Nitrogen Processes in Large Rivers Workshop
Bibliography of Nitrogen Studies on the Mississippi River

Amy A. Lee, U.S. Army Engineer Research & Development Center, Vicksburg, MS

1 Abstract

This effort is a review of Mississippi River/nitrogen publications posted on the Engineer Research and Development Centers (ERDC) and United States Geological Survey (USGS) websites. ERDC sites investigated included Environmental Laboratory - Products, Coastal and Hydraulics Laboratory – Publications, Geotechnical and Structural Laboratory - Publications. USGS sites investigated included The NAWQA Bibliography and National Water-Quality Assessment (NAWQA) - Publications. Seventy citations were identified including Fact Sheets, conference proceedings, reports, and articles in peer reviewed journals. The references are organized to reflect the focus of the Nitrogen Processes in Large Rivers Workshop format: Studies, Tools and Techniques, and Strategies for Management.

Review of the findings revealed four noteworthy trends. First, with the exception of Sabol, Winfield, and Tocyzdlowski (1984), the earliest works are from the early to mid 1990s. This is believed to be a function of current reporting methods of the agencies and not a lack of previous studies. Indeed, much historic research has been completed throughout the Mississippi River Valley. Identifying the myriad studies and publications is recommended. When compiling these various studies, one consideration is the variety of reporting formats. Care should be given to highlight these differences. For future research efforts, this information will be invaluable for establishing baseline conditions. Second, there are twice as many upper Mississippi publications than lower Mississippi publications. Based on their onset, it appears that many upper Mississippi publications are a result of the Upper Mississippi Navigation Study and therefore reported on the ERDC sites. Third, there were nine publications regarding biota/habitat. One reason for this may be that biota and habitat have not historically fallen within the purview of ERDC or USGS. Publications associating Mississippi River biota/habitat to water quality may be found more readily with state Fish and Wildlife agencies or the U.S. Fish and Wildlife Service (FWS). Finally, Environmental Sustainability is a newly emphasized component of the Corps mission (Flowers 2002). As such, there is a lag in ERDC publications affiliating Mississippi River biota/habitat quality with specific metrics such as nitrogen. It is anticipated that interest and publications will increase in the future.

These gaps in our collective memory will become more critical as we seek a better understanding of the Mississippi River watershed. It is worthwhile to develop a more robust bibliography. The first step will be to prioritize information needs. Second, it is necessary to determine the temporal extent of our research needs. Finally, the findings from this effort should be placed in a common repository, such as the SWWRP Information Depot.

2 Findings

Studies

Andrews, William J., Fallon, James D., Kroening, Sharon E., Lee, Kathy E., and Stark, James R.,1996, Water-quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin--Review of selected literature: U.S. Geological Survey Water-Resources Investigations Report 96-4149, 21 p. March 31, 2005

Water-Quality Assessment of the Eastern Iowa Basins-Nitrogen, Phosphorus, Suspended Sediment, and Organic Carbon in Surface Water, 1996-98 Water-Resources Investigations Report 01-4175 by Kent D. Becher, Stephen J. Kalkhoff, Douglas J. Schnoebelen, Kimberlee K. Barnes, and Von E. Miller

- **Abstract:** Twelve sites on streams and rivers in the Eastern Iowa Basins study unit were sampled monthly and during selected storm events from March 1996 through September 1998 to assess the occurrence, distribution, and transport of nitrogen, phosphorus, suspended sediment, and organic carbon as part of the U.S. Geological Survey's National Water-Quality Assessment Program. One site was dropped from monthly sampling after 1996. Dissolved nitrogen and phosphorus were detected in every water sample collected. Nitrate accounted for 92 percent of the total dissolved nitrogen. About 22 percent of the samples had nitrate concentrations that exceeded the U.S. Environmental Protection Agency's maximum contaminant level of 10 milligrams per liter as nitrogen for drinking-water regulations. The median concentration of total dissolved nitrogen for surface water in the study unit was 7.2 milligrams per liter. The median total phosphorus concentration for the study unit was 0.22 milligram per liter. About 75 percent of the total phosphorus concentrations exceeded the U.S. Environmental Protection Agency recommended total phosphorus concentration of 0.10 milligram per liter or less to minimize algal growth. Median suspended sediment and dissolved organic-carbon concentrations for the study unit were 82 and 3.5 milligrams per liter, respectively.

  Median concentrations of nitrogen, phosphorus, and suspended sediment varied annually and seasonally. Nitrogen, phosphorus, and suspended-sediment concentrations increased each year of the study due to increased precipitation and runoff. Median concentrations of dissolved organic carbon were constant from 1996 to 1998. Nitrogen concentrations were typically higher in the spring after fertilizer application and runoff. During winter, nitrogen concentrations typically increased when there was little in-stream processing by biota. Nitrogen and phosphorus concentrations decreased in late summer when there was less runoff and in-stream processing of nitrogen and phosphorus was high. Dissolved organic

carbon was highest in February and March when decaying vegetation and manure were transported during snowmelt. Suspended sediment concentrations were highest in early summer (May June) during runoff and lowest in January when there was ice cover with very little overland flow contributing to rivers and streams. Based on historical and study-unit data, eastern Iowa streams and rivers are impacted by both nonpoint and point-source pollution. Indicator sites that have homogeneous land use, and geology had samples with significantly higher concentrations of total dissolved nitrogen (median, 8.2 milligrams per liter) than did samples from integrator sites (median, 6.2 milligrams per liter) that were more heterogeneous in land use and geology. Samples from integrator sites typically had significantly higher total phosphorus and suspended-sediment concentrations than did samples from indicator sites. Typically, there was very little difference in median dissolved organic carbon concentrations in samples from indicator and integrator sites.

Concentrations of nitrogen and phosphorus varied across the study unit due to land use and physiography. Basins that are located in areas with a higher percentage of row-crop agriculture typically had samples with higher nitrogen concentrations. Basins that drain the Southern Iowa Drift Plain and the Des Moines Lobe typically had samples with higher total phosphorus and suspended-sediment concentrations.

Total nitrogen loads increased each year from 1996 through 1998 in conjunction with increased concentrations and runoff. Total phosphorus loads in the Skunk River Basin decreased in 1997 due to less runoff and decreased sediment transport, but increased in 1998 due to higher runoff and increased sediment transport. Total nitrogen and total phosphorus loads varied seasonally. The highest loads typically occurred in early spring and summer after fertilizer application and runoff. Loads were lowest in January and September when there was typically very little runoff to transport nitrogen and phosphorus in the soil to the rivers and streams.

Total nitrogen loads contributed to the Mississippi River from the Eastern Iowa Basins during 1996, 1997, and 1998 were 97,600, 120,000, and 234,000 metric tons, respectively. Total phosphorus loads contributed to the Mississippi River from the Eastern Iowa Basins during 1996, 1997, and 1998 were 6,860, 4,550, and 8,830 metric tons, respectively. Suspended sediment loads contributed to the Mississippi River from the Eastern Iowa Basins during 1996, 1997, and 1998 were 7,480,000, 4,450,000, and 8,690,000 metric tons, respectively. The highest total nitrogen and total phosphorus yields typically occurred in samples from indicator sites. Sampling sites located in drainage basins with higher row-crop percentage typically had higher nitrogen and phosphorus yields. Sites that were located in the Des Moines Lobe and the Southern Iowa Drift Plain typically had higher phosphorus yields, probably due to physiographic features (for example, erodable soils, steeper slopes).

Synoptic samples collected during low and high base flow had nitrogen, phosphorus, and organic-carbon concentrations that varied spatially and seasonally. Comparisons of water quality data from six basic-fixed sampling sites and 19 other synoptic sites suggest that the water quality data from basic-fixed

sampling sites were representative of the entire study unit during periods of low and high base flow when most streamflow originates from ground water.

Caskey, B.J., 2003, Relations of stream fish communities to physical and chemical parameters and land use in the Mississippi alluvial plain ecoregion: U.S. Geological Survey Open-File Report 03-31, 99 p.

Coupe, R.H., 1998, Concentrations and loads of nitrogen and phosphorus in the Yazoo River, northwestern Mississippi, 1996-97: U.S. Geological Survey Water-Resources Investigations Report 98-4219, 17 p.

Coupe, Richard H., 2002, Nitrogen and phosphorus concentrations and fluxes of streams in the Mississippi Embayment Study Unit, 1996-1998: U.S. Geological Survey Water-Resources Investigations Report 01-4024, 65 p.

Fallon, James D., and McNellis, Ryan P., 2000, Nutrients and suspended sediment in snowmelt runoff from part of the Upper Mississippi River Basin, Minnesota and Wisconsin, 1997: U.S. Geological Survey Water-Resources Investigations Report 00-4165, 23 p.

Gonthier, Gerard J., 2000, Water quality of the deep tertiary aquifers of the Mississippi Embayment, 1996: U.S. Geological Survey Water-Resources Investigations Report 99-4131, 91 p.

Gonthier, Gerald J., 2002, Quality of shallow ground water in recently developed residential and commercial areas, Memphis vicinity, Tennessee, 1997: U.S. Geological Survey Water-Resources Investigations Report 02-4294, 105 p.

Sources and Transport of Nitrogen in the Mississippi River Basin by Donald A. Goolsby, William A. Battaglin, U.S. Geological Survey, Lakewood, CO and Richard P. Hooper, U.S. Geological Survey, Atlanta, GA. Presented at the American Farm Bureau Federation Workshop "From the Corn Belt to the Gulf...Agriculture and Hypoxia in the Mississippi River Watershed", July 14-15, 1997, St. Louis, Missouri

- **Abstract:** The Mississippi and Atchafalaya Rivers are the primary riverine sources of fresh water and nutrients discharged to the Gulf of Mexico. The combined annual mean stream flow for the Mississippi and Atchafalaya Rivers (21,800 cubic meters per second) represents about 80 percent of the estimated freshwater discharge to the Gulf (Dunn, 1996). These two rivers account for an estimated 90 percent of total nitrogen (N) load and 87 percent of the total phosphorus load discharged annually to the Gulf (Dunn, 1996). Nitrate along with other nutrients has been implicated as a possible cause of oxygen depletion (hypoxia) in a large zone of the Gulf of Mexico along the Louisiana-Texas coast (Justic, et. al., 1993; Justic et. al., 1994; Turner and Rabalais, 1991; Rabalais, et. al., 1996). The seasonal reduction in dissolved oxygen (DO) occurs each year

during late spring and summer following high inflows of fresh water and nutrients to the Gulf. For example, following the 1993 flood, the hypoxia zone (DO less than 2 parts per million) covered nearly 17,000 square kilometers, twice the size of Chesapeake Bay. In 1994, 1995, and 1996 the zone of hypoxia was reported to be as large or larger (about 18,000 square kilometers) than during the summer of 1993 (Rabalais and Turner, press release, 1996). Estimates of the size of the zone of hypoxia prior to the 1993 flood (1985-1992) averaged about 10,000 square kilometers.

Hanson, Paul E., 1998, Pesticides and nitrates in surficial sand and gravel aquifers as related to modeled contamination susceptibility in part of the Upper Mississippi River Basin: U.S. Geological Survey Fact Sheet FS 107- 98, 4 p.

Justus, B.G., and Kleiss, B.A., 1997, Ongoing activities of the National Water Quality Assessment Program in the Mississippi Embayment: Proceedings of the 28th Mississippi Water Resources Conference, April 7-8 1998, Raymond, MS, p. 174-184.

Kleiss, Barbara A., Coupe, Richard H., Gonthier, Gerard J., and Justus, Billy G., 2000, Water quality in the Mississippi Embayment, Mississippi, Louisiana, Arkansas, Missouri, Tennessee, and Kentucky, 1995-98: U.S. Geological Survey Circular 1208, 36 p.

Kroening, Sharon E., 1996, Nitrogen and phosphorus in streams in part of the Upper Mississippi River Basin, Minnesota and Wisconsin, 1984-93 *in* Maxwell, W.H.C., Preul, H.C., and Stout, G.E., eds., Proceedings of the Rivertech96 1st International Conference on New/Emerging concepts for Rivers, Chicago, IL, September 22-26, 1996, p. 37-44. March 31, 2005.

Kroening, Sharon E., and Andrews, William J., 1997, Water-quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin--Nitrogen and phosphorus in streams, streambed sediment, and ground water, 1971-94: U.S. Geological Survey Water-Resources Investigations Report 97-4107, 61 p.

Kroening, Sharon, and Stark, James, 1997, Variability of nutrients in streams in part of the Upper Mississippi River Basin, Minnesota and Wisconsin: U.S. Geological Survey Fact Sheet FS-164-97, 4 p.

Kroening, Sharon, 1998, Nutrient sources within the Upper Mississippi River Basin, Minnesota and Wisconsin, 1991-93: U.S. Geological Survey Fact Sheet 121-98, 4 p.

Kroening, S.E., Lee, K.E., and Goldstein, R.M., 2003, Water-quality assessment of part of the Upper Mississippi River Basin study unit, Minnesota and Wisconsin--Nutrients, chlorophyll *a*, phytoplankton, and suspended sediment in streams,

1996-98, U.S. Geological Survey Water-Resources Investigations Report 02-4287, 34 p.

Lee, Kathy E., 1998,U.S. Geological Survey's National Water Quality Assessment in the Upper Mississippi River Basin: MinneGram, Water Resources Center, University of Minnesota, March 1998, p. 4.

Mallory, M.J., 1994, The Mississippi Embayment National Water-Quality Assessment Study: Proceedings of the 24th Mississippi Water Resources Conference, Jackson, MS, p. 171-177.

Mallory, Michael J., 1994, National Water-Quality Assessment Program—The Mississippi Embayment: U.S. Geological Survey Fact Sheet 94-047, 2 p.

Mueller, D.K., Ruddy, B.C., and Battaglin, W.A., 1994, Nitrate and atrazine in surface waters of the Upper-Midwestern United States: An example of regional synthesis, [abs.], in Sorenson, Stephen K., ed., 1994, Proceedings abstracts American Water Resources Association's symposium on the National Water-Quality Assessment Program--November 7-9, 1994, Chicago, Illinois: U.S. Geological Survey Open-File Report 94-397, p. 7.

Monitoring the Water Quality of the Nation's Large Rivers Mississippi River Basin NASQAN Program

- **Abstract:** The U.S. Geological Survey (USGS) has monitored water quality in the Mississippi River Basin as part of the National Stream Quality Accounting Network (NASQAN) since 1995, applying a basin wide perspective to understanding water quality on a regional scale (Hooper and others, 1997). The objectives of the Mississippi River Basin NASQAN Program are to provide an ongoing characterization of the concentrations and mass fluxes of sediment and chemicals at key locations in the basin, to determine regional source areas for these materials, and to assess the effect of human influences on observed concentrations and fluxes. NASQAN complements the ongoing USGS National Water-Quality Assessment (NAWQA) Program, which is performing a detailed assessment in 23 subbasins within the Mississippi River Basin (Hirsch and others, 1988). NASQAN monitors the large rivers in the Mississippi River Basin, downstream of NAWQA study units. NASQAN, in conjunction with NAWQA, can provide the data and information needed by other USGS programs, Federal and State agencies, other segments of the scientific community, and by the public to address the present and future status of water quality in the Mississippi River Basin.

Nutrients in ground waters of the conterminous United States, 1992-1995 by Bernard T. Nolan and Jeffrey D. Stoner *(Article in Environmental Science and Technology, volume 34, number 7, p. 1156-1165)*

- **Abstract:** Results of a national water quality assessment indicate that nitrate is detected in 71 percent of ground-water samples, more than 13 times as often as ammonia, nitrite, organic nitrogen, and orthophosphate, based on a common detection threshold of 0.2 mg/L. Shallow ground water (typically 5 m deep or less) beneath agricultural land has the highest median nitrate concentration (3.4 mg/L), followed by shallow ground water beneath urban land (1.6 mg/L) and deeper ground water in major aquifers (0.48 mg/L). Nitrate exceeds the maximum contaminant level, 10 mg/L as nitrogen, in more than 15 percent of ground-water samples from four of 33 major aquifers commonly used as a source of drinking water. Nitrate concentration in ground water is variable and depends on interactions among several factors, including nitrogen loading, soil type, aquifer permeability, recharge rate, and climate. For given nitrogen loading, factors that generally increase nitrate concentration in ground water includes well-drained soils, fractured bedrock, and irrigation. Factors that mitigate nitrate contamination of ground water include poorly drained soils, greater depth to ground water, artificial drainage systems, intervening layers of unfractured bedrock, a low rate of ground-water recharge, and anaerobic conditions in aquifers.

Nitrate Behavior in Ground Waters of the Southeastern United States by Bernard T. Nolan (A*rticle in the Journal of Environmental Quality, vol. 28, no. 5, Sep.-Oct. 1999, p. 1518-1527*)

- **Abstract:** Principal components analysis (PCA) was performed with water-quality data from studies conducted during 1993-1995 to explore potential nitrate-attenuation processes in ground waters of the southeastern United States. Nitrate reduction is an important attenuation process in selected areas of the Southeast. A "nitrate-reduction" component explains 23% of the total variance in the data and indicates that nitrate and dissolved oxygen are inversely related to ammonium, iron, manganese, and dissolved organic carbon. Additional components extracted by PCA include "calcite dissolution" (18% of variance explained) and "phosphate dissolution" (9% of variance explained). Reducing conditions in ground waters of the region influence nitrate behavior through bacterially mediated reduction in the presence of organic matter, and by inhibition of nitrate formation in anoxic ground water beneath forested areas. Component scores are consistent with observed water-quality conditions in the region. For example, median nitrate concentration in ground-water samples from the ALBE Coastal Plain is <0.05 mg/L, median dissolved organic carbon concentration is 4.2 mg/L, and median dissolved oxygen (DO) concentration is 2.1 mg/L, consistent with denitrification. Nitrate reduction does not occur uniformly throughout the Southeast. Median DO concentrations in ground-water samples from the Apalachicola-Chattahoochee-Flint River Basin are 6.2-7.1 mg/L, and median nitrate concentrations are 0.61-2.2 mg/L, inconsistent with denitrification. Similarly, median DO concentration in samples from the Georgia-Florida Coastal Plain is 6.0 mg/L and median nitrate concentration is 5.8 mg/L.

Nolan, B.T., 2001, Relating nitrogen sources and aquifer susceptibility to nitrate in shallow ground waters of the United States (*Article in Ground Water, vol. 39, no. 2, March-April 2001, p. 290-299.*)

- **Abstract:** Characteristics of nitrogen loading and aquifer susceptibility to contamination were evaluated to determine their influence on contamination of shallow ground water by nitrate. A set of 13 explanatory variables was derived from these characteristics, and variables that have a significant influence were identified using logistic regression (LR). Multivariate LR models based on more than 900 sampled wells predicted the probability of exceeding 4 mg/L of nitrate in ground water. The final LR model consists of the following variables: (1) nitrogen fertilizer loading (p-value = 0.012), (2) percent cropland-pasture ($p < 0.001$), (3) natural log of population density ($p < 0.001$), (4) percent well-drained soils ($p = 0.002$), (5) depth to the seasonally high water table ($p = 0.001$), and (6) presence or absence of a fracture zone within an aquifer ($p = 0.002$). Variables 1-3 were compiled within circular, 500-m radius areas surrounding sampled wells, and variables 4-6 were compiled within larger areas representing targeted land use and aquifers of interest. Fitting criteria indicate that the full logistic-regression model is highly significant ($p < 0.001$), compared with an intercept-only model that contains none of the explanatory variables. A goodness-of-fit test indicates that the model fits the data very well, and observed and predicted probabilities of exceeding 4 mg/L nitrate in ground water are strongly correlated ($r2 = 0.971$). Based on the multivariate LR model, vulnerability of ground water to contamination by nitrate depends not on any single factor but on the combined, simultaneous influence of factors representing nitrogen loading sources and aquifer susceptibility characteristics.

Nonpoint and point sources of nitrogen in major watersheds of the United States by Larry J. Puckett (USGS Water-Resources Investigations Report 94-4001)

- **Abstract:** Estimates of nonpoint and point sources of nitrogen were made for 107 watersheds located in the U.S. Geological Survey's National Water-Quality Assessment Program study units throughout the conterminous United States. The proportions of nitrogen originating from fertilizer, manure, atmospheric deposition, sewage, and industrial sources were found to vary with climate, hydrologic conditions, land use, population, and physiography. Fertilizer sources of nitrogen are proportionally greater in agricultural areas of the West and the Midwest than in other parts of the Nation. Animal manure contributes large proportions of nitrogen in the South and parts of the Northeast. Atmospheric deposition of nitrogen is generally greatest in areas of greatest precipitation, such as the Northeast. Point sources (sewage and industrial) generally are predominant in watersheds near cities, where they may account for large proportions of the nitrogen in streams. The transport of nitrogen in streams increases as amounts of precipitation and runoff increase and is greatest in the Northeastern United States. Because no single nonpoint nitrogen source is dominant everywhere, approaches to control nitrogen must vary throughout the Nation. Watershed-based approaches

to understanding nonpoint and point sources of contamination, as used by the National Water-Quality Assessment Program, will aid water-quality and environmental managers to devise methods to reduce nitrogen pollution.

Runner, M.S., Turnipseed, D.P., and Coupe, R.H., 2002, Streamflow and nitrogen data for the Yazoo River below Steele Bayou near Long Lake, Mississippi, 1996-2000: U.S. Geological Survey Water-Resources Investigations Report 02-4215, 35 p.

Sorenson, S.K., Porter, S.D., Akers, K.K.B, Harris, M.A., Kalkhoff, S.J., Lee, K.E., Roberts, L.R., and Terrio, P.J., 1999, Water quality and habitat conditions in Upper Midwest streams relative to riparian vegetation and soil characteristics, August 1997: Study design, methods and data: U.S. Geological Survey Open-File Report 99-202, 53 p.

Water Quality in the Upper Mississippi River Basin, Minnesota, Wisconsin, South Dakota, Iowa, and North Dakota, 1995–98 b*y* J.R. Stark, P.E. Hanson, R.M. Goldstein, J.D. Fallon, A.L. Fong, K.E. Lee, S.E. Kroening, *and* W.J. Andrews U.S. GEOLOGICAL SURVEY CIRCULAR 1211

Stark, J.R., Hanson, P.E., Goldstein, R.M., Fallon, J.D., Fong, A.L., Lee, K.E., Kroening, S.E., and Andrews, W.J., 2001, Water quality in the Upper Mississippi River Basin, Minnesota, Wisconsin, South Dakota, Iowa, and North Dakota, 1995-98: U.S. Geological Survey Circular 1211, 35 p.

Comparison of nitrogen, phosphorus, and selected pesticides in the Minnesota, Mississippi, and St. Croix Rivers, Minnesota and Wisconsin, 1971-1994 by Stark, J.R., Fallon, J.O., and Kroening, S.E. (*Article in Journal of the Minnesota Academy of Science*)

- **Abstract:** The U.S. Geological Survey summarized nitrogen and phosphorus data from 1984-93 from streams and selected pesticide data from 1971094 from streams and selected pesticide data from 1971-94 from streams and streambed sediments from the Upper Mississippi River Basin. Information obtained from data bases maintained by federal, state, and local agencies was analyzed as part of the work for the Upper Mississippi River Basin study of the U.S. Geological Survey's National Water Quality Assessment. The analysis focused on a 19,500 square mile area in the eastern portion of the Upper Mississippi River Basin from Royalton, Minnesota to the outlet of Lake Pepin, the Minnesota River Basin from Jordan, Minnesota to the confluence with the Mississippi River, and the entire drainage basins of the St. Croix, Cannon and Vermillion Rivers. Concentrations of loads of nutrients and concentrations and detection frequencies of selected pesticides in these rivers and in selected tributaries were compared. Water quality data were obtained from the Metropolitan Council Environmental Services, the Minnesota Department of Agriculture, the Minnesota Pollution Control Agency, the U.S. Army Corps of Engineers, the U.S. Geological Survey, and the Wisconsin Department of Natural Resources.

Proceedings from the North American Benthological Society, Nitrogen Cycling in Freshwaters, presided by E Strauss, U.S. Geological Survey; R Alexander, U.S. Geological Survey

- Including presentations: Hydrologic Control of Nitrate Loading and Transformation in Backwater Lakes of the Upper Mississippi River, Importance of Stream Denitrification in the Nitrogen Mass Balance of a Midwestern Agricultural Region, and Temporal Patterns in Sediment Denitrification Rates in an Agricultural Stream

USGS Information and Activities Related to Nutrients in the Mississippi River Basin and Hypoxia in the Gulf of Mexico (USGS Hypoxia in the Gulf of Mexico Program web site)

- **Summary:** This site presents documents associated with monitoring, assessment, modeling, and research on the Mississippi River and the Gulf of Mexico.

Fertilizers largest source of nitrogen in White River Watershed, says USGS (*U.S. Water News Online. February 1997*)

- **Summary:** This news brief emphasized the role of agriculture to total N contributions.

Vadose Zone Nitrogen: Sources, Fate, and Transport (*Proceedings from the Geological Society of America 2004 Conference, presided by Scott W. Tyler and W. Mike Edwards*)

- **Summary:** Proceedings from the Denver 2004 Annual Meeting of the Geological Society of America. Presenters were predominantly from western states. These presentations provide information about fate and transport of N in the vadose zone

Tools and Techniques

Alexander, Richard B., Johnes, Penny J., Boyer, Elizabeth W., and Smith, Richard A., 2002, A comparison of models for estimating the riverine export of nitrogen from large watersheds: Biogeochemistry, vol. 57, no. 58, p. 295- 339.

Effect of Stream Channel Size on the Delivery of Nitrogen to the Gulf of Mexico by Richard B. Alexander, Richard A. Smith, & Gregory E. Schwarz (*Article in Nature, vol. 403, 17 February 2000, pp. 758-761*)

- **Abstract:** An increase in the flux of nitrogen from the Mississippi River during the latter half of the twentieth century has caused eutrophication and chronic seasonal hypoxia in the shallow waters of the Louisiana shelf in the northern Gulf of Mexico. This has led to reductions in species diversity, mortality of benthic communities, and stress in fishery resources. There is evidence for a predominantly anthropogenic origin of the increased nitrogen flux, but the location of the most significant sources in the Mississippi basin responsible for the delivery of nitrogen to the Gulf of Mexico have not been clearly identified, because the parameters influencing nitrogen-loss rates in rivers are not well known. Here, we present an analysis of data from 374 US monitoring stations, including 123 along the six largest tributaries to the Mississippi, which shows a rapid decline in the average first-order rate of nitrogen loss with channel size—from 0.45 per day in small streams to 0.005 per day in the Mississippi River. Using stream depth as an explanatory variable, our estimates of nitrogen-loss rates agreed with values from earlier studies. We conclude that the proximity of sources to large streams and rivers is an important determinant of nitrogen delivery to the estuary in the Mississippi basin, and possibly also in other large river basins.

Brezonik, P.L., Bierman, V.J., Alexander, R., Anderson, J, Barko, J., Dortch, M., Hatch, L., Keeney, D., Mulla, D., Smith, V., Walker, C., Whitledge, T., and W. Wiseman, W., 1999, Effects of reducing nutrient loads to surface waters within the Mississippi River Basin and the Gulf of Mexico, Report of Task Group 4 to the White House Committee on Environment and Natural Resources, Hypoxia Work Group, Federal Register, 64, 23834-23835.

Caskey, B.J., 2003, Relations of stream fish communities to physical and chemical parameters and land use in the Mississippi alluvial plain ecoregion: U.S. Geological Survey Open-File Report 03-31,99 p.

Gilliom, R.J., Mueller, D.K., and Nowell, L.H., 1998, Methods for comparing water-quality conditions among National Water-Quality Assessment Study Units, 1992-1995: U.S. Geological Survey Open-File Report 97-589, 54 p.

Nitrogen in the Mississippi Basin-Estimating Sources and Predicting Flux to the Gulf of Mexico by Donald A. Goolsby and William A. Battaglin, USGS Fact Sheet 135-00 December 2000.

- **Summary:** The observed fluxes indicate that the nitrate transport to the Gulf has not increased appreciably since the early 1980's. However, the year-to-year variability has become large, probably because of variability in precipitation and an abundant reservoir of soluble nitrate in the soil/ground-water system. Thus, nitrate inputs to the Gulf appear to have stabilized for the current level of nitrogen inputs and outputs. However, in future years the flux of nitrate to the Gulf will likely respond quickly and perhaps dramatically to variations in precipitation and runoff. Because of the amount of nitrate stored in the soil/ground-water system,

fluxes of nitrate will be low in dry years and high in wet years. Also, because of the huge storage capacity of the soil/ground-water system, the flux of nitrate will likely change very slowly in response to increases or decreases in nitrogen inputs to the basin.

Nitrogen Input to the Gulf of Mexico by Donald A. Goolsby[a], William A. Battaglin[a], Brent T. Aulenbach[b] and Richard P. Hooper (*Article in Journal of Environmental Quality 30:329-336 2001*)

- **Abstract:** Historical streamflow and concentration data were used in regression models to estimate the annual flux of nitrogen (N) to the Gulf of Mexico and to determine where the nitrogen originates within the Mississippi Basin. Results show that for 1980–1996 the mean annual total N flux to the Gulf of Mexico was 1568000 t yr^{-1}. The flux was about 61% nitrate N, 37% organic N, and 2% ammonium N. The flux of nitrate N to the Gulf has approximately tripled in the last 30 years with most of the increase occurring between 1970 and 1983. The mean annual N flux has changed little since the early 1980s, but large year-to-year variations in N flux occur because of variations in precipitation. During wet years the N flux can increase by 50% or more due to flushing of nitrate N that has accumulated in the soils and unsaturated zones in the basin. The principal source areas of N are basins in southern Minnesota, Iowa, Illinois, Indiana, and Ohio that drain agricultural land. Basins in this region yield 1500 to more than 3100 kg N km^{-2} yr^{-1} to streams, several times the N yield of basins outside this region.

Hitt, K.J. and Nolan, B.T., 2005, Nitrate in ground water: Using a model to simulate the probability of nitrate contamination of shallow ground water in the conterminous United States: U.S. Geological Survey Scientific Investigations Map 2881.

James, W.F., and J.W. Barko. (1995) "Analysis of nutrient/seston fluxes and phytoplankton dynamics in Lake Pepin (Upper Mississippi River): First interim report, 1994," Report prepared for the Metropolitan Waste Control Commission, St. Paul, MN, and the USACE District, St. Paul under Section 22

James, W.F., and J.W. Barko. (1996) "Analysis of nutrient/seston fluxes and phytoplankton dynamics in Lake Pepin (Upper Mississippi River): Second interim report, 1995," Report prepared for the Metropolitan Waste Control Commission, St. Paul, MN, and the USACE District, St. Paul under Section 22

James, W.F., J.W. Barko, and H.L. Eakin. (1997) "Analysis of nutrient/seston fluxes and phytoplankton dynamics in Lake Pepin (Upper Mississippi River): Third interim report, 1996," Final report prepared for the Metropolitan Waste Control Commission, St. Paul, MN, and the USACE District, St. Paul under Section 22

James, W.F., J.W. Barko, and H.L. Eakin. (1997) "Evaluation of sediment characteristics and rates of nutrient release from sediments in Lake Pepin and Spring Lake,

Upper Mississippi River," Final report prepared for the Metropolitan Waste Control Commission, St. Paul, MN, and the USACE District, St. Paul under Section 22

James, W.F., Barko, J.W., and H.L. Eakin. (1997) "Evaluation of Sediment Characteristics and Rates of Nutrient Release from Sediment in Lake Pepin and Spring Lake, Upper Mississippi River," Report prepared for the Metropolitan Council Environmental Services and the USAED, St. Paul, MN

James, W.F., Barko, J.W., and H.L. Eakin. (1998) "Analysis of Nutrient/Seston Fluxes and Phytoplankton Dynamics in Lake Pepin (Upper Mississippi River), 1996," Third interim report prepared for the Metropolitan Council Environmental Services and USAED, St. Paul, MN

James, W.F., Barko, J.W., Davis, M., Eakin, H.L., Rogala, J.T., and A.C. Miller. (2000) "Filtration and Excretion by Zebra Mussels: Implications for Water Quality Impacts in Lake Pepin, Upper Mississippi River," *Journal of Freshwater Ecology* 15: 429-437

James, W.F, Barko, J.W., Eakin, H.L., Hendrickson, J.S., Miller, A.C., and J. Sauer (2000) "Nutrient Recycling Impacts by Zebra Mussels in Harper's Ferry Slough, Upper Mississippi River," WQTN-PD-07

James, W.F., Barko, J.W., and H.L. Eakin (2002) "Experimental Determination of the Impacts of Sediment Desiccation and Rewetting on Sediment Physical and Chemical Characteristics in Lawrence Lake, Pool 8, Upper Mississippi River," APCRP-EA-05

Mueller, D.K., Ruddy, B.C., and Battaglin, W.A., 1993, Relation of nitrate concentrations in surface water to land use in the upper-midwestern United States, 1989-1990, in Goolsby, D.A., Boyer, L.L., and Mallard, G.E., compilers, Selected papers on agricultural chemicals in water resources of the midcontinental United States: U.S. Geological Survey Open-File Report 93-418, p. 41-50.

Mueller, D.K., Martin, J.D., and Lopes, T.J., 1997, Quality-control design for surface-water sampling in the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 7-223, 17 p.

Mueller, D.K., Ruddy, B.C., and Battaglin, W.A., 1997, Logistic model of nitrate in streams of the upper-midwestern United States: Journal of Environmental Quality, v. 26, p. 1223-1230.

Mueller, D.K., and Stoner, J.D., 1998, Identifying the potential for nitrate contamination of streams in agricultural areas of the United States in Proceedings of the National Water-Quality Monitoring Conference, July 7-9, 1998, Reno, Nev., p. III-163 to III-173.

Nitrogen Isotope Study Answers Questions about the Transport of Nutrients in Streams at USGS Toxic Substances Hydrology Program website

Transport and Fate of Nitrate in a Glacial Outwash Aquifer in Relation to Ground-Water Age, Land Use Practices and Redox Processes by Larry J. Puckett and Timothy K. Cowdery (A*rticle in Journal of Environmental Quality, vol. 31, no. 3)*

- **Abstract:** A combination of ground-water modeling, chemical and dissolved gas analyses, and chlorofluorocarbon age dating of water was used to determine the relation between changes in agricultural practices, and NO_3^- concentrations in ground water of a glacial outwash aquifer in west-central Minnesota. The results revealed a redox zonation throughout the saturated zone with oxygen reduction near the water table, NO_3^- reduction immediately below it, and then a large zone of ferric iron reduction, with a small area of sulfate (SO_4^{2-}) reduction and methanogenesis (CH_4) near the end of the transect. Analytical and NETPATH modeling results supported the hypothesis that organic carbon served as the electron donor for the redox reactions. Denitrification rates were small, 0.005 to 0.047 mmol NO_3^- yr^{-1}, and were limited by the small amounts of organic carbon, 0.01 to 1.45 percent. In spite of the organic carbon limitation, denitrification was virtually complete because residence time is sufficient to allow even slow processes to reach completion. Ground-water sample ages showed that maximum residence times were on the order of 50-70 years. Reconstructed NO_3^- concentrations, estimated from measured NO_3^- and dissolved nitrogen gas showed that NO_3^- concentrations have been increasing in the aquifer since the 1940s have been above the 714 mmol L^{-1} maximum contaminant level at most sites since the mid- to late-1960s. This increase in NO_3^- has been accompanied by a corresponding increase in agricultural use of fertilizer, identified as the major source of NO_3^- to the aquifer.

Estimation of nitrate contamination of an agro-ecosystem outwash aquifer using a nitrogen mass-balance budget by Larry J. Puckett, Timothy K. Cowdery, David L. Lorenz, and Jeffrey D. Stoner *(Article in Journal of Environmental Quality, vol. 28, no. 6, Nov.-Dec. 1999)*

- **Abstract:** A mass-balance budget of N cycling was developed for an intensive agricultural area in west-central Minnesota to better understand NO_3^- contamination of ground water in the Otter Tail outwash aquifer. Fertilizer, biological fixation, atmospheric deposition, and animal feed were the N sources, and crop harvests, animal product exports, volatilization from fertilizer and manure, and denitrification were the N sinks in the model. Excess N, calculated as the difference between the sources and sinks, was assumed to leach to ground water as NO_3^-. The budget was developed using ground water data collected throughout the 212-km^2 study area. Denitrification was estimated by adjusting its value so the predicted and measured concentrations of NO_3^- in ground water agreed. Although biological fixation was the largest single N source, most was

removed when crops were harvested, indicating that inorganic fertilizer was the primary source of N reaching the water table. It was estimated that denitrification removed almost half of the excess NO_3^- that leached below the root zone. Even after accounting for denitrification losses, however, it was concluded that the ground water system was receiving approximately three times as much N as would be expected under background conditions.

Using Chemical, Hydrologic, and Age Dating Analysis to Delineate Redox Processes and Flow Paths in the Riparian Zone of a Glacial Outwash Aquifer-Stream System by Larry J. Puckett, Timothy K. Cowdery, Peter B. McMahon, Lan H. Tornes, and Jeffrey D. Stoner (*Article in Water Resources Research vol. 38, no. 8, August 2002)*

- **Abstract:** A combination of chemical and dissolved gas analyses, chlorofluorocarbon age dating and hydrologic measurements were used to determine the degree to which biogeochemical processes in a riparian wetland were responsible for removing NO_3^- from ground waters discharging to the Otter Tail River in west-central Minnesota. An analysis of river chemistry and flow data revealed that NO_3^- concentrations in the river increased in the lower half of the 8.3 km study reach as the result of ground-water discharge to the river. Ground-water head measurements along a study transect through the riparian wetland revealed a zone of ground-water discharge extending out under the river. On the basis of combined chemical, dissolved gas, age date, and hydrologic results, it was determined that water chemistry under the riparian wetland was controlled largely by up-gradient ground waters that followed flow paths up to 16 m deep and discharged under the wetland, creating a pattern of progressively older, more chemically reduced, low NO_3^- water the further one progressed from the edge of the wetland towards the river. These findings pose challenges for researchers investigating biogeochemical processes in riparian buffer zones because the progressively older ground waters entered the aquifer in earlier years when less NO_3^- fertilizer was being used. NO_3^- concentrations originally present in the ground water had also decreased in the up-gradient aquifer as a result of denitrification and progressively stronger reducing conditions there. The resulting pattern of decreasing NO_3^- concentrations across the riparian zone may be incorrectly interpreted as evidence of denitrification losses there instead of in the up-gradient aquifer. Consequently, it is important to understand the hydrogeologic setting and age structure of the ground waters being sampled in order to avoid misinterpreting biogeochemical processes in riparian zones.

Resources on Isotopes, USGS Isotope Tracers Project, Menlo Park, CA

- **Summary:** Site provides Nitrogen isotope information

Richardson, W.B., E.A. Strauss, E.M. Monroe, L.A. Bartsch, J.C. Cavanaugh, L. Vingum, and D. Soballe. (2004) "Denitrification in the Upper Mississippi River:

rates, controls and contribution to nitrate flux," *Canadian Journal of Fisheries and Aquatic Sciences* In press

Denitrification and sediment ammonia in the Upper Mississippi River by Bill Richardson (*Poster presented at Workshop on Nutrient Processes in the Upper Mississippi River Basin*)

- **Summary:** A fact sheet regarding upcoming research in the Upper Mississippi River.

Sabol, B. M., Winfield, L. E., and Toczydlowski, D. G. (1984). "Investigation of water quality and plankton in selected aquatic habitats on the lower Mississippi River," Technical Report E-84-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS., NTIS No. AD A142 794.

Soballe, D. M. and J. Wiener. (1999) "Water and sediment quality. [in] K. Lubinski and C. Theiling eds. Ecological status and trends of the Upper Mississippi River System 1998," LTRMP 99-T001, U. S. Geological Survey, La Crosse, Wisconsin April 1999

Stark, J.R., and Amos, G.L., 1996, Water-quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin--Compilation of related literature: U.S. Geological Survey Open-File Report 96-579, 286 p.

Stark, James, 1997, Causes of variations in water quality and aquatic ecology in rivers of the Upper Mississippi River Basin, Minnesota and Wisconsin: U.S. Geological Survey Fact Sheet 96-249, 4 p.

Strauss, E. A. , W. B. Richardson, L. A. Bartsch, J. C. Cavanaugh, D. A. Bruesewitz, H. Imker, J. A. Heinz, and D. M. Soballe. (2004) "Nitrification in the Upper Mississippi River: patterns, controls, and contribution to the NO3- budget," *J. N. Am. Benthol. Soc* 23(1): 1-14

Strom, Eric W., 1997, Hydrogeologic interpretations of natural-gamma logs for 31 shallow wells in the Memphis, Tennessee, area: U.S. Geological Survey Water-Resources Investigations Report 97-4181, 43 p.

Strategies for Management

Nutrients in the Upper Mississippi River: Scientific Information to Support Management Decisions

- **Summary:** Fact sheet that summarizes some research on the Upper Mississippi to date.