle in the Illinois River Basin.

2.2.1 The Nitrogen Cycle

Section 2.2.1 discusses biogeochemical cycling in the Illinois River Basin. Here we look specifically at the nitrogen cycle in this region and the impacts of human activity on this cycle. Nitrogen gas (N_2) comprises 79% of the Earth's atmosphere. While nitrogen is plentiful in the atmosphere, nitrogen is limited in soils and often constrains plant growth. Furthermore, plants absorb soil nitrogen readily and the supply of nitrogen is often less than plant demand. Farmers are especially cognizant of the amount of nitrogen in the soil as it affects crop production. Because of this, farmers annually apply nitrogen fertilizer to increase the yield of certain crops, such as corn.[2] With no additional nitrogen inputs, corn yield averages around 70 bushels per acre in Illinois. With the addition of 160 pounds of nitrogen fertilizer per acre, the yield of corn increases to around 180 bushels per acre.[3] Other crops, the legumes such as soybeans, maintain symbiotic relationships with bacteria that make nitrogen available to the plants and require little if any application of nitrogen fertilizer.[4]

Nitrogen Biogeochemistry

Nitrogen moves among the atmosphere, soil, water, and organisms in a process called the nitrogen cycle. This cycle consists of five processes: nitrogen fixation, mineralization, nitrification, immobilization, and denitrification (Table 2.2.1-1).[5] Three of these processes are important in considerations of excess nitrogen, namely nitrogen fixation, nitrification and denitrification.

Table 2.2.1-1 Elements of the nitrogen cycle.[6]

Reaction	**Formula**	**O_2 Environment**	**Biological Mediator**
Fixation	$N_2 \leftrightarrow \text{organic } N$	*Aerobic*	*Bacteria*
Mineralization	$\text{organic } N \leftrightarrow NH_3, NH_4^+$	*Both*	*Bacteria*
Nitrification	$NH_4^+ \leftrightarrow NO_2^{2-} \leftrightarrow NO_3^-$	*Aerobic*	*Bacteria*
Immobilization	$NO_3^-, NH_4^+ \leftrightarrow \text{organic } N$	*Aerobic*	*Plants, Bacteria*
Denitrification	$NO_3^- \leftrightarrow NO_2^{2-} \leftrightarrow N_2$	*Anaerobic*	*Bacteria*

Nitrogen fixation is the conversion of atmospheric nitrogen gas to ammonia (NH_3) and then to organic forms usable by plants. There are two main processes through which nitrogen fixation occurs, lightning and biological fixation. Biological fixation is the more important process in terms of anthropogenic increases in nitrogen in the Illinois River Basin. The enzyme nitrogenase found in the bacteria of the genus *Rhizobium* mediates biological fixation. *Rhizobium* bacteria live in the rhizomes (underground stems) of leguminous plants such as soybeans, forming colonies that produce root nodules.[7] Biological fixation is an oxygen dependent reaction and therefore is prevalent in legumes growing in aerated, upland soils.

The biological oxidation of ammonium (NH_4^+) to nitrite (NO_2^{2-}) and then to nitrate (NO_3^-) is the process called nitrification. Ammonium and nitrite exist in soils but are unstable molecules that readily accept oxygen, leaving nitrate as the dominant form of nitrogen in aerated soils. Soil nitrate remains soluble in aqueous solutions and available for plant root uptake. Consequently, nitrate is the most important form of nitrogen in terms of agriculture. However, because nitrate is readily water-soluble, it is subject to high rates of leaching out of the soil and into groundwater and streams. During the winter and spring months many plants are dormant with no active uptake of nitrogen. Concomitantly, there exists surplus soil water and groundwater recharge; consequently, most nitrate leaching occurs during this time of year.[8]

Denitrification is the process whereby certain species of facultative and anaerobic organisms reduce nitrate and nitrite to molecular nitrogen or nitrogen oxides.[9] Under anaerobic conditions, nitrates are subject to high rates of denitrification.[10] Denitrifying bacteria occur in wetlands and poorly drained soils. Therefore, drained floodplain wetlands along the Illinois River, if restored, could function to convert water-borne nitrogen into nitrogen gas and then release it into the atmosphere. While denitrification occurs under anaerobic conditions such as those found in wetlands, biological fixation and nitrification (oxygen dependent reactions) occur at highly reduced rates or not at all.

Nitrate concentrations in the Illinois River Basin

In the late 1800s, the average concentration of nitrate in the Illinois River was around 0.80 mg/l. In that period, the highest nitrate concentrations occurred between January and March. The lowest concentrations occurred between October and December. Rates of plant uptake and assimilation of nitrate as well as plant decomposition and the subsequent release of nitrate back into the environment regulated this cycle.[11]

In contrast, by the 1980's, the average concentration of nitrate was 5mg/l with a range of 3-6.5 mg/l. The highest concentration of nitrate now occurs in late spring (May-June) in each year. This peak arises from fertilizer applied during the fall after the harvest. The lowest concentrations of nitrate occurred during the autumn.[12] The onset of modern nutrient intensive agriculture, and especially the amount and timing of fertilizer applications, brought about this change. Figure 2.2.1-1 shows the concentration of nitrate in the river at the Ottawa, Illinois gauging station upstream from the HLD (March 1999 – February 2000). The graph illustrates the variability in the concentration of nitrate throughout the year.

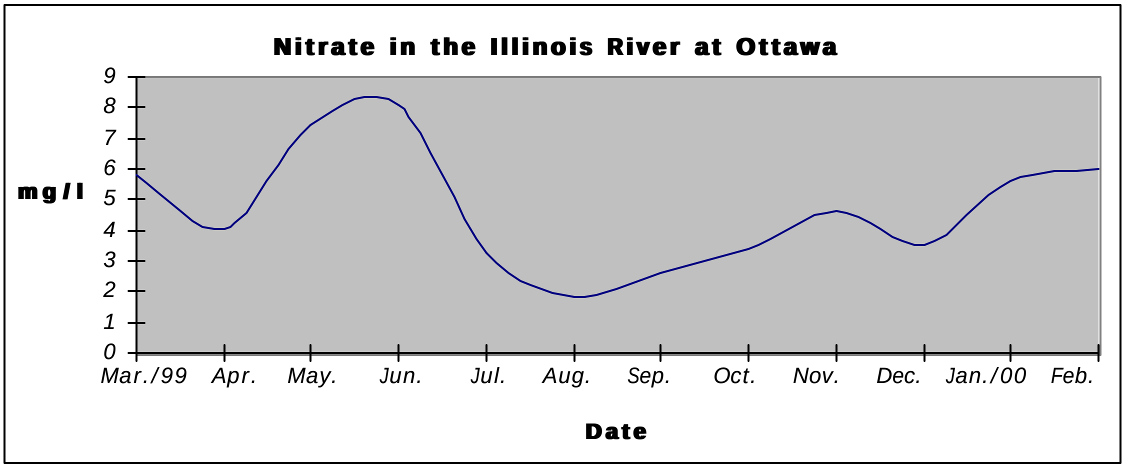

Figure 2.2.1-1 The concentration of nitrate in the Illinois River at Ottawa from March 1999 to February 2000.[13]

Methods used to facilitate the expedient drainage of agricultural fields, such as stream channelization and the removal of riparian vegetation, allows nitrate-enriched water to move more quickly to the main rivers. This expedient drainage limits the amount of denitrification that historically occurred in water journeying from fields to the Illinois River. Furthermore, the loss of wetlands in and around agricultural fields further cripples the ability of the land to remove excess nitrate.

Annually, the Illinois River yields some 126,000 tons of nitrates to the Mississippi River, comprising roughly 12% of the total nitrate load that reaches the Gulf of Mexico from the entire Mississippi River Basin. However, the Illinois River only contributes about 3% of the water volume in the Mississippi River.[14] Clearly, the Illinois River Basin produces a disproportionate amount of nitrate.

Consequences of Nitrate Pollution

Humans altered the historic nitrogen cycle in the Illinois River Basin by increasing the amount of nitrogen and especially nitrate in the system. What are the consequences of this increased nitrogen? Here we examine how elevated nitrate concentrations affect groundwater deposits used for human and livestock consumption and the effect of elevated nitrate concentrations on the Gulf of Mexico.

Nitrogen Pollution in Groundwater

Human infants, during the first few months, are susceptible to acute nitrate poisoning caused by consuming water with nitrate concentrations of 10mg/l or greater. This condition is known as methemoglobinemia (blue-baby syndrome). Bacteria in an infant's digestive system will convert nitrate into the more toxic nitrite. Nitrite reacts with hemoglobin and prevents oxygen transport by the blood, turning the oxygen-starved infants a bluish color.[15] Such high levels of nitrate occur in some ground water deposits in the state of Illinois.[16]

Methemoglobinemia occurs also in ruminant animals (sheep and cattle) and in infant monogastric animals (chickens and pigs), albeit at higher nitrate concentrations than in human infants. Still, this concerns farmers as concentrations of nitrate in agricultural drains sometimes reach 20-40 mg/l or more.[17]

Nitrogen Pollution in the Gulf of Mexico: Hypoxia

Figure 2.2.1-2 shows the distribution of nitrogen fertilizer application throughout the Upper Mississippi River Basin. Nitrogen-rich waters flow from fields and municipalities into streams and rivers from the agricultural Upper Mississippi River Basin states and finally into the Mississippi River itself. The water flows down the Mississippi and into the Gulf of Mexico. The freshwater river also contributes warmer, less dense water during the summer, causing stratification in the Gulf of Mexico. The warmer, less dense river water remains on top, thereby trapping the cooler, more dense, salty ocean water below.

Nitrogen is a limiting nutrient in ocean waters. When a high influx of nitrogen in the form of nitrate reaches the Gulf of Mexico waters, it allows the growth of algae and other organisms to rapidly accelerate. These organisms quickly overwhelm the ecosystem's capacity to support them, die off, and sink to the bottom of the Gulf. Bacteria then decompose the abundant organic matter; a process requiring dissolved oxygen. These bacteria quickly deplete the available dissolved oxygen creating areas of deoxygenated water. The deoxygenated areas become hypoxic, defined as water where the level of dissolved oxygen falls to less than 2.0 mg/l. The hypoxic area is unable to replenish itself with the oxygen-rich surface water because of the stratification. With such low dissolved oxygen levels, stress and/or death claim those organisms that cannot easily leave the hypoxic zone (e.g., plankton, plants, mussels, crabs, shrimp, etc.).[18] Not only does this pose a threat to the commercial species but also to the species forming the forage base for the commercial species. Before the 1950's, hypoxic conditions were not common in the Northern Gulf of Mexico. Since that time, as the amount of nitrate loading to the Mississippi River and the Gulf of Mexico increased, hypoxia began to occur annually during the summer months.[20] However, the hypoxic zone in the Gulf of Mexico is highly variable. For example, in the summer of 1999 the zone reached its greatest extent at some 20,000 square kilometers. In stark contrast, during the dry summer of 2000, the hypoxic zone covered 4,400 square kilometers. While the nitrate load to the Gulf is dependent on the amount of precipitation

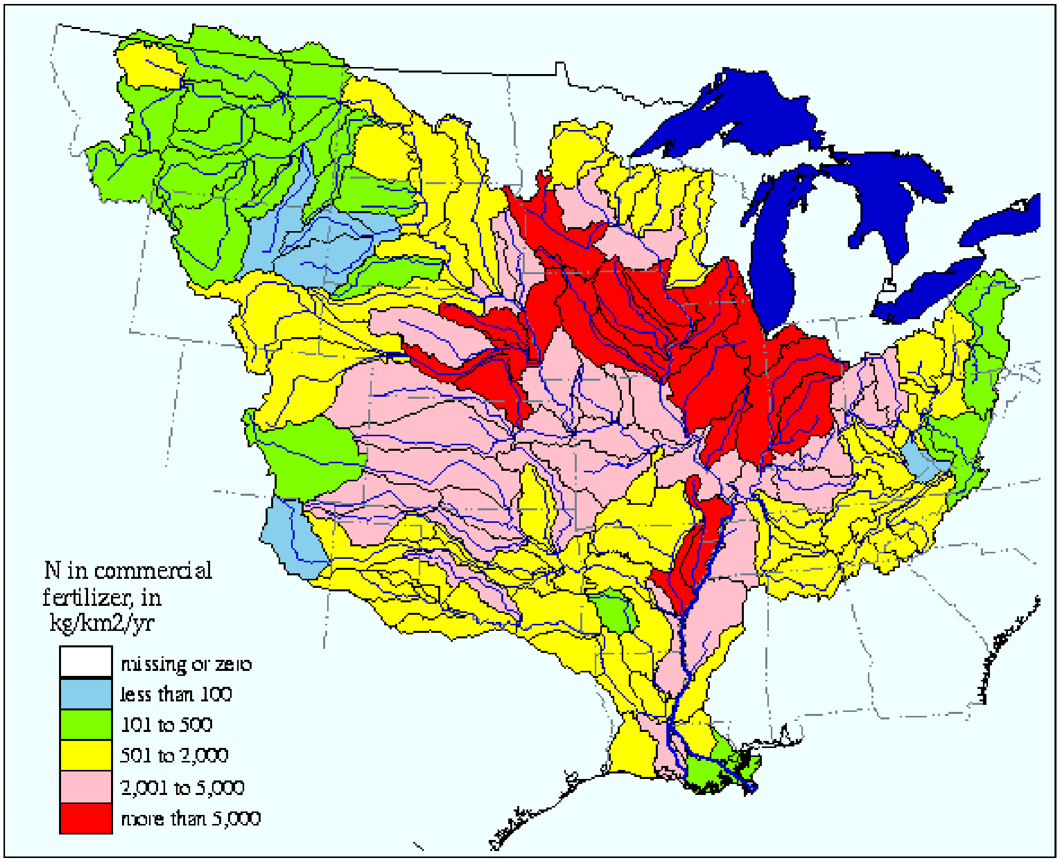

Figure 2.2.1-2 Nitrogen fertilizer use in the Mississippi River Basin shown by hydrologic accounting unit for 1992.[19]

in the Mississippi River Basin, it averages over 1,000,000 tons. These numbers far surpass the averages from 1955 to 1970 when 360,000 tons per year of total nitrogen, not just nitrate, entered into the Gulf of Mexico from the Mississippi River.[21]

Sources of Excess Nitrogen in the Illinois River Basin

Next, we examine the sources of the excess nitrogen. The HLD lies just south of the Upper Illinois River Basin, so it is logical to examine the amount of nitrogen produced in the watershed that will flow by and potentially through the HLD. The primary sources of anthropogenic nitrogen are agricultural, municipal/industrial, and atmospheric deposition.

Agricultural Sources of Nitrogen

In Putnam County, where the HLD is located, corn and soybean row crops grow on 92% of the agricultural land, with roughly 49% in corn and 43% in soybeans. For all of Illinois, the 1989-1998 Illinois Agricultural Statistics show an average application of 157 lbs of nitrogen per acre per year on corn acreage.[22] In contrast, soybean fertilizer application averages 22 lbs of nitrogen per acre per year. However, only slightly over ten percent of farmers in Illinois use nitrogen fertilizer on fields of soybeans because soybeans fix nitrogen.[23] By growing fields of legumes, farmers can increase the amount of soil nitrogen considerably. Estimates show that an acre of soybeans can fix 140 pounds of nitrogen per year.[24] Nevertheless, when harvested, up to one half of the nitrogen fixed by the legumes is removed with the plants.[25] Some of the remaining soil nitrogen leaches and the rest is then available to the next year's crops.

Illinois Municipal/Industrial Sources

The more industrial and populous portions of Illinois also produce excess nitrogen. The nitrogen contribution from municipal and industrial sources in the Upper Illinois River Basin can be calculated based on estimates of the nitrogen effluent produced by residents of the Upper Illinois River Basin. One study estimated the per capita nitrogen sewage quantities for Illinois, measured at publicly owned waste treatment facilities. Treatment plants are a convenient source to measure for water pollution because they act as point sources (Section 2.2.2) that collect all the effluent from an urbanized area. For the northeastern portion of the state (the Upper Illinois River Basin), estimates show an average of 4.37 kg of nitrogen per capita per year.[26] This implies the following estimates:

Total population in the Upper Illinois River Basin = **7,600,000**[27]

Estimated contribution to sewage effluent by the Upper Illinois River Basin
= 7,600,000 individuals x 4.37kg nitrogen/person/year =
33,212,000 kg N/year

Total sewage effluent contributed by the Upper Illinois River Basin Illinois in tons
33,212,000kgN/year x 2.205lb/kg x 1ton/2000lbs = **36,600** tons N/year

The estimates indicate that sewage effluent from the upper basin accounts for 36,600 tons of nitrogen pollution input into the Illinois River annually. Interestingly, sewage effluent affects the nitrogen concentration in the Illinois River system much more than in the Mississippi River system. The difference lies in the different volume of water in each system and the quantity of sewage effluent produced. Because Chicago reroutes its effluent into the Illinois River and away from Lake Michigan (Section 2.1), and because northeastern Illinois is a highly populous area, the volume of the Illinois River is not enough to dilute the large quantities of effluent to the same extent as the Mississippi River would.

These calculations of the nitrogen pollution contributed by municipal and industrial sources provide an estimate only of the total nitrogen exiting wastewater treatment facilities. However, most reduction efforts target reducing nitrate concentrations. Unfortunately, estimates of the nitrate levels exiting wastewater treatment facilities were unavailable. Therefore, herein, the total nitrogen estimate acts as a surrogate for the nitrate concentrations. In reality, the amount of nitrate exiting the wastewater treatment plants is less than our estimates (See the discussion of using wastewater treatment plants for nitrogen removal in 2.2.3).

Total Illinois Sources

Agricultural sources of nitrogen account for roughly 50% (fertilizers 20-25% and legume fixation 21-25%) of the nitrogen loading in the entire Illinois River Basin, while municipal and industrial sources contribute another estimated 20%.[28] Obviously, combining these sources does not account for the total amount of nitrogen. The remaining sources include atmospheric and natural nitrogen cycling. Atmospheric sources of nitrogen include lightning, photochemical oxidation in the stratosphere, chemical oxidation of ammonia, soil production by microbes, and fossil fuel combustion. Atmospheric ammonia arises from fertilizer manufacturing, anaerobic decay of organic matter, the bacterial decomposition of excreta and the burning of coal.[29] Nitrogen cycling also contributes to the total nitrogen loading in the basin.

Distributional Impacts

Besides looking at the consequences of excess nitrate and the nitrogen sources, we must also look at the distributional impacts. Nitrate can be both a uniformly mixing pollutant and a non-uniformly mixing pollutant. When contributing to Gulf of Mexico hypoxia, nitrate acts as a uniformly mixing pollutant in that neither the exact source of the nitrate nor the overall amount in the Illinois River per se is as important as the overall amount of nitrate pollution that exits the Mississippi River into the Gulf. Since nitrate pollution factors into Gulf of Mexico hypoxic conditions, concerned individuals desire the removal of nitrate from the Mississippi River Basin. However, this removal of nitrate could occur anywhere in the Mississippi River Basin where there is excess nitrate with equivalent impact to the Gulf.

In contrast, nitrate may act as a non-uniformly mixing pollutant. Locally high concentrations of nitrate in groundwater may represent more of a problem than the overall amount of nitrate in the Illinois River Basin due to human and animal related toxicity. This distinction is very important when considering the goals of the nitrate reduction effort.

2.2.2 Nitrogen Regulatory Policy

Policy Development

Several types of policy are used to control and prevent nutrient pollution, such as taxing effluent, subsidizing/mandating the use of Best Management Practices (BMPs), mandating tertiary treatment at wastewater treatment facilities, or wetland restoration.[30] These policies include both Federal and State programs. These policies fall under the general headings of point source, nonpoint source (NPS), agricultural subsidy programs, groundwater, and Gulf of Mexico hypoxia.

Point Source Pollution Policy

Point source pollution arises from a single location such as an industrial complex or a wastewater treatment facility. Therefore, it is possible to monitor the amount of effluent pollution exiting a given location directly. The U.S. Environmental Protection Agency (EPA) defines a point source as follows:

> A point source is defined as any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding production, landfill leachate collection system, or vessel, or any floating craft from which pollutants are or may be discharged. The term “point sources” includes stormwater discharges from municipal separate storm sewers generally serving communities with populations of greater than 100,000 and storm water discharges associated with industrial activities, but does not include return flows from irrigated agriculture or agricultural runoff.[31]

The U.S. EPA maintains the authority to regulate point sources under the direction of the Clean Water Act (CWA). It issues National Pollutant Discharge Elimination Systems (NPDES) permits to effluent dischargers (Appendix 1). The permits establish limitations on effluent, such as nitrate, from end-of-pipe industrial and municipal sources. Furthermore, the operators of the point sources are required to monitor, record, and report their effluent data to the regulatory agency (Section 308, CWA). Management of the NPDES permit programs generally occurs on the state level.

Nonpoint Source Pollution Policy

In contrast to point source pollution, agricultural NPS pollution is difficult to monitor because it does not issue from a single point but is diffuse, arising from many different areas on an agricultural field. Given the diffuse nature of NPS pollution, monitoring the runoff and leaching of nitrate from agricultural lands is both difficult and prohibitively expensive. Natural resource agencies lack the financial and human resources to monitor the various points of effluent discharge on individual farms.

Complicating this matter is a delay between fertilizer application and the presence of nitrate in rivers. Furthermore, the amount of nitrate moving from agricultural fields to the Illinois River depends upon rainfall, temperature and other climate factors. Due to these constraints, performance based policies (policies based on target runoff goals) are not effective for controlling NPS pollution. Design based policies such as the use of agricultural BMPs work more effectively.[32]

Responsibility for dealing with NPS falls to the state. The CWA does not contain a provision for regulation by a Federal permit program. Instead, the CWA provides for the distribution of grants to individual states with the intent that these states develop plans for reducing pollution from NPS. If regulated on a state level, management programs for NPS must adhere to all applicable state and local regulations and policies.

Federal Agricultural Programs

The U.S. Department of Agriculture (USDA) offers economic incentives for implementing BMPs to improve water quality through its Environmental Quality Incentives Program (EQIP), which is part of the Federal Agriculture Improvement and Reform Act of 1996 (P.L. 104-127).[33] The goal of the EQIP is to provide payments and technical assistance to farmers willing to use approved BMPs to help ameliorate the negative impacts of agricultural pollution on surface water and groundwater.

Other Federal agricultural subsidy programs, such as the Conservation Reserve Program (CRP), reduce NPS pollution inadvertently. Administered by the USDA, the CRP allows agricultural producers to retire their highly erodible or otherwise environmentally sensitive lands for periods of 10 or more years. Farmers with land enrolled in the program receive rental payments as well as cost-sharing and technical assistance for approved plantings. The goals of the CRP are to achieve environmental benefits such as erosion control and wildlife habitat while curbing excess agricultural production.[34] Although not specifically a goal of the CRP, the program helps reduce NPS pollution by removing land from production and restoring wetlands.

Groundwater Policy

Protection of groundwater falls under the Wellhead Protection Act of 1986, part of the 1974 Safe Drinking Water Act (P.L. 93-523).[35] By this act, the U.S. EPA must set standards for acceptable limits of toxic chemicals in drinking water. The Maximum Contaminant Level Goals are the highest advisable limits at or below which "no known or anticipated adverse effects on health of persons occur and which allow an adequate margin for safety."[36] The standard for nitrate concentration in drinking water sources is 10 mg/l. Usually the EPA uses the incidence of cancer as a guide for developing their drinking water standards. However, no reliable evidence exists that links high nitrate concentrations with cancer in humans. Therefore, the EPA uses the occurrence of methemoglobinemia in humans as a surrogate measure.[37]

Illinois Nutrient Pollution Policy

The CWA (section 303(d)) mandates that states establish Total Maximum Daily Limits (TMDLs) for all impaired waterways (Appendix 1). According to the US EPA, Illinois tops all states with 634 nutrient impaired waterways.[38] The Illinois Environmental Protection Agency (IEPA) is currently pursuing the required development of TMDLs. However, in reviewing actions taken by the IEPA, there is little indication that the state is actively addressing nutrient problems through TMDLs. Currently, only six sections of watershed in Illinois are close to completing TMDLs. An additional 13 are beginning the TMDL process: a process requiring a minimum of 18 months.[39] Further slowing the progress of TMDL designation, the IEPA anticipates legal challenges to some of its TMDL designations after the EPA gives final approval.[40]

The TMDLs designated by the IEPA only addresses point source pollution. In contrast, no current policies exist for managing agricultural NPS nitrogen pollution in Illinois.[41] However, the Nonpoint Source Unit of the IEPA currently works to develop and implement voluntary NPS pollution control projects through assisting farmers with watershed management plans and BMPs. The IEPA's Targeted Watershed Approach is the mechanism used to determine impaired watersheds. Its plans for future NPS controls for impaired waterways are as follows:

> The IEPA proposes to expand the Nonpoint Source Management Program (NSMP) using funds made available from program grants and Section 319 of the CWA. Additional base program activities in those watersheds impacted by NPS will include: expanded monitoring; consultation and technology transfer/awareness programs directed at contributing watershed landowners; intergovernmental working agreements; increased attention to storm water sources; and accelerated implementation of program activities identified in the approved NSMP (Illinois EPA, 1994). Section 319 projects will place emphasis on correction of specific watershed problems and development of watershed implementation plans.[42]

There is a clear indication, however, that the voluntary programs are not meeting expectations. Public comments call for management that is more aggressive, the use of techniques such as regulatory NPS control programs and annual reviews that measure goal attainment. However, the IEPA maintains that voluntary measures are the best way to manage NPS pollution.[43]

While the IEPA works on developing TMDLs and expanding the NSMP, the Illinois Department of Natural Resources (IDNR) implements the Conservation Reserve Enhancement Program (CREP). The Illinois CREP is an outgrowth of the CRP that provides CRP enrolled farmers with an opportunity to extend their contracts by 15 or 35 years or to enter into a permanent conservation easement (Appendix 1). The IDNR views the CREP as a promising means of voluntary reduction of NPS related problems and an opportunity to restore wildlife habitat. Illinois' goal is the enrollment of up to 132,000 acres throughout the state. Through the CREP, Illinois wants to:

- reduce the amount of silt and sedimentation entering the main-stem of the Illinois River by 20%;
- reduce the amount of phosphorus and nitrogen in the Illinois River by 10%;
- increase the populations of migratory birds, and State and Federally listed threatened or endangered species by 15%; and
- increase the native fish and mussel stocks by 10 % in the lower reaches of the Illinois River (Peoria, La Grange and Alton reaches).[44]

Lands enrolled in the CRP or CREP programs can receive technical assistance for land management and habitat restoration. Illinois enrolled 38,482 acres in state options in the first two and a half years of the program, including 34,270 acres (89%) under permanent conservation easements.[45] Sixty-five percent of these formerly farmed acres are now wetlands. The state considers this program a substantial success in terms of taking marginal farmlands out of production and restoring some of the natural functions of the land.[46] There is some question as to the level of effectiveness of this kind of program in reducing nutrient loads to the Illinois River. According to last year's annual CREP report, monitoring is occurring for sediment and habitat creation, but techniques to quantify nutrient reductions require development.[47]

The Illinois CREP does not allow for the creation of large-scale restoration projects, such as restoring floodplains. Currently, the maximum area of a CREP enrollment is restricted and there is a $50,000 dollar cap for each property. Expansion of the program may allow for the creation of larger reserve areas. However, TWI is creatively attempting to become an exception by dividing an entire levee district into several independent non-for-profit corporations thereby maximizing the Federal and state acreage retirement payments.

Gulf of Mexico Hypoxia Policy

Hypoxic conditions in other major world fisheries caused catastrophic reductions in the harvest of commercial species and devastated many benthic (ocean bottom) fisheries (Table 2.2.2-1). Although not realized in the Gulf States, the current conditions alarm fishing industry officials, Gulf of Mexico scientists, and environmentalists. Much of the concern surrounds the fisheries because they are major industries in the affected Gulf States of Texas, Mississippi and especially Louisiana.[48] As an example of the region's economic importance, in 1996 the Louisiana Shelf of the Gulf of Mexico supplied 8% of the total U.S. commercial catch.[49]

Table 2.2.2-1 Ecological and economic effects of anthropogenic hypoxic zones in coastal regions, including the Gulf of Mexico (Louisiana Shelf).[50]

System Area Affected	**Km²**	**Benthic Response**	**Benthic Recovery**	**Fisheries Response**
Louisiana Shelf	*15,000*	*Mortality*	*Annual*	*Stressed, but still highly productive.*
Kattegat, Sweden–Denmark	*2,000*	*Mass Mortality*	*Slow*	*Collapse of Norway lobster, reduction of ocean bottom fish. Hypoxia prevents recruitment of lobsters.*
Black Sea North-west Shelf	*20,000*	*Mass Mortality*	*Annual*	*Loss of ocean bottom fisheries; shift to planktonic species.*

Baltic Sea	100,000	Eliminated	None	Loss of ocean bottom fisheries; shift to planktonic species. Hypoxia is bottleneck for cod recruitment.

A coalition between the Mississippi River Basin states and the Federal Government is working towards reducing the nitrogen flux to the Gulf of Mexico. This coalition wrote the *Action Plan for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico*, in accordance with The Harmful Algal Bloom and Hypoxia Research and Control Act of 1998.[51] The purpose of the plan is to reduce the average nitrate loads by 40% to the 1955-1970 average, thereby preventing damages from hypoxia. Considering that some 1,050,000 tons of nitrate discharge from the Mississippi River into the Gulf of Mexico annually, a 40% reduction would require the elimination of 420,000 tons of nitrates.[52] To achieve this reduction, the Action Plan outlines two main methods of reducing hypoxia in the Gulf:

- reduce nitrogen loads from watersheds to streams and rivers in the Basin; and
- restore and enhance denitrification and nitrogen retention within the Basin and on the coastal plains of Louisiana.

To meet their target reduction, the Action Plan lays out a timeline with eleven priority actions. Examples of these actions include:

- assess the nutrient contributions of sub-basins and smaller watersheds by the spring of 2002;
- develop strategies for nutrient reduction on the sub-basin level by fall of 2002;
- identify the significant point source dischargers by January of 2003;
- promote the voluntary implementation of BMPs by spring of 2003; and
- conduct assessments of the nitrogen load reduction every five years.[53]

In contrast to the Action Plan Committee's recommendations, Hey argues that an 80% reduction in nitrate levels is necessary to prevent damages from Gulf of Mexico hypoxia. This level of reduction would require the elimination of 840,000 tons of nitrate per year from the Mississippi River Basin.[54]

Conflicting Opinions of the Threat of Gulf of Mexico Hypoxia

The hypoxia situation is a strongly contentious issue, with potential government-mandated limitations on nutrient effluent strongly supported by the environmental community and vehemently opposed by the agricultural sector.[55] While none of the stakeholders denies the existence of a hypoxic zone in the Gulf of Mexico, they certainly differ on the possible consequences.

For example, a report on the website of a prominent environmental group, the Sierra Club, maintains that: "This condition [hypoxia] kills every oxygen-dependent sea creature within its 7,000 square mile zone… The economic impacts could become more serious if the Dead Zone continues to grow. The Gulf Coast faces the risk of developing hypoxia severe enough to wipe out almost the entire commercial fishery. A loss such as this would devastate the economy of the Gulf region and be felt across the nation."[56]

In contrast, an article found on the American Farm Bureau web site questions whether Gulf of Mexico fisheries would realize the potential financial and environmental calamity that may result from prolonged hypoxia. The author further criticizes the U.S. Government's Hypoxia Work Group for suggesting the removal of 5 million acres of farmland in the Mississippi River Basin from production to reduce nitrogen loading and alleviate the hypoxic condition.[57] Regarding this, the author states that the "lost production will eventually move, not only out of the basin, but out of the country, into regions far less suitable for agriculture, into far less fertile, far more biodiverse ecosystems, such as the world's rain forests which are already being destroyed at appalling rates for low-yield, unsustainable, subsistence agriculture. Losses to biodiversity, wildlife habitat, and to species will be significant. With every unreasonable, senseless, ill-advised, and unjustifiable limitation the environmental movement succeeds in placing on American agriculture, the greater the devastation of the world's environment will be."[58]

Hyperbole aside, this article does bring up one important issue that is contrary to the Sierra Club report. The author correctly points out that the Hypoxia Work Group found no indication of economic harm to the region. To quote the NOAA report: "To date, there are no clear indications of hypoxic effects in fisheries or fish populations in the published literature or data evaluated."[59] Furthermore, "the economic assessment based on fisheries data failed to detect effects attributable to hypoxia."[60]

NOAA's economists counter the expected criticism by explaining that the absence of current data or historical data showing the negative economic and ecological effects of Gulf of Mexico hypoxia does not prove that these conditions will never appear. They point to other coastal regions where hypoxic conditions worsened until adverse ecologic and economic effects occurred (Table 2.2.2-1).[61]

2.2.3 Nitrate Pollution Reduction Techniques

The excess nitrogen in the Illinois River Basin arises from diverse anthropogenic activities such as agriculture, industry, and municipal wastewater treatment plants. Farmers can reduce their contribution to the nitrate pollution in the Illinois River using BMPs. Municipalities and industry may use other techniques for reducing nitrate levels in the Illinois River (i.e., tertiary treatment at wastewater treatment facilities and denitrification through wetland restoration). Another possibility is the development of watershed-based trading, a system that would take advantage of the cost differentials between nutrient reduction techniques.

Best Management Practices and Wetlands for Nutrient Removal

Best Management Practices

Agriculture accounts for roughly 50% of the nitrogen loading to the Illinois River Basin. Two factors affect agricultural NPS pollution: the fertilizer application techniques and the land management practices. Agricultural BMPs target the nitrogen effluent discharging from agricultural lands. Three classes of BMPs designed to reduce the amount of nitrogen leaving agricultural fields include improved nitrogen application techniques, alternative cropping systems and drainage. Each class includes several options:

Improved nitrogen application techniques:

- apply fertilizer and manure at agronomically recommended rates; and
- switch from fall to spring application.

Alternative cropping systems:

- change from row cropping to perennial cropping;
- plant cover crops for fall and winter nutrient absorption; and
- change from conventional to ridge-tilling or other reduced tillage practices.

Drainage:

- ensure that the lateral spacing of surface tile drainage is not less than 15 meters apart;
- control the water table to promote denitrification; and
- route the soil drainage through wetlands, grass buffers or riparian forest buffers.[62]

Farmers receive information about recommended rates of fertilizer application for a given year from universities and agricultural extension agencies. In Illinois, farmers apply fertilizers using one of three techniques; fall application (Oct.-Nov.), spring application (before planting in Mar.-Apr.), or a split application (one half of the fertilizer is applied in the spring and one half side-dressed after the corn is 0.3m tall, in late May or early June).[63] Fall application of nitrogen fertilizer results in nitrogen losses due to such factors as denitrification and/or ground water and drainage tile leaching. Studies estimate that nitrogen losses can range between 10 and 20 percent on fine and/or medium textured soils and increase to 20 to 50 percent on more coarse textured soils.[64] Furthermore, research conducted by the University of Illinois suggests farmers need to apply only 100 lbs of nitrogen in the spring to achieve the same yield as 120 lbs of nitrogen in the fall. Thus, changing the time of year in which a farmer applies fertilizer can save the farmer money on fertilizer costs and reduces the amount of nitrogen introduced into the environment.[65]

Other management practices specifically aimed at reducing nutrient pollution include altering the chemical form, the rate, the method and/or the timing of fertilizer application. For example, farmers could apply the nitrogen several times throughout the growing season in smaller doses or apply ammonia/ammonium fertilizer as opposed to nitrate fertilizer. The ammonia/ammonium fertilizer adsorbs more strongly in the soil and is less likely to leach out. However, policymakers and farmers need to assess the benefits and costs before implementing BMPs. Some of these techniques are prohibitively expensive to farmers while others are rather ineffective towards reducing agricultural water based pollution. For example, the gains in terms of pollution reduction by substituting ammonia/ammonium for nitrate are minimal because soil bacteria readily convert the ammonia/ammonium to nitrate.[66]

Farmer Reluctance to Implement BMPs

Even though Federal assistance exists for farmers to use BMPs for nitrogen effluent reduction through programs such as the EQIP, few farmers use these resources. There are several reasons why farmers may not use BMPs. One major factor is that farmers have no real incentive to reduce their nitrogen effluent. For example, no legislation exists restricting the use of nitrogen fertilizers. In fact, farmers often over apply nitrogen fertilizer to their fields resulting in increased nitrogen leaching. Why do farmers apply more nitrogen fertilizer than is necessary for maximum crop production? Economically, the application of greater amounts of nitrogen fertilizer is relatively inexpensive. The results of one agricultural study found that the producers who over applied nitrogen by large amounts and those who applied nitrogen close to the recommended rates showed comparable net economic returns.[67] Farmers are also concerned that mandated fertilizer reductions might decrease their productivity, acreage, and their profits, potentially driving them out of business.[68]

Habitual practices also factor into farmer’s decision making. For example, due to spatial variation, some soils on a farm may contain higher nutrient concentrations. For these areas, agricultural experts often recommend a significantly lower fertilizer application rate than the conventional rate. However, farmers often apply fertilizer at rates approximating the conventional rate to these acres, which then become a major source of nitrogen leaching.[69] The farmers seem to be uncomfortable applying lower rates of nitrogen fertilizer because they are accustomed to applying the greater conventional rates.

Effluent Treatment at Publicly Owned Wastewater Treatment Facilities

Industrial and municipal wastewater often contains high total nitrogen concentrations. Most of this nitrogen is in the form of ammonia and organic nitrogen. Publicly owned waste treatment plants convert the ammonia into nitrate using oxidation during secondary treatment. Tertiary treatment to remove the nitrate is uncommon, as removing nitrate is expensive and it not usually required by law. However, this may change if policy makers introduce legislation to reduce nitrogen loading in the Mississippi River Basin. In most cases, the dilution of nitrate rich urban effluent with nitrate poor water addresses the problem. In cases where dilution is not applicable, treatment plants use other methods such as reverse osmosis or constructed wetlands.[70]

Wetlands for Tertiary Treatment

Natural wetlands are another option for tertiary treatment. The U.S. EPA limits the use of wetlands for tertiary treatment of waste that already underwent conventional secondary treatment for several reasons including:

- a lack of knowledge about natural ecosystems and how they function;
- concerns about the possible contamination of wildlife and humans;
- concerns about reliability of the process; and
- concerns about containing the effluent.[71]

Wetlands used for tertiary treatment have advantages over conventional wastewater treatment. For example, wetlands may offer a lower cost method to achieve the same level of treatment, effluent discharge may enhance the water quality and biological integrity of the receiving wetland, and the level of treatment may exceed the level attainable by conventional methods.[72]

However, using wetlands for nutrient removal may result in unintended biological consequences. High nutrient levels in a wetland may cause the unchecked growth of certain plant species. For example, cattails (*Typha* spp.), although native, can form monocultures and crowd out other plant species. One specific example of this is the Houghton Lake wastewater treatment system in Houghton, Michigan. The city pumps its wastewater into a series of holding ponds, then to a small stream and finally into an extensive peatland wetland: pumping around 485,000m^3 per year during the months of May through September. The elevated concentration of nutrients in the wastewater altered the chemistry of the peatland and allowed monocultures of cattails to grow in a system where they previously did not exist.[73] Section 3.3 provides an analysis of using the restored HLD as a tertiary treatment system for removing nitrates from the Illinois River Basin.

Watershed-Based Trading

According to the U.S. EPA, " Trading is an innovative way for water quality agencies and community stakeholders to develop commonsense, cost-effective solutions for water quality problems in their watershed."[74] More specifically, watershed-based trading is a market-based system that allows effluent dischargers to meet or exceed water quality standards by generating or buying effluent credits. Trading can take place when multiple pollution inputs affect the water quality within defined watershed boundaries.

The simplest hypothetical example is a watershed with two factories, factory A and factory B, which pump their effluent into the local river. The watershed containing the two factories has a limit established by a regulatory agency for allowable effluent so that the river achieves a specific water quality standard, such as boatable, fishable, or swimable.[75] Since the river must meet the water quality standard, the factories must reduce their effluent level. The regulatory agency assigns each factory an effluent level according to the individual factory's historical effluent discharge. In response to the new standard, factory A decides to retrofit its equipment thereby reducing its effluent level below the level required by the water quality standard. In contrast, factory B finds reduction more costly. Under watershed-based trading, factory A will generate credits by reducing its effluent discharge below what it is required. Factory B, facing high costs to meet its effluent reduction requirement, can buy the credits generated by factory A. In this scenario, factory A will profit from the sale of the credits to factory B. Furthermore, factory B will meet its reduction goals at a lower cost. Overall, the combined reduction of the factories meets the effluent reduction goal established by the regulatory agency.

The mechanism for selling a credit can either be through a direct trade between the factories or through an agency or organization that administers the trading system. In this simplified case, to meet the water quality standard, the amount of effluent reduced by factory A must equal the amount of effluent produced over the limit by factory B. If accomplished, the potential exists for significant cost savings over a strictly regulatory approach. The factory with the capacity to reduce at the least cost accomplishes the needed reduction in effluent. Under a strictly regulatory approach, in contrast, both factories need to retrofit to meet the new standard.

The form of watershed-based trading is contingent upon the ability to monitor the effluent amount an individual source contributes to a watershed. For individual point sources, NPDES permits determine effluent discharge limits and testing at the ‘point’ of origin of the pollutant provides verification. In contrast, NPS pollution is more difficult to verify and monitor. These conditions make the inclusion of nonpoint sources in a watershed-based trading program more challenging. Nevertheless, policymakers creatively address the challenge through mechanisms such as trading ratios and incentive programs.

Trading Ratios

Trading ratios relate to the relative water quality impact of the various effluent dischargers. Determination of appropriate trading ratios is a main design point for a watershed-based trading system. A one-ton reduction of nitrogen through the implementation of a BMP by a nonpoint source may not have the same impact of a one-ton reduction at a point source. Furthermore, the locations of dischargers may affect an impaired water body differently. These issues lead to uncertainty in the exchange of credits between various dischargers. To address these issues, developers of existing programs created several types of trading ratios. In practice, trading ratios provide a margin of error to ensure that adequate amounts of reductions are being made to meet water quality standards.

- **Uncertainty ratios** are based on the reliability and efficiency (percent of nitrogen or phosphorus removed) of nutrient reduction controls, and are generally associated with NPS controls. For example, most trading programs attempt to address NPS reduction uncertainties by assigning a rate greater than 1:1(e.g., 2:1 or 3:1) requiring that more than one nonpoint credit be traded for one point source credit.
- **Delivery ratios** refer to discount factors used to compensate for nutrient delivery differences from sources in various locations. Such discount factors estimate the rate of attenuation during transport from source to main-stem or affected area.
- **A retirement ratio** designates that a portion of the credit transferred between buyer and seller be given to the state as a set-aside for long-term water quality improvement.[76]

The applicability of each type of trading ratio depends on the conditions in the watershed under consideration, the desired level of nutrient reduction, the participants in a trading program, and the level of scientific knowledge. Reducing the level of uncertainty as to the relative impact of any individual discharger reduces the need to establish a trading ratio. When uncertainty exists, policymakers can decide to use a trading ratio in their programs. One example of this is the common 2:1 ratio for point/nonpoint source trades. A 2:1 ratio requires nonpoint sources to reduce twice as much pollution as point sources in order to equal the same amount of credit.

Types of Trading

There are two general types of trading: closed and open. " Closed systems have been developed and implemented in areas where ambient environmental standards are not being met to provide a more cost-effective means of achieving the reductions necessary to attain these standards… Often called "cap and trade," these systems include a mandatory "cap" on emissions or discharges and individual allowances to sources within a defined trading area."[77] The establishment of a TMDL for an impaired water body conveniently creates a cap (Appendix 1). Open systems, in contrast, are commonly voluntary and depend on current regulations to provide a baseline. They can be used in situations where ambient levels are already being met. Making reductions from the baseline generates credits. The credits can then be traded, banked (particularly if it looks like stricter regulations are going to be developed), or used to comply with regulations.[78] The main difference between the two systems is the current state of environmental quality. With an open system, the dischargers have the opportunity to improve the ambient conditions or reduce their effluent level in anticipation of more stringent regulations. They can also have a profit motive if they anticipate being able to sell credits at a good rate in the near future.

The EPA established eight guidelines to direct national watershed-based trading policy, primarily geared towards closed trading systems.

- Trading participants must meet applicable CWA technology-based requirements;
- Trades must be consistent with water quality standards throughout a watershed, including anti-backsliding, and other requirements of the CWA, other Federal laws, state laws, and local ordinances (Appendix 1).

- Trades are developed within a TMDL or other equivalent analytical or management framework.
- Trades occur within the context of current regulatory and enforcement mechanisms.
- Trade boundaries are of a manageable size, generally coinciding with watershed or water body segments.
- Trading will generally add to existing ambient monitoring.
- Careful consideration is given to the types of pollutants traded.
- Stakeholders are involved in the process of developing and implementing trading.[79]

The EPA also identified five types of trading in a watershed context. The most common type of trading involves point/point source trading. The intent of offering different types of trading mechanisms is to allow more opportunities for trade.

- **Point/Point Source Trading:** A point source arranges for another point source(s) to undertake greater-than-required reductions in pollutant discharges in lieu of reducing its own level of pollutant discharge, beyond the minimum technology-based discharge standards, to achieve water quality objectives more cost-effectively.
- **Intra-Plant Trading:** A point source allocates pollutant discharges among its dischargers in a cost-effective manner, provided that the combined permitted discharge with trading is no greater than the combined permitted discharge without trading, and discharge from each outfall complies with the requirements necessary to meet applicable water quality standards.
- **Pretreatment Trading:** An indirect industrial source that discharges to a publicly owned treatment works (POTW) arranges for greater-than-required reductions in pollutant discharge by other sources in lieu of upgrading its own pretreatment beyond the minimum technology-based discharge standard, to achieve water quality goals more cost-effectively.
- **Point/Nonpoint Source Trading:** A point source arranges for control of pollutants from a nonpoint source to undertake greater-than-required pollutant reductions in lieu of upgrading its own treatment beyond minimum technology-based discharge standards, to achieve water quality objectives more cost-effectively.

- **Nonpoint/Nonpoint Source Trading:** A nonpoint source arranges for more cost-effective control of other nonpoint sources in lieu of installing or upgrading its own control or implementing pollution prevention practices.[80]

Credit Generation Using Restored Floodplains

What is the potential role of the restored floodplains in a watershed-based trading program? The TWI Hennepin floodplain project provides an example of a restoration that could generate point source equivalent trading credits. Careful management of a floodplain involving the removal of discrete and carefully monitored amounts of nitrate from the river should qualify a nitrogen farm as an equivalent to a point source in terms of watershed credit trading (Sections 3.3.3 and 3.4).

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[1] Nitrate-nitrogen (NO_3^--N) is the correct chemical designation for this form of nitrogen, however, for reasons of parsimony and clarity, we refer to nitrate-nitrogen as simply nitrate.

[2] Hey, D. L. 1999.

[3] Hoeft, R.G. et al. 1999. in Hey, D. L. 1999.

[4] Foth, H. D. 1990. p185.

[5] Ibid. p186-188.

[6] Adapted from Wiley, M. 2000. N_2 = nitrogen gas; NH_3 = ammonia; NH_4^+ = ammonium; NO_2^{2-}= nitrite; NO_3^- = nitrate.

[7] Foth, H. D. 1990. p188.

[8] Ibid. p192-193.

[9] These nitrogen oxides are known greenhouse gases.

[10] Foth, H. D. 1990. p194., and Hey, D. L. 1999.

[11] Hey, D. L. 1999.

[12] Ibid.

[13] USGS. 2000.

[14] Hey, D. L. 1999.

[15] Eubank,W. et al. 1998.

[16] Hey, D. L. 1999., Downing, J. A. et al. 1999., David, M. B. and L. E. Gentry. 2000., and Rejesus, R. M. and R. H. Hornbaker. 1999.

[17] Downing, J. A. et al. 1999., and Hey, D. L. 1999.

[18] Goolsby, D. A. and W. A. Battaglin. 2000., and Downing, J. A. et al. 1999.

[19] Nitrogen fertilizer use in the Mississippi River Basin shown by hydrologic accounting unit for 1992. From graphics used in presentation to the Hypoxia Task Force in Minneapolis, MN on September 24, 1998 website.

[20] Diaz, R.J. and A. Solow, 1999.

[21] Goolsby, D.A. and W.A. Battaglin. 2000.

[22] Illinois Agricultural Statistics 1999 Annual Summary. 2000.

[23] Ibid.

[24] Weber, C. R. 1966.

[25] David, M. B. and L.E. Gentry. 2000.

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[26] Ibid.
[27] USGS. 1998.
[28] David, M. B. and L. E. Gentry. 2000.
[29] Haller, L. et al. No date.
[30] Ribaudo, M. O. et al. 2001.
[31] USEPA. 1996.
[32] Ribaudo, M. O. et al. 2001.
[33] Zinn, J. 1998.
[34] Zinn, J. 1994.
[35] Ribaudo, M. O. et al. 2001., and Tiemann, M. E. 1996.
[36] Vogt, C. and J. Cotruvo. 1987.
[37] Haller, L. et al. No date., and Eubank, W. et al. 1998.
[38] Faeth, P. 2000.
[39] Eickan, G. 6/2001.
[40] McSwiggin, T. 7/2001.
[41] Illinois does have a program for regulating Animal Waste Disposal, but it falls under their point source policy.
[42] IEPA website. 3/2001. Targeted Watershed Approach.
[43] IEPA website. 3/2001. Bureau of Water Public Hearings.
[44] Farm Service Agency.
[45] Illinois Department of Natural Resources. 2000.
[46] Mollahan, R. J. 7/2001.
[47] Illinois Department of Natural Resources. 2000.
[48] Downing, J. A. et al. 1999.
[49] Diaz, R. J. and A. Solow. 1999.
[50] Table adapted from Diaz, R. J. and A. Solow. 1999.
[51] Title VI of Public Law 105-383, section 604(b), enacted on November 13, 1998.
[52] Hey, D. L. 1999.
[53] Action Plan. 2001.
[54] Hey, D. L. 1999.
[55] Halpern, R. A. 1999., and Sierra Club. 2001.
[56] Sierra Club. 2001.
[57] The Hypoxia Work Group is a NOAA committee assigned by the U.S. Government to study the potential economic and ecological impacts of Gulf of Mexico Hypoxia.
[58] Halpern, R. A. 1999.
[59] Diaz, R. J. and A. Solow. 1999. p 52.
[60] Ibid. p. 53.
[61] Ibid.
[62] CENR. 2000.
[63] The University of Illinois Extension. 2001.
[64] Foth, H. D. 1990. p185.
[65] The University of Illinois Extension. 2001.
[66] Downing, J. A. et al. 1999.
[67] Supalla, R. J. et al. 1995.
[68] CENR. 2000., and Hatch et al. 2001.
[69] Supalla, R. J. et al. 1995.
[70] Eubank,W. et al. 1998.
[71] Breaux, A. et al. 1995.
[72] Ibid.
[73] Ewel, K. C. 1997.
[74] USEPA. 1996.
[75] These terms refer to whether a water body is safe for a person to boat in (e.g. safe for minimal contact with the water), fish from (e.g. consume fish caught from a water body), or swim in (e.g. safe for immersion in the

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water body).

[76] Chesapeake Bay, Conference Paper. 2000.

[77] Faeth, P. 2000. p14

[78] Ibid.

[79] USEPA. 1996.

[80] Ibid. Executive Summary